Final
Preliminary Assessment Report Army Aviation Support Facility, San Juan, Puerto Rico

Perfluorooctane-Sulfonic Acid (PFOS) and Perfluorooctanoic Acid (PFOA) Impacted Sites
ARNG Installations, Nationwide

March 2020

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Acronyms and Abbreviations

°F	degrees Fahrenheit
AASF	Army Aviation Support Facility
AECOM	AECOM Technical Services, Inc.
AFFF	aqueous film forming foam
AOI	Area of Interest
ARNG	Army National Guard
CAF	Compressed Air Foam
CAPECO	Caribbean Petroleum Corporation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSM	conceptual site model
EDR	Environmental Data Resources, Inc.
FTA	fire training area
IED	Installations & Environment Division
NAS	Naval Air Station
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OWS	Oil-water separator
PA	Preliminary Assessment
PFAS	per- and poly-fluoroalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
POL	Petroleum, oils, and lubricants
PRARNG	Puerto Rico Army National Guard
SI	Site Inspection
SIG	Isla Grande Airport
US	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VSI	visual site inspection
WWTP	Wastewater Treatment Plan

Executive Summary

The United States (US) Army Corps of Engineers (USACE) Baltimore District on behalf of the Army National Guard (ARNG)-Installations & Environment Division (IED), Cleanup Branch contracted AECOM Technical Services, Inc. (AECOM) to perform *Preliminary Assessments (PAs) and Site Inspections (SIs) for Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA) Impacted Sites at ARNG Facilities Nationwide*. The ARNG is assessing potential effects on human health related to processes at facilities that used per- and poly-fluoroalkyl substances (PFAS), primarily in the form of aqueous film forming foam released as part of firefighting activities, although other PFAS sources are possible.

AECOM completed a PA for PFAS at the Army Aviation Support Facility (AASF; also referred to as the "facility") in San Juan, Puerto Rico, to assess potential PFAS release areas and exposure pathways to receptors. The performance of this PA included the following tasks:

- Reviewed data resources to obtain information relevant to suspected PFAS releases
- Conducted a site visit on 20 May 2019
- Interviewed current PRARNG AASF personnel during the site visit, including the AASF safety officer, a sergeant with the Puerto Rico ARNG (PRARNG), as well as the Aviation Department Rescue and Firefighter Section Supervisor of the adjacent Isla Grande Airport.
- Completed visual site inspections at known or suspected PFAS release locations and documented with photographs
- Developed a preliminary conceptual site model (CSM) to outline the potential release and pathway of PFAS for the Area(s) of Interest (AOIs) and the facility (**Figure ES-1**)

One AOI related to a potential PFAS release was identified at the AASF during the PA. The AOI is shown on **Figure ES-1** and described in **Table ES-1** below:

Table ES-1: AOIs at AASF

Area of Interest	Name	Used by	Potential Release Date
AOI 1	Hangar and Wash Rack Areas	PRARNG	1999 - 2016

Based on the possible PFAS releases at the AOI, there is potential for exposure to PFAS contamination in surface soil to site workers and trespassers via ingestion and inhalation; in subsurface soil to construction workers via ingestion and inhalation; and in surface water and sediment to construction workers and off-facility recreational users via ingestion. Potential off-facility PFAS release areas also exist adjacent to the AASF. It is unknown whether or not the off-facility sources affect the AASF. Based on the US Environmental Protection Agency (USEPA) Unregulated Contaminant Monitoring Rule 3 data, it was indicated that no PFAS were detected in a public water system above the USEPA Health Advisory level within 20 miles of the AASF. The preliminary CSM for the AASF is shown on **Figure ES-2**.

CLIENT	ARNG			
PROJECT	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:4,560	CHK BY	JW	1/10/2020
Base Map: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)		PM	RG	1/10/2020

Area of Interest
Potential PFAS Release
No Suspected Release
Facility Boundary

Summary of Findings

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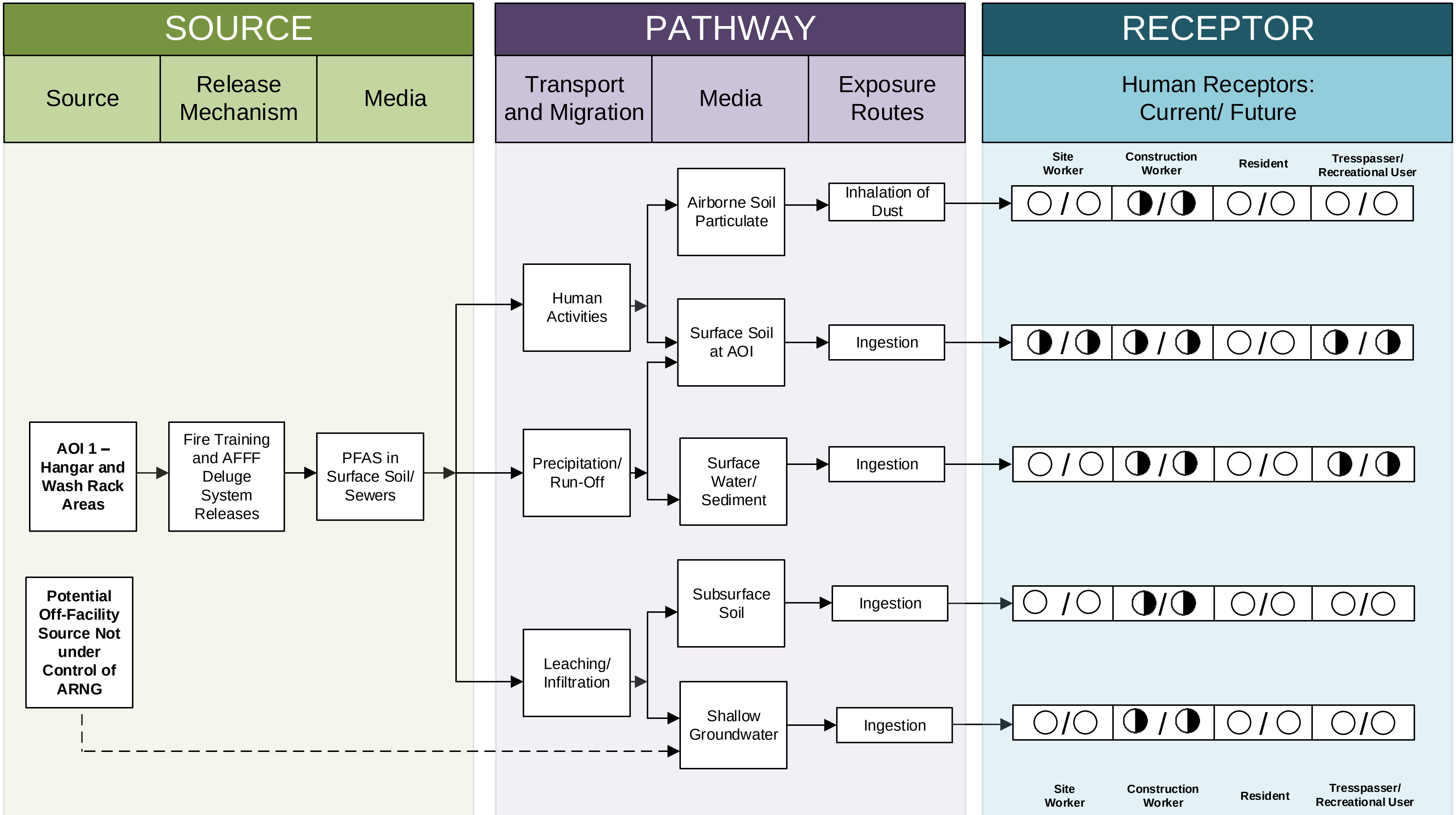
Figure ES-1

Q:\Projects\ENV\GEARS\GEO\ARNG PFAS\900-CAD-GIS\920-GIS or Graphics\MXD\PR\AASF_San_Juan_Figures\Fig_ES-1_AASF_San_Juan_Summary.mxd



LEGEND

Flow-Chart Stops

Flow-Chart Continues

Partial / Possible Flow

Incomplete Pathway

Potentially Complete Pathway

Complete Pathway

Notes:
1. The resident and recreational user receptors refer to an off-site resident and recreational user.
2. Dermal contact exposure pathway is incomplete for PFAS.

Figure ES-2
Preliminary Conceptual Site Model
AOI 1 – Hangar and Wash Rack Areas

1. Introduction

1.1 Authority and Purpose

The United States (US) Army Corps of Engineers (USACE) Baltimore District on behalf of the Army National Guard (ARNG)-Installations & Environment Division, Cleanup Branch contracted AECOM Technical Services, Inc. (AECOM) to perform *Preliminary Assessments (PAs) and Site Inspections (SIs) for Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA) Impacted Sites at ARNG Facilities Nationwide* under Contract Number W912DR-12-D-0014, Task Order W912DR17F0192, issued 11 August 2017. The ARNG is assessing potential effects on human health related to processes at facilities that used per- and poly-fluoroalkyl substances (PFAS), primarily in the form of aqueous film forming foam (AFFF) released as part of firefighting activities, although other PFAS sources are possible. In addition, the ARNG is assessing businesses or operations adjacent to the ARNG facility (not under the control of ARNG) that could potentially be responsible for a PFAS release.

PFAS are classified as emerging environmental contaminants that are garnering increasing regulatory interest due to their potential risks to human health and the environment. PFAS formulations contain highly diverse mixtures of compounds. Thus, the fate of PFAS compounds in the environment varies. The regulatory framework at both federal and state levels continues to evolve. The US Environmental Protection Agency (USEPA) issued Drinking Water Health Advisories for PFOA and PFOS in May 2016, but there are currently no promulgated national standards regulating PFAS in drinking water. In the absence of federal maximum contaminant levels, some states have adopted their own drinking water standards for PFAS. Puerto Rico does not currently have drinking water standards for PFAS.

This report presents the findings of a PA for PFAS at the Army Aviation Support Facility (AASF; also referred to as the “facility”) in San Juan, Puerto Rico, in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, the National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), and USACE requirements and guidance.

This PA documents the known fire training areas (FTAs) as well as other locations where PFAS may have been released into the environment at the AASF. The term PFAS will be used throughout this report to encompass all PFAS chemicals being evaluated, including PFOS and PFOA, which are key components of AFFF.

1.2 Preliminary Assessment Methods

The performance of this PA included the following tasks:

- Reviewed data resources to obtain information relevant to suspected PFAS releases
- Conducted a site visit on 20 May 2019
- Interviewed current Puerto Rico ARNG (PRARNG) AASF personnel during the site visit, including the AASF safety officer, a sergeant with the PRARNG, as well as the Aviation Department Rescue and Firefighter Section Supervisor of the adjacent Isla Grande Airport.
- Completed visual site inspections (VSIs) at known or suspected PFAS release locations and documented with photographs
- Developed a preliminary conceptual site model (CSM) to outline the potential release and pathway of PFAS for the Area(s) of Interest (AOIs) and the facility

1.3 Report Organization

This report has been prepared in accordance with the USEPA *Guidance for Performing Preliminary Assessments under CERCLA* (USEPA 1991). The report sections and descriptions of each are:

- **Section 1** – **Introduction:** identifies the project purpose and authority and describes the facility location, environmental setting, and methods used to complete the PA
- **Section 2** – **Fire Training Areas:** describes the FTAs at the facility identified during the site visit
- **Section 3** – **Non-Fire Training Areas:** describes other locations of potential PFAS releases at the facility identified during the site visit
- **Section 4** – **Emergency Response Areas:** describes areas of potential PFAS release at the facility, specifically in response to emergency situations
- **Section 5** – **Adjacent Sources:** describes sources of potential PFAS release adjacent to the facility that are not under the control of ARNG
- **Section 6** – **Preliminary Conceptual Site Model:** describes the pathways of PFAS transport and receptors for the AOIs and the facility
- **Section 7** – **Conclusions:** summarizes the data findings and presents the conclusions of the PA
- **Section 8** – **References:** provides the references used to develop this document
- **Appendix A** – Data Resources
- **Appendix B** – Preliminary Assessment Documentation
- **Appendix C** – Photographic Log

1.4 Facility Location and Description

The AASF is located in the Isla Verde area of Puerto Rico. The facility is directly adjacent to the Fernando Luis Ribas Dominicci Airport and is loosely bordered by the Caño San Antonio, San Juan Bay, and neighborhood of Miramar (18°27′16.32″N; 066°05′47.86″W) (**Figure 1-1**). The AASF is located within an industrial/commercial district of Isla Verde, surrounded on three sides by the waters of San Juan Bay in addition to multiple bays and inlets. The area was formerly occupied by the Naval Air Station (NAS), San Juan. Today, the primary mission of the detachment unit at the AASF is to provide aviation maintenance support and repair for aviation components.

NAS San Juan formerly served as a maintenance stationing point for US Navy ships and planes in San Juan Bay. NAS San Juan included patrol squadrons of sea planes, massive dry dock maintenance and repair facilities for naval ships, a fuel supply and refinement center, a defense housing project, storehouses and support facilities. In 1971, NAS San Juan relocated from Isla Grande to Ramey Air Force Base on the west coast of the island. Some of the areas previously occupied by NAS San Juan have been developed into neighborhoods, and other areas have been designated as industrial/commercial space. The PRARNG AASF was built in 1992 in an industrial/commercial space formerly occupied by NAS San Juan.

According to PRARNG facility staff, the AASF is anticipated to relocate within the next 5 years. Real property documents for the AASF are included in **Appendix A**.

1.5 Facility Environmental Setting

The information presented in this section is derived from several sources, including the US Department of the Interior (USDOI) 1959 Geological Survey Professional Paper 317-A, the USDOI 1978 Geological Survey Professional Paper 1012, a 1978 Soil Survey of the San Juan Area of Puerto Rico by the US Department of Agriculture (USDA), the US Geological Survey (USGS) 1995 Water Investigations Report 94-4249, and the USGS 1976 Water Investigations Report 75-41.

The AASF lies on the low and swampy northern coast of Puerto Rico, which is indented by small bays, lagoons, and the San Juan Bay. The coast is comprised mostly by sand beaches, but it crops out in the sea cliffs of San Juan and the adjoining low hills as well as in small rock chains offshore. The facility is located on the Isla Grande peninsula, adjacent to the Fernando Luis Ribas Dominicci Airport, also known as Isla Grande Airport (SIG). Topography across the AASF is very flat to accommodate the airport runway. SIG is located to the north and west of the facility, the Puerto Rico Convention Center is located to the east of the facility, and industrial/commercial areas are located to the south. Beyond the adjacent business and properties, the San Juan Bay is located to the south and west of the AASF, and the Caño San Antonio to the north separates Isla Grande from San Juan. The general San Juan area consists of a very gently sloping coastal plain (Kaye, 1959).

1.5.1 Geology

The north side of the island is underlain by limestones, marls, and some noncarbonate sediments of late Oligocene to early Miocene age. These sediments overlie Cretaceous to Paleocene or early Eocene age volcanic rocks and dip at a moderate inclination northward, away from the island. These beds are locally folded and faulted but are relatively undisturbed (Kaye, 1959). Rising gently southward from the coastal lagoons is a coastal plain made up of alluvial sediments. The coastal plain terminates to the south against hills of the uplands, which tend to increase in altitude southward towards the interior of the island (Kaye, 1959).

Isla Verde is a fragment of a former shore isolated by beach erosion with a thin soil layer. Because much of the peninsula has been developed for industrial and commercial use, much of the area is underlain with artificial fill (**Figure 1-2**). No digital data is available for soil directly beneath the AASF via the USDA Natural Resources Conservation Service (NRCS) Web Soil Survey tool. Soils in the low depressions and coastal lagoons within the vicinity of the AASF often include Martin Pena-Saladar-Hydraquents (Boccheciamp, 1978).

1.5.2 Hydrogeology

San Juan is located within the north coast limestone aquifer system of Puerto Rico, which comprises three regional hydrogeologic units: an upper aquifer, a middle confining unit, and a lower aquifer. The upper aquifer mainly consists of the Aymamon and underlying Aguada limestones and is confined in coastal areas, such as San Juan, by fine-grained surficial deposits. The limestones have been extensively eroded in the San Juan area, and the freshwater zone of the upper aquifer is underlain by a basal zone of saltwater. The upper aquifer is thin, and well yields are small in San Juan. The lower aquifer in the area is composed mostly of Mucarabones Sand, which consists of sandstone and gravel of terrestrial origin. Groundwater in the lower aquifer is brackish in some areas near San Juan (Rodriguez-Martinez, 1995). The Cibao Formation is the principal rock-stratigraphic unit of the middle confining unit and is an interbedded sequence of marl, chalk, limestone, sand, and clay as much as 230 meters thick. The Cibao Formation acts either as a confining bed or as an aquifer, depending upon the lithology. In the

San Juan area, an artesian aquifer capped by clays that are in turn overlain by water-bearing limestones are all part of the Cibao Formation (Giusti, 1978).

There are no drinking water wells at the AASF or known to be in its vicinity; the facility is provided municipal water by the Puerto Rico Aqueducts and Sewers Authority. The Río Grande de Loíza and the Río de la Plata watersheds are the principal sources of public water supply for the San Juan metropolitan area. Two USGS wells are located on the San Juan peninsula north of the facility and are shown on the Environmental Data Resources, Inc. (EDR) report included in **Appendix A**. Groundwater depth at the facility is unknown but a shallow water table is assumed. Groundwater flow at the AASF is expected to be radial towards the San Juan Bay and Caño San Antonio (**Figure 1-2**). Based on the USEPA Unregulated Contaminant Monitoring Rule 3 data, it was indicated that no PFAS were detected in a public water system above the USEPA Health Advisory level within 20 miles of the AASF.

1.5.3 Hydrology

San Juan is located in the San Juan Bay Estuary Watershed. Rainfall on inland mountain slopes drains into the Rio Piedras, which empties into the San Juan Bay. The Rio Piedras basin lies predominantly on relatively impervious volcanic rock; runoff is rapid, commonly resulting in flash flooding in the lower urbanized reaches of the streams in the area (Miller, Gary L.; Lugo, Ariel E, 2009). San Juan annually receives approximately 56.35 inches of rain on the north coast(National Oceanic and Atmospheric Administration [NOAA], 2019). Water infiltrating the volcanic rock flows largely through the weathered zone and then into stream valleys (Anderson, 1976).

The AASF is surrounded by commercial and industrial developments, primarily associated with the adjoining airport. There are no surface water bodies located within the facility boundary. Because the AASF is located on the center of the Isla Grande peninsula, it is surrounded by water on three sides (Figure 1-3). Surface water runoff is expected to generally flow south, away from the SIG runway, and empty into the San Juan Bay.

Surface water runoff at the AASF drains to catch basins that channel water towards an oil-water separator (OWS) located in the southeastern corner of the AASF property, adjacent to the southern corner of the Hangar. According to AASF personnel, transport of runoff beyond the OWS is unknown.

1.5.4 Climate

Puerto Rico is located in the tropics, and its maritime climate experiences warm sea breezes throughout the year, preventing major fluctuations in temperature. The average temperature in San Juan in the summer is 83.5 degrees Fahrenheit (°F), while the average temperature in the winter is 78.1 °F (NOAA, 2019). The coastal plains endure the smallest temperature fluctuations. Seasonal variation in the temperate zone is very low; however, there is considerable variation in temperature and precipitation resulting from variable topography and prevailing winds. The east-west mountain chain intercepts the easterly trade winds and provides the north side of the island with an abundance of rain (Miller, Gary L.; Lugo, Ariel E, 2009). Rainfall is distributed throughout the year, with May through November considered the raining period. January to March is drier, but may have cold fronts coming in from the temperate zone to the north that can produce rain. Annual precipitation in San Juan is approximately 56.35 inches (NOAA, 2019).

Puerto Rico is in the hurricane belt of the western Atlantic and Caribbean. Hurricanes are Puerto Rico's predominant weather problem because of the catastrophic high winds and waves, large volumes of rain, and the enormous structural change they can produce on natural ecosystems and on human populations and their infrastructure. Typically, six to ten hurricanes develop yearly in the western North Atlantic region. Hurricanes have impacted Puerto Rico recently, most notably with Hurricane Maria in 2017 (Miller, Gary L.; Lugo, Ariel E, 2009).

1.5.5 Current and Future Land Use

According to PRARNG personnel, the AASF is expected to be relocated within the next five years. It is unknown what the land may be used for following the relocation of the AASF; however, the land is expected to remain designated for commercial/industrial use.

CLIENT	ARNG			
NOTES	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:18,000	CHK BY	JW	1/10/2020
Base Map: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI,		PM	RG	1/10/2020

N

Facility Location

AECOM
12420 Milestone Center Drive
Germantown, MD 20876

Figure 1-1

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CLIENT	ARNG			
NOTES	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:12,000	CHK BY	JW	1/10/2020
Base Map: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,		PM	RG	1/10/2020

Groundwater Features

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Figure 1-2

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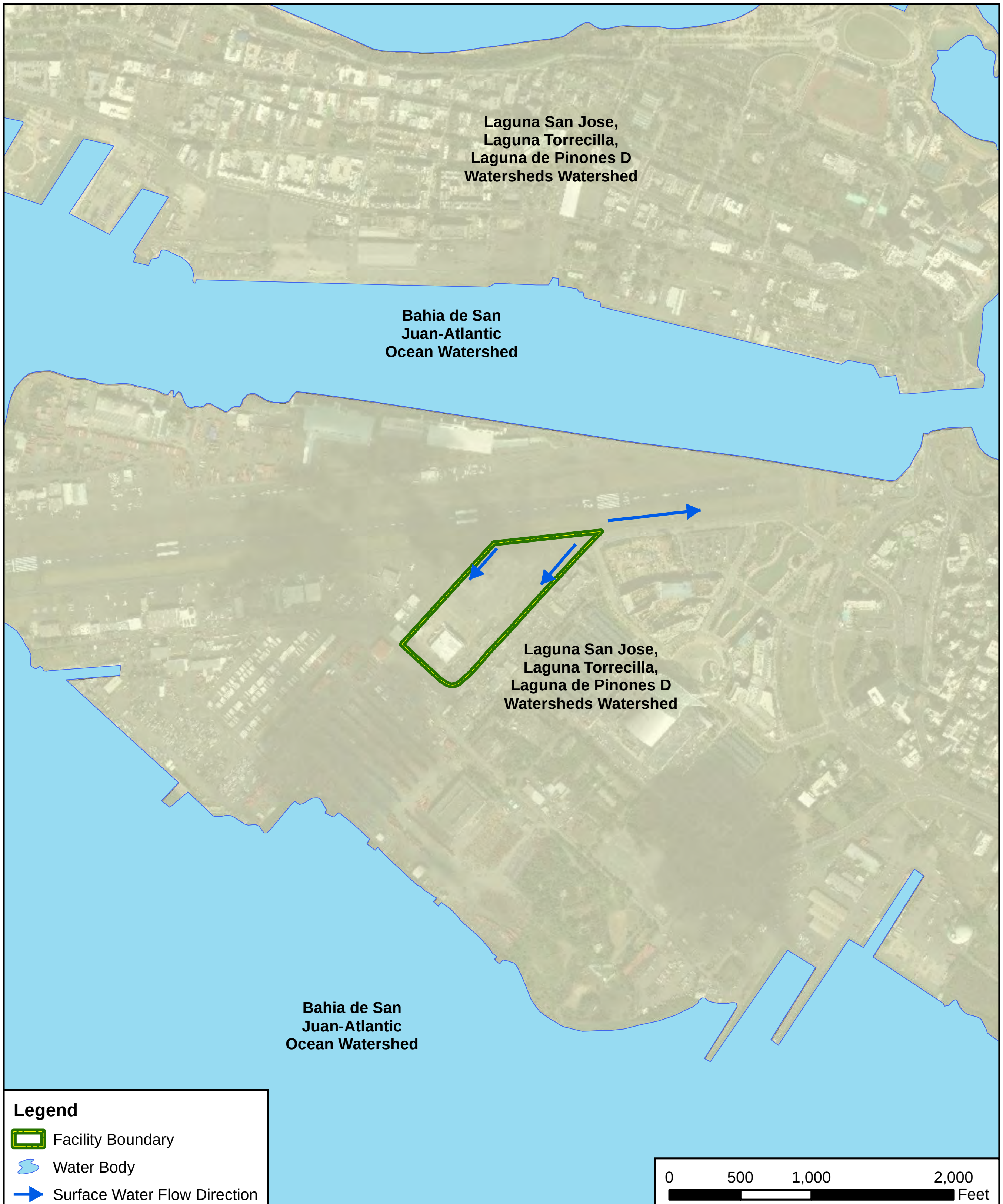

CLIENT	ARNG				
NOTES	Preliminary Assessment for PFAS at AASF San Juan, PR				
REVISED	1/10/2020	GIS BY	MS	1/10/2020	
SCALE	1:12,000	CHK BY	JW	1/10/2020	
Base Map: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,		PM	RG	1/10/2020	

Surface Water Features

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Figure 1-3

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2. Fire Training Areas

FTAs are considered areas where deliberate discharge of AFFF or other firefighting materials is performed for purposes of training personnel. One FTA was identified at the AASF (**Figure 2-1**) during PA through interviews, and review of the EDR report for a 1-mile radius surrounding the facility (**Appendix A**).

2.1 Wash Rack

The AASF Wash Rack is located in the southeastern corner of the PRARNG property, south of the Hangar and adjacent to the Pump House (18°27'14.56"N; 66°5'48.55"W). The Wash Rack is typically used for the controlled cleaning of heavy equipment; however, it has also been used regularly as an FTA by PRARNG personnel. According to an interviewee whose tenure at the AASF spans from 1999 to present, fire training occurred annually the Wash Rack from 1999 to approximately 2016. It is possible that fire training occurred prior to 1999.

During the annual fire training, one TRI-MAX™ 30 Wheeled Compressed Air Foam (CAF) was typically discharged fully to the Wash Rack. Occasionally, the local fire academy assisted in training by igniting a fire in the Wash Rack for PRARNG staff to extinguish, but the fire academy never used their own materials to extinguish the flames. The TRI-MAX™ 30 CAF contains 30 gallons of AFFF foam solution that produce approximately 600 gallons of expanded foam. The type and concentration of AFFF discharged during training events are unknown, but material safety data sheets for AFFF stored at the AASF (**Appendix A**) provided by the PRARNG indicate that Chemguard 3% AFFF C-303 and Chemguard 3% AR-AFFF C-333 may have been used.

As-built drawings for the Wash Rack were not provided during this PA. PRARNG staff stated that the AASF floor drains, including the Wash Rack drain, flow in unknown directions. The fate of AFFF released during the fire training events is unknown.

CLIENT	ARNG			
NOTES	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:2,643	CHK BY	JW	1/10/2020
Base Map: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,		PM	RG	1/10/2020

N

Fire Training Area

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Figure 2-1

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3. Non-Fire Training Areas

Several non-FTAs where AFFF was potentially stored and/or released were investigated during the PA. A description of each non-FTA is presented below, and the non-FTAs are shown on **Figure 3-1**.

3.1 AASF Hangar

The AASF Hangar is located in the southwest portion of the PRARNG property (18°27'16.50"N; 66°5'48.04"W). The Hangar is used to provide aviation maintenance support and repair for aviation components. The fire suppression system at the Hangar includes a deluge system that is served by a 900 gallon AFFF tank charged with Ansul 3% AFFF and four fixed deluge guns located in the four corners of the Hangar; however, the deluge system is not currently operational. Two TRI-MAX™ 30 CAF wheeled extinguishers are also staged within the Hangar.

According to PRARNG AASF personnel, two AFFF releases have occurred at the Hangar. An AFFF release occurred between 2006 and 2008, when a fire marshal inspector accidentally triggered the deluge system in the AASF Hangar. During the release, the Hangar doors were open, and AFFF escaped the Hangar via the northeast and southwest doors. The majority of the escaping AFFF traveled southwest from the AASF Hangar towards the Wash Rack. AFFF may have also entered storm drains and the OWS, which is located between the hangar and the Wash Rack. Approximately 900 gallons of AFFF was released during the event. The type and concentration of AFFF released during the incident are unknown, but the deluge system tank is currently charged with Ansul 3% AFFF.

AASF staff also stated during interviews that a test of the Hangar deluge system was performed in 2009. The 2009 test also resulted in a full release of the deluge system tank (900 gallons of AFFF), and the AFFF released traveled towards the Wash Rack, similarly to the accidental release between 2006 and 2008.

AASF personnel stated that during the releases, the Hangar filled with approximately 6 feet of standing AFFF, and that the majority of AFFF flowed southwest towards the OWS, the Wash Rack, and stormwater drains.

The fate of AFFF entering drains within the Hangar as well as storm drains, the OWS, and the Wash Rack outside the Hangar is unknown.

3.2 Former Fire Station

The Former Fire Station at the AASF operated between 1992 and 1997. The Former Fire Station bay, where the fire station stored its firetruck, was located on the northern corner of the AASF Hangar (18°27'17.49"N; 66°5'48.44"W). The firetruck remained in the fire station bay until 2004, despite the fire station's closure in 1997. According to an interviewee whose tenure at the AASF spans from 1999 to present, the firetruck was never used between 1999 and 2004. It is unknown whether the firetruck were capable of using AFFF, and it is also unknown whether the fire department stored or trained with AFFF. Because AFFF was stored and used elsewhere at the AASF, it is possible that AFFF was stored and/or used at the Former Fire Station. The Former Fire Station is considered a potential PFAS release area.

3.3 Oil-Water Separator

The OWS is located in the southeastern corner of the AASF property, adjacent to the southern corner of the Hangar (18°27'14.93"N; 66°5'47.88"W). Two full deluge system tank releases in

2006-2008 and 2009, previously described in **Section 2.1** and **Section 3.1**, have resulted in an unknown type, volume, and concentration of AFFF entering the OWS. Due to the proximity of the OWS to the Wash Rack, it is also possible that AFFF discharged during training events could have flowed out of the Wash Rack perimeter and into the OWS.

As previously stated, the fate of AFFF entering surface drains at the AASF is unknown.

3.4 Pump House

The Pump House is located in the southeastern corner of the AASF property, adjacent to the Wash Rack (18°27'14.11"N; 66°5'48.05"W). The Pump House stores the 900-gallon Ansulite 3% AFFF storage tank that serves the Hangar deluge system. Ansul Silv-Ex Class A Fire Control Concentrate is also stored in 5-gallon containers within the Pump House. Material safety data sheets for the Silv-Ex foam are included in **Appendix A**. AASF personnel stated that additional AFFF formerly stored in 5-gallon buckets in the Pump House was disposed of in 2017 via the Defense Reutilization and Marketing Office or the Defense Logistics Agency. No records for the disposal were provided during this PA. A dry chemical handheld fire extinguisher is also staged outside the Pump House door.

AASF staff stated during interviews that the deluge system is not currently operational. No available interviewees were present at the AASF immediately following its construction in 1992; it is unknown when the AFFF deluge system was constructed. According to interviewees, no AFFF leaks or other releases have occurred within the Pump House. During the VSI, no indication of corrosion or leaks were apparent within the Pump House.

3.5 Petroleum, Oils, and Lubricants Storage Area

The Petroleum, Oils, and Lubricants (POL) Storage Area is located in the southwestern portion of the AASF property, northwest of the Hangar (18°27'17.35"N; 66°5'50.19"W). The POL Storage Area includes a covered vehicle parking area and a 12,500 gallon bermed area that stores two Jet Fuel 24 aboveground storage tanks. No AFFF fire suppression system is established in the POL Storage Area; however, a condemned TRI-MAX™ Super 60 Skid is currently stored within the area. AASF personnel stated that the TRI-MAX™ units staged at the AASF have 12 year lifespans. It is unclear whether the TRI-MAX™ Super 60 Skid was condemned due to expiration or for other reasons. The TRI-MAX™ Super 60 Skid unit is being stored in the POL Storage Area until it can be properly disposed of by the PRARNG. The maintenance manual for the unit is included in **Appendix A**.

No known AFFF releases have occurred in the POL Storage Area.

3.6 Flightline

The Flightline is located in the northeast portion of the AASF property and comprises the majority of the AASF. Flightlines can be the location of fueling incidents and crashes that commonly require AFFF fire suppression in response. According to AASF personnel whose tenure at the AASF spans from 1999 to present, no crashes or accidents requiring AFFF response have ever occurred on the flightline. Two TRI-MAX™ 30 CAF wheeled extinguishers are staged on the flightline for emergency response; one TRI-MAX™ 30 CAF unit is staged on the northwest of the boundary of the flightline, the other is staged on the southeastern border of the flightline. The TRI-MAX™ units have never been discharged or maintained.

No known AFFF releases have occurred on the AASF Flightline.

CLIENT	ARNG				N	**Non-Fire Training Area**
NOTES	Preliminary Assessment for PFAS at AASF San Juan, PR					
REVISED	1/10/2020	GIS BY	MS	1/10/2020		AECOM 12420 Milestone Center Drive Germantown, MD 20876
SCALE	1:2,643	CHK BY	JW	1/10/2020		**Figure 3-1**
Base Map: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,		PM	RG	1/10/2020		

Q:\Projects\ENV\GEARS\GEO\ARNG PFAS\900-CAD-GIS\920-GIS or Graphics\MXD\PR\AASF_San_Juan_Figures\Fig_3-1_AASF_San_Juan_Non-Fire_Training_Areas.mxd

4. Emergency Response Areas

No emergency response areas were identified within the AASF property boundary. PRARNG staff confirmed that no known incidents have occurred during their collective tenure (spanning 1999-present). Online research and the EDR report (**Appendix A**) also did not indicate that any incidents have occurred at the facility. Emergency responses to crashes sometimes require flame suppression, which may result in the release of PFAS to the environment in the form of AFFF.

The SIG Aviation Department Rescue and Firefighter Section (also referred to as “the Section”) provides emergency response for the airport and surrounding areas, including the AASF, between 7:00 am and 7:00 pm. The San Juan Fire Department, stationed in Santurce, responds to emergencies between 7:00 pm and 7:00 am.

5. Adjacent Sources

Several potential off-facility sources of PFAS adjacent to the AASF, not under the control of the PRARNG, were identified during the PA through interviews, review of the EDR report for a 1-mile radius surrounding the facility (**Appendix A**), and historical document review. A description of each potential adjacent source is presented below, and the sources are shown on **Figure 5-1**.

5.1 Fernando Ribas Dominicci Airport (SIG)

SIG is located adjacent to the AASF to the north. The SIG airport runway runs from the western tip of the Isla Grande peninsula northwest towards a marina located in the Caño San Antonio. The main terminal at SIG is located approximately 0.1 mile northwest of the AASF Hangar (18°27'20.97"N; 66°5'52.36"W). The airport supports general aviation as well as international and domestic commercial flights. SIG functioned as Puerto Rico's main international airport until the opening of Luis Muñoz Marín International Airport in 1954.

Airports can represent potential adjacent sources of PFAS because airport emergency response and rescue operations often use AFFF to suppress crash flames. The SIG Aviation Department Rescue and Firefighter Section stores 6% AFFF solution in one firetruck staged approximately 100 feet northwest of the AASF POL Storage Area, and in one firetruck staged adjacent to the main SIG terminal building, on its northwest side. The SIG Aviation Department Rescue and Firefighter Section also stores AFFF in 5-gallon buckets within its office space in the main SIG terminal.

According to the SIG Aviation Department Rescue and Firefighter Section Supervisor, the Section performs nozzle testing on their equipment in the center of the SIG runway area using only water. The exact location of the nozzle testing is unclear. The Section also formerly performed equipment testing with water and expiring AFFF on the east and west ends of the SIG runway approximately once per month. Because there was not always expiring AFFF available to the Section, the training did not always involve AFFF. The tenure of the Section supervisor interviewed began in 2017. Previous AFFF use and storage practices by the Sig Aviation Department Rescue and Firefighter Section are unknown.

PRARNG AASF personnel also stated that AFFF was sprayed by the SIG Aviation Department Rescue and Firefighter Section on the SIG airport runway circa 2005 to prevent a fire during the attempted landing of a malfunctioning Cessna 421 Golden Eagle. The Cessna eventually landed without fire after several touchdowns. The exact location of AFFF that was sprayed during this event is unknown. Incident reports for the Caribbean Petroleum Corporation (CAPECO) fire are included in **Appendix A**.

5.2 Police Station

A police station is located immediately adjacent to the AASF to the west (18°27'17.29"N; 66°5'51.57"W). The police station operates out of a building formerly used by the Department of Natural Resources. During the VSI, four wheeled fire extinguishers, similar to the Buckeye A-150-SP ABC Dry Chemical Wheeled Stored Pressure Fire Extinguishers observed at Camp Santiago, were observed outside the police station. The type of fire extinguisher at the police station is unclear, and it is unknown whether the extinguishers contain AFFF. The police station practices regarding fire suppression are unknown.

5.3 2009 Caribbean Petroleum Fire

In 2009, a massive fire and explosion occurred at the CAPECO facility located in Bayamon, Puerto Rico, approximately 3.4 miles southwest of the AASF. A fuel vapor cloud, created when a 5-million gallon aboveground storage tank overflowed, reached an ignition source elsewhere in the CAPECO facility and erupted, causing multiple fires and secondary explosions. The fires burned for approximately 60 hours, and petroleum products leaked into the soil, nearby wetlands, and navigable waterways in the surrounding area.

The emergency response by the local fire departments and CAPECO was not sufficient to control the fire. According to PRARNG firefighters at Camp Santiago and Fort Allen, PRARNG aided in fire suppression efforts using AFFF.

The incident resulted in the release of thousands of gallons of oil, fire suppression foam of unknown types and concentrations, and contaminated runoff to the wetlands surrounding the CAPECO facility. These wetlands include Las Lajas Creek, Lago del Caño de San Fernando, and Malaria Creek, which empties into the San Juan Bay. The volume of AFFF that reached the San Juan Bay is unclear.

5.4 Wastewater Treatment Plant

There are no wastewater treatment plants (WWTPs) located at the AASF. The location of the nearest WWTP, which could be a potential adjacent PFAS source, is unknown. WWTPs are not usually a primary potential release area of PFAS, but sludges and liquids from areas of potential release that are treated at WWTPs may create a secondary source of contamination.

5.5 Landfills

There are no landfills located at the AASF. The location of the nearest landfill, which could be a potential adjacent PFAS source, is unknown. Landfills are also not usually a primary potential release area of PFAS, but materials disposed of in landfills may create a secondary source of contamination. Such materials, to name a few, may include sludge from a WWTP that processes PFAS-laden water, or products associated with waterproofing uniforms or boots.

CLIENT	ARNG			
PROJECT	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:117,032	CHK BY	JW	1/10/2020
Base Map: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)		PM	RG	1/10/2020

TITLE

Adjacent Sources

AECOM

12420 Milestone Center Drive
Germantown, MD 20876

Figure 5-1

Q:\Projects\ENV\GEARS\GEO\ARNG PFAS\900-CAD-GIS\920-GIS or Graphics\MXD\PR\AASF_San_Juan_Figures\Fig_5-1_AASF_San_Juan_Adjacent_Sources.mxd

6. Preliminary Conceptual Site Model

Based on the PA findings, one AOI was identified at the AASF: the Hangar and Wash Rack Areas. The AOI is shown on **Figure 6-1**. The following sections describe the CSM components and the specific preliminary CSM developed for the AOI. The CSM identifies the three components necessary for a potentially complete exposure pathway: (1) source, (2) pathway, (3) receptor. If any of these elements are missing, the pathway is considered incomplete.

In general, the potential PFAS exposure pathways are ingestion and inhalation. Human exposure via the dermal contact pathway may occur, and current risk practice suggests it is an insignificant pathway compared to ingestion; however, exposure data for dermal pathways are sparse and continue to be the subject of PFAS toxicological study (National Ground Water Association, 2018). Receptors at the AASF include site workers, construction workers, trespassers, and off-facility recreational users of the surrounding water bodies. The preliminary CSM diagram for the AASF (**Figure 6-2**) indicates which specific receptors could potentially be exposed to PFAS.

6.1 AOI 1 Hangar and Wash Rack Areas

AOI 1 comprises the AASF Hangar, Wash Rack, and areas where known PFAS releases could have surficially migrated. Each annual fire training event at the Wash Rack between 1999 and 2016 included the release of 30 gallons of AFFF concentrate, and two Hangar deluge system discharges occurring between 2006-2009 released approximately 900 gallons of AFFF apiece.

PFAS releases at the AOI occurred on paved surfaces and were guided towards floor drains. Some small landscaped areas exist adjacent to the release areas. Surface soil in the landscaped areas at the AOI may have received AFFF runoff during PFAS releases. Surface soil at AOI 1 is considered a potentially complete pathway for PFAS exposure to site workers, construction workers, and trespassers via ingestion and inhalation.

AFFF releases may also have infiltrated subsurface soil via cracks in pavement, joints between areas that are paved with different materials, and landscaped areas. Floor drain discharge points within the AOI are unknown and could potentially transport runoff to subsurface soil. If AFFF released at the AOI infiltrated the subsurface, then ground-disturbing activities may result in PFAS exposure to construction workers via ingestion and inhalation. Accidental ingestion of groundwater is also considered a potentially complete pathway for PFAS exposure during construction activities due to the unknown depth to groundwater at the AASF.

PFAS are water soluble and can migrate readily from soil to groundwater via leaching; however, the AASF and surrounding areas are provided municipal water by the Puerto Rico Aqueducts and Sewers Authority. No drinking water wells exist at the AASF. Groundwater is considered an incomplete pathway for PFAS exposure to site workers and residents via ingestion.

Groundwater at the AASF discharges to the San Juan Bay and the Caño San Antonio. AASF surface drains discharge to unknown locations, which could include San Juan Bay and the Caño San Antonio. As a result, releases of AFFF on the facility may be migrating to the surrounding off-facility waters. AASF interviewees stated that recreational fishing and swimming occur in the waters surrounding Isla Grande. Additionally, the annual Ironman Triathlon in San Juan includes a 1.2-mile swimming course within the adjacent Condado Lagoon. The Caño San Antonio connects to the Condado Lagoon to the east. As a result of AFFF releases at the AASF, it is possible that PFAS have migrated to surface water and sediment surrounding the Isla Grande peninsula, including the San Juan Bay, the Caño San Antonio, and the Condado Lagoon; and it is possible that PFAS-laden surface water and sediment is present within the area stormwater network. As such, the pathway for PFAS exposure to recreational users of these waters and construction workers working within the area stormwater network via ingestion of surface water and sediment is considered potentially complete.

CLIENT	ARNG
PROJECT	Preliminary Assessment for PFAS at AASF San Juan, PR

REVISED 1/10/2020	GIS BY	MS	1/10/2020
SCALE 1:4,560	CHK BY	JW	1/10/2020
Base Map: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)	PM	RG	1/10/2020

Area of Interest
Potential PFAS Release
No Suspected Release
Facility Boundary
Surface Water Flow Direction
Inferred Groundwater Flow Direction
Monitoring Well/Piezometer
Other/Unknown Well

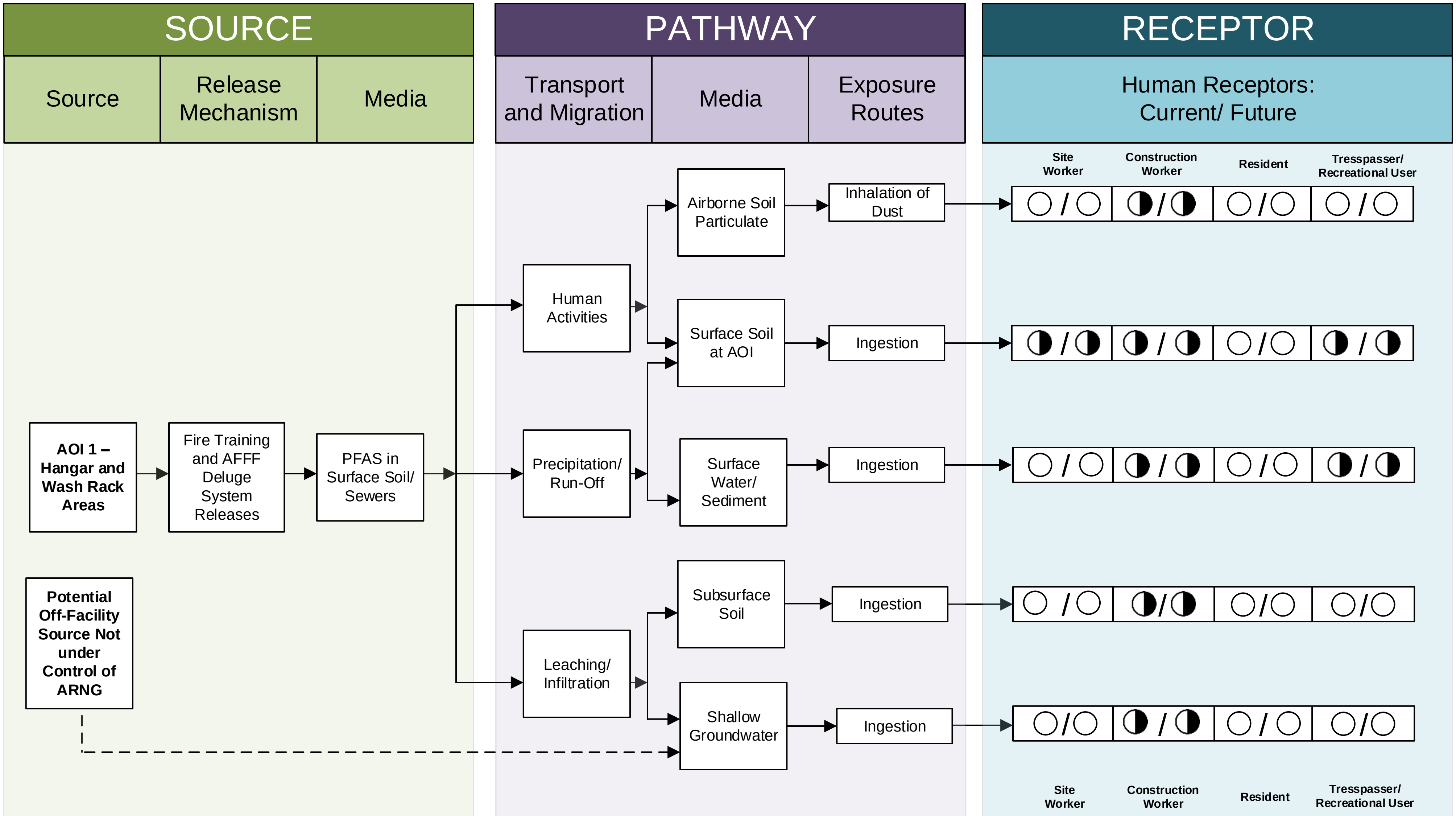
N

Area of Interest

AECOM 12420 Milestone Center Drive Germantown, MD 20876

Figure 6-1

Q:\Projects\ENV\GEARS\GEO\ARNG PFAS\900-CAD-GIS\920-GIS or Graphics\MXD\PR\AASF_San_Juan_Figures\Fig_6-1_AASF_San_Juan_AOIs.mxd



LEGEND

Flow-Chart Stops

Flow-Chart Continues

Partial / Possible Flow

Incomplete Pathway

Potentially Complete Pathway

Complete Pathway

Notes:

1. The resident and recreational user receptors refer to an off-site resident and recreational user.
2. Dermal contact exposure pathway is incomplete for PFAS.

Figure 6-2
Preliminary Conceptual Site Model
AOI 1 – Hangar and Wash Rack Areas

7. Conclusions

This report presents a summary of available information gathered during the PA on the use and storage of AFFF and other PFAS-related activities at the AASF. The PA findings are based on personnel interviews, environmental investigations and reports, historical documents, and the VSI (**Appendix A** and **Appendix B**).

7.1 Findings

One AOI related to potential PFAS release was identified at the AASF based on PA data (**Figure 7-1**) and is summarized in **Table 7-1** below:

Table 7-1: AOIs at AASF

Area of Interest	Name	Used by	Potential Release Dates
AOI 1	Hangar and Wash Rack Areas	PRARNG	1999 - 2016

Based on the possible PFAS releases at the AOI, there is potential for exposure to PFAS contamination in surface soil to site workers and trespassers via ingestion and inhalation; in subsurface soil to construction workers via ingestion and inhalation; and in surface water and sediment to construction workers and off-facility recreational users via ingestion. The preliminary CSM for AASF is shown on **Figure 6-2**.

The following areas discussed in **Section 2** through **Section 5** were determined to have no suspected release:

Table 7-1: No Suspected Release Areas

No Suspected Release Area	Used by	Rationale for No Suspected Release Determination
Flightline	PRARNG	According to interviewees, no AFFF has been used on the flightline despite using the flightline to stage TRI-MAX™ fire extinguishers.
Pump House	PRARNG	According to interviewees, no AFFF has been released at the Pump House despite using the space to store the facility AFFF deluge system tank.
POL Storage Area	PRARNG	According to interviewees, no AFFF has been released at the POL Storage Area despite using the area to store a condemned TRI-MAX™ fire extinguisher.

7.2 Uncertainties

A number of information sources were investigated during this PA to determine the potential for PFAS-containing materials to have been present, used, or released at the AASF. Historically, documentation of PFAS use was not required because PFAS were considered benign. Therefore, records were not typically kept by the PRARNG on the use, storage, or disposition of AFFF.

The conclusions of this PA are predominantly based on the information provided during interviews with personnel who had direct knowledge of PFAS use at the facility. Sometimes, the provided information was vague. Gathered information has a degree of uncertainty due to the absence of written documentation, the limited number of personnel with direct knowledge, the time passed since PFAS were first used by the ARNG (1969 to present), and a reliance on personal recollection. Inaccuracies may arise in potential PFAS release locations, dates of releases, volumes of releases, and concentrations of AFFF used during releases. There is also a possibility the PA has missed a source of PFAS, as the science of how PFAS may enter the environment continually evolves.

In order to minimize the level of uncertainty, readily available data regarding storage of PFAS were reviewed, tenured personnel were interviewed, multiple persons were interviewed for the same potential source area, and potential source areas were visually inspected.

The following table summarizes the uncertainties associated with the PA:

Table 7-3: Sources of Uncertainty

Location	Source of Uncertainty
Former Fire Station	It is unknown whether the fire station used or stored AFFF, or whether the firetruck were maintenance at the AASF
Hangar	The type and concentration of AFFF discharged during the two deluge system releases are unknown. The fate of AFFF entering floor drains at the Hangar is unknown. The extent to which AFFF escaped through the Hangar doors during releases is unknown. The fate of AFFF released during these events is unknown because the transport of runoff beyond the facility OWS is unclear. It is possible that additional releases associated with the Hangar occurred prior to 1999; AASF staff interviewed only have first-hand knowledge dating back to 1999.
Wash Rack	Without records, the type, concentration, and volume of AFFF released during fire training are unknown. It is unknown whether AFFF escaped the Wash Rack during training events. The fate of AFFF entering the Wash Rack during training events is unknown. It is unknown whether similar fire training occurred prior to the tenure of staff interviewed for this PA.
Oil Water Separator	The volume of AFFF entering the OWS during the Hangar deluge system releases and the fire training activities at the Wash Rack is unknown.
POL Storage Area	The reason the TRI-MAX™ Super 60 Skid staged in the POL Storage Area is considered condemned is unknown.

7.3 Potential Future Actions

Interviews with PRARNG AASF staff, whose first-hand knowledge of the facility span 1999-present, indicate that ARNG activities may have resulted in the release of AFFF at one AOI identified during the PA. Based on the preliminary CSM developed for the AOI, there is potential for PFAS to be exposed to human receptors (see **Section 7.1**). **Table 7-4** summarizes the rationale used to determine if the AOI should be considered for further investigation under the CERCLA process and undergo an SI.

Table 7-4: PA Findings Summary

Area of Interest	AOI Location	Rationale	Potential Future Action
AOI 1 Hangar and Wash Rack Areas	18°27'16.50"N; 66°5'48.04"W	Multiple AFFF releases to paved surfaces, surface soil, and floor drains between 1999-2016	Proceed to an SI, focus on soil and surface water

ARNG will evaluate the need for an SI at the AASF based on the potential receptors, the potential migration of PFAS contamination off the facility, and the availability of resources.

CLIENT	ARNG			
PROJECT	Preliminary Assessment for PFAS at AASF San Juan, PR			
REVISED	1/10/2020	GIS BY	MS	1/10/2020
SCALE	1:4,560	CHK BY	JW	1/10/2020
Base Map: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)		PM	RG	1/10/2020

Area of Interest
Potential PFAS Release
No Suspected Release
Facility Boundary

N

Summary of Findings

AECOM
12420 Milestone Center Drive
Germantown, MD 20876

Figure 7-1

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8. References

Anderson, Henry R., 1976. Ground Water in the San Juan Metropolitan Area, Puerto Rico. United States Geological Survey; Water-Resources Investigations Report 75-41.

Boccheciamp, Rafael A., 1978. Soil Survey of San Juan Area of Puerto Rico. United States Department of Agriculture, Soil Conservation Service. November 1978.

Giusti, Ennio V., 1978. Hyrdogeology of the Karst of Puerto Rico; Geological Survey Professional Paper 1012. United States Department of the Interior. 1978.

Kaye, Clifford A., 1959. Geology of the San Juan Metropolitan Area, Puerto Rico; Geological Survey Professional Paper 317-A. United States Department of the Interior. 1959.

National Ground Water Association, 2018. Groundwater and PFAS: State of Knowledge and Practice. January.

Miller, Gary L.; Lugo, Ariel E, 2009. Guide to the ecological systems of Puerto Rico. Gen. Tech. Rep. IITF-GTR-35. San Juan, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry.

Rodriguez-Martinez, Jesus, 1995. Hydrogeology of the North Coast Limestone Aquifer System of Puerto Rico. United Sates Geological Survey Water Investigations Report 94-4249.

United States Environmental Protection Agency (USEPA), 1991. *Guidance for Performing Preliminary Assessments under CERCLA.* September.

Appendix A
Data Resources

Data Resources will be provided separately on CD. Data Resources for the AASF includes:

AASF EDR Report

- 2019 AASF EDR Report 5714997

Environmental Information Sources

- 1959 USDOI Geological Survey Professional Paper 317: Coastal Geology of Puerto Rico
- 1976 USGS Water-Resources Investigation Report 41-75: Ground Water in the San Juan Metropolitan Area, Puerto Rico
- 1978 USDOI Geological Survey Professional Paper 1012: Hydrogeology of the Karst of Puerto Rico
- 1978 USDA Soil Conservation Service Soil Survey of San Juan Area of Puerto Rico
- 1995 USGS Water-Resources Investigations Report 94-4249: Hydrogeology of the North Coast Limestone Aquifer System of Puerto Rico
- 2019 USDA NRCS Custom Soil Resource Report for San Juan Area, Puerto Rico

AASF Firefighting Material Information

- 1990 AASF Fire Pump Schematic
- 2003 Ansul Silv-Ex Foam Concentrate Material Safety Data Sheet
- 2006 Chemguard 3% AFFF C-303 Material Safety Data Sheet
- 2006 Chemguard 3% AR-AFFF C-333 Material Safety Data Sheet
- 2010 TRI-MAX Super-60 Skid Compressed Air Foam System Operations, Training and Maintenance Manual
- TRI-MAX 30 Wheeled Specifications

CAPECO Fire Incident Report

- 2009 Chemical Safety and Hazard Investigation Board Field Investigation Report for the Caribbean Petroleum Tank Terminal Explosion and Multiple Tank Fires

Real Property Documents

- 1989 Certificate of Title
- 1989 Federal-State Agreement DAHA 70-89-H-0006 Approval
- 2019 Agreement AP-19-20-5-031

Data Resources will be provided separately on CD. Data Resources for the AASF includes:

AASF EDR Report

- 2019 AASF EDR Report 5714997

Environmental Information Sources

- 1959 USDOI Geological Survey Professional Paper 317: Coastal Geology of Puerto Rico
- 1976 USGS Water-Resources Investigation Report 41-75: Ground Water in the San Juan Metropolitan Area, Puerto Rico
- 1978 USDOI Geological Survey Professional Paper 1012: Hydrogeology of the Karst of Puerto Rico
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- 2010 TRI-MAX Super-60 Skid Compressed Air Foam System Operations, Training and Maintenance Manual
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- 2019 Agreement AP-19-20-5-031

AASF Isla Grande
600-600 Calle Lindbergh
San Juan, PR 00907

Inquiry Number: 5714997.2s
July 12, 2019

The EDR Radius Map™ Report with GeoCheck®

6 Armstrong Road, 4th floor
Shelton, CT 06484
Toll Free: 800.352.0050
www.edrnet.com

TABLE OF CONTENTS

Thank you for your business.
Please contact EDR at 1-800-352-0050
with any questions or comments.

EXECUTIVE SUMMARY

A search of available environmental records was conducted by Environmental Data Resources, Inc (EDR). The report was designed to assist parties seeking to meet the search requirements of EPA's Standards and Practices for All Appropriate Inquiries (40 CFR Part 312), the ASTM Standard Practice for Environmental Site Assessments (E 1527-13), the ASTM Standard Practice for Environmental Site Assessments for Forestland or Rural Property (E 2247-16), the ASTM Standard Practice for Limited Environmental Due Diligence: Transaction Screen Process (E 1528-14) or custom requirements developed for the evaluation of environmental risk associated with a parcel of real estate.

TARGET PROPERTY INFORMATION

ADDRESS

600-600 CALLE LINDBERGH
SAN JUAN, PR 00907

COORDINATES

Latitude (North):	18.4552640 - 18˚ 27' 18.95''
Longitude (West):	66.0960150 - 66˚ 5' 45.65''
Universal Tranverse Mercator:	Zone 19
UTM X (Meters):	806735.1
UTM Y (Meters):	2042894.9
Elevation:	10 ft. above sea level

USGS TOPOGRAPHIC MAP ASSOCIATED WITH TARGET PROPERTY

Target Property Map:	5964476 SAN JUAN, PR
Version Date:	2013

MAPPED SITES SUMMARY

Target Property Address:
600-600 CALLE LINDBERGH
SAN JUAN, PR 00907

Click on Map ID to see full detail.

MAP ID	SITE NAME	ADDRESS	DATABASE ACRONYMS	RELATIVE ELEVATION	DIST (ft. & mi.) DIRECTION
1	NAVAL STATION SAN JU		FUDS	Higher	50, 0.009, North
A2	COE	AVE. FERNANDEZ JUNCO	LUST	Higher	1990, 0.377, NNE
A3	ANTILLIES ENGINEERIN		FUDS	Higher	2042, 0.387, North

EXECUTIVE SUMMARY

TARGET PROPERTY SEARCH RESULTS

The target property was not listed in any of the databases searched by EDR.

DATABASES WITH NO MAPPED SITES

No mapped sites were found in EDR's search of available ("reasonably ascertainable ") government records either on the target property or within the search radius around the target property for the following databases:

STANDARD ENVIRONMENTAL RECORDS

Federal NPL site list

NPL........................ National Priority List
Proposed NPL.............. Proposed National Priority List Sites
NPL LIENS.................. Federal Superfund Liens

Federal Delisted NPL site list

Delisted NPL............... National Priority List Deletions

Federal CERCLIS list

FEDERAL FACILITY......... Federal Facility Site Information listing
SEMS....................... Superfund Enterprise Management System

Federal CERCLIS NFRAP site list

SEMS-ARCHIVE............ Superfund Enterprise Management System Archive

Federal RCRA CORRACTS facilities list

CORRACTS................. Corrective Action Report

Federal RCRA non-CORRACTS TSD facilities list

RCRA-TSDF................ RCRA - Treatment, Storage and Disposal

Federal RCRA generators list

RCRA-LQG.................. RCRA - Large Quantity Generators
RCRA-SQG.................. RCRA - Small Quantity Generators
RCRA-CESQG.............. RCRA - Conditionally Exempt Small Quantity Generator

Federal institutional controls / engineering controls registries

LUCIS....................... Land Use Control Information System
US ENG CONTROLS........ Engineering Controls Sites List

EXECUTIVE SUMMARY

US INST CONTROL - - - - - - - - - - Sites with Institutional Controls

Federal ERNS list

ERNS - Emergency Response Notification System

State- and tribal - equivalent CERCLIS

SHWS - This state does not maintain a SHWS list. See the Federal CERCLIS list and Federal NPL list.

State and tribal leaking storage tank lists

INDIAN LUST - - - - - - - - - - - - - - - Leaking Underground Storage Tanks on Indian Land

State and tribal registered storage tank lists

FEMA UST - - - - - - - - - - - - - - - - - - Underground Storage Tank Listing
UST - Underground Storage Tank Facilities
INDIAN UST - - - - - - - - - - - - - - - - - Underground Storage Tanks on Indian Land

State and tribal voluntary cleanup sites

INDIAN VCP - - - - - - - - - - - - - - - - - Voluntary Cleanup Priority Listing

ADDITIONAL ENVIRONMENTAL RECORDS

Local Brownfield lists

US BROWNFIELDS - - - - - - - - - - A Listing of Brownfields Sites

Local Lists of Landfill / Solid Waste Disposal Sites

INDIAN ODI - - - - - - - - - - - - - - - - - Report on the Status of Open Dumps on Indian Lands
DEBRIS REGION 9 - - - - - - - - - - Torres Martinez Reservation Illegal Dump Site Locations
ODI - Open Dump Inventory
IHS OPEN DUMPS - - - - - - - - - - Open Dumps on Indian Land

Local Lists of Hazardous waste / Contaminated Sites

US HIST CDL - - - - - - - - - - - - - - - Delisted National Clandestine Laboratory Register
US CDL - National Clandestine Laboratory Register

Local Land Records

LIENS 2 - CERCLA Lien Information

Records of Emergency Release Reports

HMIRS - Hazardous Materials Information Reporting System

Other Ascertainable Records

RCRA NonGen / NLR - - - - - - - - RCRA - Non Generators / No Longer Regulated

EXECUTIVE SUMMARY

DOD	Department of Defense Sites
SCRD DRYCLEANERS	State Coalition for Remediation of Drycleaners Listing
US FIN ASSUR	Financial Assurance Information
EPA WATCH LIST	EPA WATCH LIST
2020 COR ACTION	2020 Corrective Action Program List
TSCA	Toxic Substances Control Act
TRIS	Toxic Chemical Release Inventory System
SSTS	Section 7 Tracking Systems
ROD	Records Of Decision
RMP	Risk Management Plans
RAATS	RCRA Administrative Action Tracking System
PRP	Potentially Responsible Parties
PADS	PCB Activity Database System
ICIS	Integrated Compliance Information System
FTTS	FIFRA/ TSCA Tracking System - FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act)/TSCA (Toxic Substances Control Act)
MLTS	Material Licensing Tracking System
COAL ASH DOE	Steam-Electric Plant Operation Data
COAL ASH EPA	Coal Combustion Residues Surface Impoundments List
PCB TRANSFORMER	PCB Transformer Registration Database
RADINFO	Radiation Information Database
HIST FTTS	FIFRA/TSCA Tracking System Administrative Case Listing
DOT OPS	Incident and Accident Data
CONSENT	Superfund (CERCLA) Consent Decrees
INDIAN RESERV	Indian Reservations
FUSRAP	Formerly Utilized Sites Remedial Action Program
UMTRA	Uranium Mill Tailings Sites
LEAD SMELTERS	Lead Smelter Sites
US AIRS	Aerometric Information Retrieval System Facility Subsystem
US MINES	Mines Master Index File
ABANDONED MINES	Abandoned Mines
FINDS	Facility Index System/Facility Registry System
ECHO	Enforcement & Compliance History Information
UXO	Unexploded Ordnance Sites
DOCKET HWC	Hazardous Waste Compliance Docket Listing
FUELS PROGRAM	EPA Fuels Program Registered Listing

EDR HIGH RISK HISTORICAL RECORDS

EDR Exclusive Records

EDR MGP	EDR Proprietary Manufactured Gas Plants
EDR Hist Auto	EDR Exclusive Historical Auto Stations
EDR Hist Cleaner	EDR Exclusive Historical Cleaners

EDR RECOVERED GOVERNMENT ARCHIVES

Exclusive Recovered Govt. Archives

RGA LUST	Recovered Government Archive Leaking Underground Storage Tank

SURROUNDING SITES: SEARCH RESULTS

Surrounding sites were identified in the following databases.

EXECUTIVE SUMMARY

Elevations have been determined from the USGS Digital Elevation Model and should be evaluated on a relative (not an absolute) basis. Relative elevation information between sites of close proximity should be field verified. Sites with an elevation equal to or higher than the target property have been differentiated below from sites with an elevation lower than the target property.
Page numbers and map identification numbers refer to the EDR Radius Map report where detailed data on individual sites can be reviewed.

Sites listed in ***bold italics*** are in multiple databases.

Unmappable (orphan) sites are not considered in the foregoing analysis.

STANDARD ENVIRONMENTAL RECORDS

State and tribal leaking storage tank lists

LUST: Leaking Underground Storage Tanks.

A review of the LUST list, as provided by EDR, and dated 07/27/2018 has revealed that there is 1 LUST site within approximately 0.5 miles of the target property.

Equal/Higher Elevation	Address	Direction / Distance	Map ID	Page
COE Facility Id: 93-0033	AVE. FERNANDEZ JUNCO	NNE 1/4 - 1/2 (0.377 mi.)	A2	8

ADDITIONAL ENVIRONMENTAL RECORDS

Other Ascertainable Records

FUDS: The Listing includes locations of Formerly Used Defense Sites Properties where the US Army Corps Of Engineers is actively working or will take necessary cleanup actions.

A review of the FUDS list, as provided by EDR, and dated 03/07/2019 has revealed that there are 2 FUDS sites within approximately 1 mile of the target property.

Equal/Higher Elevation	Address	Direction / Distance	Map ID	Page
NAVAL STATION SAN JU		N 0 - 1/8 (0.009 mi.)	1	7
ANTILLIES ENGINEERIN		N 1/4 - 1/2 (0.387 mi.)	A3	8

EXECUTIVE SUMMARY

Due to poor or inadequate address information, the following sites were not mapped. Count: 44 records.

Site Name	Database(s)
UNITED STATES COAST GUARD SECTOR S	CORRACTS, RCRA-TSDF, RCRA-SQG, MANIFEST
"NEW" ARMY AVIATION SUPPORT	SEMS-ARCHIVE, DOCKET HWC
LA RIVIERA S/S 215	LUST
SHELL 804967	LUST
	LUST
RAMON RODRIGUEZ #311	LUST
COMPLEJO MEDICO SOCIAL ANTILLANA	LUST
TEXACO S/S #223	LUST
ANTIGUO EDIFICIO TEXACO	LUST
ESSO 2P-341	LUST
APOLO S/S #366	LUST
ENG. JOSE BETANCOURT	LUST
TORAL S/S	LUST
GULF 436	LUST
AMERICAN INDUSTRIAL CO	LUST
SHELL #3786	LUST
GULF #458	LUST
GULF #010	LUST
VELVIS DEVELOPMENT CORP.	LUST
ESC. VILLA CAPRI	LUST
ESC. CARMEN SANABRIA	LUST
CENTERS DISEASE CONTROL	LUST
VENUS GARDENS S/S 388	LUST
ESSO 3P-219	LUST
SHELL 0302	LUST
SHEL # 0337	LUST
ESSO S/S 79205	LUST
PEDRO RODRIGUEZ	LUST
SHELL S/S #0310	LUST
GULF 399	LUST
HOSP. PEDIATRICO CENTRO MEDICO	LUST
LCO. ANGEL M. RIVERA MUNICH	LUST
GULF 176	LUST
NUEVA PUERTA	LUST
LOM SERVICE STATION	LUST
ANTIGUA BASE NAVAL	LUST
SHELL #4770	LUST
ESSO 019	LUST
ESSO CO-186	LUST
SHELL #4738	LUST
ESSO GARAVITO SERVICE STATION	LUST
SCORPIO RECYCLING CO. ISLA GRANDE	FINDS
UPLAND DEVELOPMENT - ISLA GRANDE T	FINDS, ECHO
ISLA GRANDE TERMINAL IMPROVEMENTS	FINDS, ECHO

OVERVIEW MAP - 5714997.2S

Target Property

Sites at elevations higher than or equal to the target property

Sites at elevations lower than the target property

Manufactured Gas Plants

National Priority List Sites

Dept. Defense Sites

Indian Reservations BIA

County Boundary

100-year flood zone

500-year flood zone

National Wetland Inventory

This report includes Interactive Map Layers to display and/or hide map information. The legend includes only those icons for the default map view.

SITE NAME: AASF Isla Grande	CLIENT: AECOM
ADDRESS: 600-600 Calle Lindbergh San Juan PR 00907	CONTACT: Hans Sund
	INQUIRY #: 5714997.2s
LAT/LONG: 18.455264 / 66.096015	DATE: July 12, 2019 2:39 pm

DETAIL MAP - 5714997.2S

Target Property

Sites at elevations higher than or equal to the target property

Sites at elevations lower than the target property

Manufactured Gas Plants

Sensitive Receptors

National Priority List Sites

Dept. Defense Sites

0 | 1/16 | 1/8 | 1/4 Miles

Indian Reservations BIA

100-year flood zone

500-year flood zone

National Wetland Inventory

This report includes Interactive Map Layers to display and/or hide map information. The legend includes only those icons for the default map view.

SITE NAME: AASF Isla Grande ADDRESS: 600-600 Calle Lindbergh San Juan PR 00907 LAT/LONG: 18.455264 / 66.096015	CLIENT: AECOM CONTACT: Hans Sund INQUIRY #: 5714997.2s DATE: July 12, 2019 2:40 pm

MAP FINDINGS SUMMARY

Database	Search Distance (Miles)	Target Property	< 1/8	1/8 - 1/4	1/4 - 1/2	1/2 - 1	> 1	Total Plotted
STANDARD ENVIRONMENTAL RECORDS								
Federal NPL site list								
NPL	1.000		0	0	0	0	NR	0
Proposed NPL	1.000		0	0	0	0	NR	0
NPL LIENS	1.000		0	0	0	0	NR	0
Federal Delisted NPL site list								
Delisted NPL	1.000		0	0	0	0	NR	0
Federal CERCLIS list								
FEDERAL FACILITY	0.500		0	0	0	NR	NR	0
SEMS	0.500		0	0	0	NR	NR	0
Federal CERCLIS NFRAP site list								
SEMS-ARCHIVE	0.500		0	0	0	NR	NR	0
Federal RCRA CORRACTS facilities list								
CORRACTS	1.000		0	0	0	0	NR	0
Federal RCRA non-CORRACTS TSD facilities list								
RCRA-TSDF	0.500		0	0	0	NR	NR	0
Federal RCRA generators list								
RCRA-LQG	0.250		0	0	NR	NR	NR	0
RCRA-SQG	0.250		0	0	NR	NR	NR	0
RCRA-CESQG	0.250		0	0	NR	NR	NR	0
Federal institutional controls / engineering controls registries								
LUCIS	0.500		0	0	0	NR	NR	0
US ENG CONTROLS	0.500		0	0	0	NR	NR	0
US INST CONTROL	0.500		0	0	0	NR	NR	0
Federal ERNS list								
ERNS	TP		NR	NR	NR	NR	NR	0
State- and tribal - equivalent CERCLIS								
SHWS	N/A		N/A	N/A	N/A	N/A	N/A	N/A
State and tribal leaking storage tank lists								
LUST	0.500		0	0	1	NR	NR	1
INDIAN LUST	0.500		0	0	0	NR	NR	0
State and tribal registered storage tank lists								
FEMA UST	0.250		0	0	NR	NR	NR	0
UST	0.250		0	0	NR	NR	NR	0
INDIAN UST	0.250		0	0	NR	NR	NR	0
State and tribal voluntary cleanup sites								
INDIAN VCP	0.500		0	0	0	NR	NR	0

MAP FINDINGS SUMMARY

Database	Search Distance (Miles)	Target Property	< 1/8	1/8 - 1/4	1/4 - 1/2	1/2 - 1	> 1	Total Plotted
ADDITIONAL ENVIRONMENTAL RECORDS								
Local Brownfield lists								
US BROWNFIELDS	0.500		0	0	0	NR	NR	0
Local Lists of Landfill / Solid Waste Disposal Sites								
INDIAN ODI	0.500		0	0	0	NR	NR	0
DEBRIS REGION 9	0.500		0	0	0	NR	NR	0
ODI	0.500		0	0	0	NR	NR	0
IHS OPEN DUMPS	0.500		0	0	0	NR	NR	0
Local Lists of Hazardous waste / Contaminated Sites								
US HIST CDL	TP		NR	NR	NR	NR	NR	0
US CDL	TP		NR	NR	NR	NR	NR	0
Local Land Records								
LIENS 2	TP		NR	NR	NR	NR	NR	0
Records of Emergency Release Reports								
HMIRS	TP		NR	NR	NR	NR	NR	0
Other Ascertainable Records								
RCRA NonGen / NLR	0.250		0	0	NR	NR	NR	0
FUDS	1.000		1	0	1	0	NR	2
DOD	1.000		0	0	0	0	NR	0
SCRD DRYCLEANERS	0.500		0	0	0	NR	NR	0
US FIN ASSUR	TP		NR	NR	NR	NR	NR	0
EPA WATCH LIST	TP		NR	NR	NR	NR	NR	0
2020 COR ACTION	0.250		0	0	NR	NR	NR	0
TSCA	TP		NR	NR	NR	NR	NR	0
TRIS	TP		NR	NR	NR	NR	NR	0
SSTS	TP		NR	NR	NR	NR	NR	0
ROD	1.000		0	0	0	0	NR	0
RMP	TP		NR	NR	NR	NR	NR	0
RAATS	TP		NR	NR	NR	NR	NR	0
PRP	TP		NR	NR	NR	NR	NR	0
PADS	TP		NR	NR	NR	NR	NR	0
ICIS	TP		NR	NR	NR	NR	NR	0
FTTS	TP		NR	NR	NR	NR	NR	0
MLTS	TP		NR	NR	NR	NR	NR	0
COAL ASH DOE	TP		NR	NR	NR	NR	NR	0
COAL ASH EPA	0.500		0	0	0	NR	NR	0
PCB TRANSFORMER	TP		NR	NR	NR	NR	NR	0
RADINFO	TP		NR	NR	NR	NR	NR	0
HIST FTTS	TP		NR	NR	NR	NR	NR	0
DOT OPS	TP		NR	NR	NR	NR	NR	0
CONSENT	1.000		0	0	0	0	NR	0

MAP FINDINGS SUMMARY

Database	Search Distance (Miles)	Target Property	< 1/8	1/8 - 1/4	1/4 - 1/2	1/2 - 1	> 1	Total Plotted
INDIAN RESERV	1.000		0	0	0	0	NR	0
FUSRAP	1.000		0	0	0	0	NR	0
UMTRA	0.500		0	0	0	NR	NR	0
LEAD SMELTERS	TP		NR	NR	NR	NR	NR	0
US AIRS	TP		NR	NR	NR	NR	NR	0
US MINES	0.250		0	0	NR	NR	NR	0
ABANDONED MINES	0.250		0	0	NR	NR	NR	0
FINDS	TP		NR	NR	NR	NR	NR	0
ECHO	TP		NR	NR	NR	NR	NR	0
UXO	1.000		0	0	0	0	NR	0
DOCKET HWC	TP		NR	NR	NR	NR	NR	0
FUELS PROGRAM	0.250		0	0	NR	NR	NR	0
EDR HIGH RISK HISTORICAL RECORDS								
EDR Exclusive Records								
EDR MGP	1.000		0	0	0	0	NR	0
EDR Hist Auto	0.125		0	NR	NR	NR	NR	0
EDR Hist Cleaner	0.125		0	NR	NR	NR	NR	0
EDR RECOVERED GOVERNMENT ARCHIVES								
Exclusive Recovered Govt. Archives								
RGA LUST	TP		NR	NR	NR	NR	NR	0
- Totals --		0	1	0	2	0	0	3

NOTES:

TP = Target Property

NR = Not Requested at this Search Distance

Sites may be listed in more than one database

N/A = This State does not maintain a SHWS list. See the Federal CERCLIS list.

1 North < 1/8 0.009 mi. 50 ft.	**NAVAL STATION SAN JUAN** **SAN JUAN, PR**	**FUDS**	**1007212743 N/A**

Relative: Higher

Actual: 10 ft.

FUDS:

EPA Region:	2
Installation ID:	PR29799F417600
Congressional District Number:	98
Facility Name:	NAVAL STATION SAN JUAN
FUDS Number:	I02PR0957
City:	SAN JUAN
State:	PR
County:	SAN JUAN MUNICIPIO
Telephone:	904-232-2235
USACE Division:	South Atlantic Division (SAD)
USACE District:	Jacksonville District (SAJ)
Status:	Properties with all projects at site closeout
Current Owner:	Local Government; Other Federal Government; State Government
X Coord:	-7357754.4731497504
Y Coord:	2091103.0212044499
Latitude:	18.456944
Longitude:	-66.095832999999999

FUDS Detail as of Jan 2015:

Fiscal Year:	2013
Federal Facility ID:	PR9799F4176
RAB:	Not reported
NPL Status:	Not Listed
Description:	The 501.8 acre site is located on and around Isle Grande, San Juan, PR. 456.07 acres of the site are eligible under the DERP-FUDS program.
History:	Between 1898 and 1968, the U.S. acquired the property for use as a Naval Air Base and for other naval activities. The site was developed and named the Naval Air Station, San Juan. The Navy constructed a complete Naval Air Station at the site consisting of 197 buildings including family housing, dispensary, school facilities, barracks, hangars, runways, wharfs, storage and supply structures, administrative buildings, and various utility facilities. The site was utilized until March 1971 when most of its functions were relocated elsewhere. In 1975, the Navy declared 456.07 acres at the site excess and turned the property over to the General Services Administration (GSA) for disposal. In 1991, as a result of a Quiet Title action by Commonwealth of Puerto Rico against the U.S., the Commonwealth of Puerto Rico received title to 457.0263 acres and the U.S. received title to 42.9749 acres. The 42.9749 acres are still utilized by the Navy. The U.S. Coast Guard has use of a 41-acre housing area until it can relocate.
CTC:	12873.9
Current Program:	Not reported
Future Program:	Not reported
Institutional ID:	53649

A2
NNE
1/4-1/2
0.377 mi.
1990 ft.

COE
AVE. FERNANDEZ JUNCOS #400
SAN JUAN, PR

Site 1 of 2 in cluster A

LUST **S103554130** **N/A**

Relative: **Higher**
Actual: **10 ft.**

PR LUST:

Facility ID:	93-0033
Status:	INACTIVE
Released:	Yes
Released Date:	08/23/2003
How Known:	Unknown
Date Known:	21-Nov-95
Owner Name:	U.S. Army C.O.E.

A3
North
1/4-1/2
0.387 mi.
2042 ft.

ANTILLIES ENGINEERING COMPOUND

NO CITY, PR

Site 2 of 2 in cluster A

FUDS **1024902219** **N/A**

Relative: **Higher**
Actual: **10 ft.**

FUDS:

EPA Region:	2
Installation ID:	PR29799F418500
Congressional District Number:	98
Facility Name:	ANTILLIES ENGINEERING COMPOUND
FUDS Number:	I02PR0985
City:	NO CITY
State:	PR
County:	SAN JUAN MUNICIPIO
Telephone:	904-232-2235
USACE Division:	South Atlantic Division (SAD)
USACE District:	Jacksonville District (SAJ)
Status:	Properties without projects
Current Owner:	State Government
X Coord:	-7357630.8216258697
Y Coord:	2091755.06208335
Latitude:	18.462499999999999
Longitude:	-66.094722219999994

Count: 44 records. ORPHAN SUMMARY

City	EDR ID	Site Name	Site Address	Zip	Database(s)
SAN JUAN	S103554015	LA RIVIERA S/S 215	AVE DE DIEGO ESQ. CALLE 48/ LA		LUST
SAN JUAN	S103553834	SHELL 804967	AVE 65 INFANTERIA ESQ. CALLE N		LUST
SAN JUAN	S101442999		AVE PONCE DE LEON & CALLE OCAS		LUST
SAN JUAN	S106917737	RAMON RODRIGUEZ #311	AVE DE DIEGO ESQ. CALLE LOIZA		LUST
SAN JUAN	S105073605	COMPLEJO MEDICO SOCIAL ANTILLANA	AVE. 65 INFANTERIA KM 3.4		LUST
SAN JUAN	S104540010	TEXACO S/S #223	AVE. FERNANDEZ JUNCOS/PARADA 6		LUST
SAN JUAN	S105421738	ANTIGUO EDIFICIO TEXACO	AVE. FERNANDEZ JUNCOS ESQ. CAL		LUST
SAN JUAN	S106917714	ESSO 2P-341	AVE. BARBOSA, ESQ. CALLE GUAYA		LUST
SAN JUAN	S106917747	APOLO S/S #366	AVENIDA APOLO, CALLE MERCURIO		LUST
SAN JUAN	S103553996	ENG. JOSE BETANCOURT	CALLE O'NEILL, HATO REY		LUST
SAN JUAN	S104540021	TORAL S/S	CALLE PALMA #1304		LUST
SAN JUAN	S105840975	GULF 436	CALLE TAPIA ESQ. EDUARDO CONDE		LUST
SAN JUAN	S103553746	AMERICAN INDUSTRIAL CO	CALLE CORCHADO SANTURCE 1202		LUST
SAN JUAN	S103554097	SHELL #3786	CALLE SICILIA URB. SAN JOSE		LUST
SAN JUAN	S104904818	GULF #458	CALLE BALDORIOTY & DEGETAU		LUST
SAN JUAN	S101442768	GULF #010	CALLE 52 & 54 RIO PIEDRAS		LUST
SAN JUAN	S103554174	VELVIS DEVELOPMENT CORP.	CALLE 21/MARIO JULIA		LUST
SAN JUAN	S103554164	ESC. VILLA CAPRI	CALLE VERONA ESQ. NIZA, VILLA		LUST
SAN JUAN	S103554166	ESC. CARMEN SANABRIA	CALLE ARKANSAS SAN GERARDO		LUST
SAN JUAN	S103554152	CENTERS DISEASE CONTROL	CALLE 2 CASIA		LUST
SAN JUAN	S103554010	VENUS GARDENS S/S 388	CALLE ACUARIO Y LESBOS / VENUS		LUST
SAN JUAN	S103553958	ESSO 3P-219	CALLE 1 ESQ. TIZOL		LUST
SAN JUAN	S103553894	SHELL 0302	CALLE WILSON INT. CALLE LOIZA		LUST
SAN JUAN	S103553892	SHEL # 0337	CALLE LOIZA ESQ.SANTA CECILIA		LUST
SAN JUAN	S103553933	ESSO S/S 79205	CALLE LOIZA 2207/SANTA TERESIT		LUST
SAN JUAN	S104904835	PEDRO RODRIGUEZ	CALLE QUISQUEYA # 55		LUST
SAN JUAN	S104539999	SHELL S/S #0310	CALLE LABRA/PARADA 18		LUST
SAN JUAN	S103554081	GULF 399	CALLE LOIZA ESQ. LOS BANOS		LUST
SAN JUAN	S105421749	HOSP. PEDIATRICO CENTRO MEDICO	CALLE PERIFERAL CENTRO MEDICO		LUST
SAN JUAN	S105073594	LCO. ANGEL M. RIVERA MUNICH	CALLE PONCE DE LEAN		LUST
SAN JUAN	S105840977	GULF 176	CALLE AMATISTA BUCARE		LUST
SAN JUAN	S106452747	NUEVA PUERTA	CALLE RUIZ BELVIS 237		LUST
SAN JUAN	S106917650	LOM SERVICE STATION	CARR. 1 KM. 13.5 SECTOR EL CIN		LUST
SAN JUAN	1018161525	"NEW" ARMY AVIATION SUPPORT	ISLA GRANDE ROAD OFF HACIA FER		SEMS-ARCHIVE, DOCKET HWC
SAN JUAN	1016278533	SCORPIO RECYCLING CO. ISLA GRANDE	LINDBERGH ST, NEAR INT RTE 1 &	00907	FINDS
SAN JUAN	1023656417	UPLAND DEVELOPMENT - ISLA GRANDE T	LINDBERGH STREET, ISLA GRANDE	00907	FINDS, ECHO
SAN JUAN	1023656398	ISLA GRANDE TERMINAL IMPROVEMENTS	LINDBERGH STREET ISLA GRANDE	00907	FINDS, ECHO
SAN JUAN	1000233097	UNITED STATES COAST GUARD SECTOR S	5 LA PUNTILLA STREET FINAL	00901	CORRACTS, RCRA-TSDF, RCRA-SQ MANIFEST
SAN JUAN	S106917846	ANTIGUA BASE NAVAL	SITE 36 / W-5 SECOND FLOOR		LUST
SAN JUAN	S103553835	SHELL #4770	VIEJO SAN JUAN - CALLE COMERIO		LUST
SANTURCE	S105840979	ESSO 019	CALLE LOIZA ESQ TAFT		LUST
SANTURCE	S101442889	ESSO CO-186	CALLE LOIZA ESQ. CALLE TAPIA		LUST

Count: 44 records.

ORPHAN SUMMARY

City	EDR ID	Site Name	Site Address	Zip	Database(s)
SANTURCE	S101442823	SHELL #4738	CALLE LOIZA ESQ. KINGS COURT		LUST
SANTURCE	S101442887	ESSO GARAVITO SERVICE STATION	CALLE LABRA, & AVE R.H. TOOD,		LUST

GOVERNMENT RECORDS SEARCHED / DATA CURRENCY TRACKING

To maintain currency of the following federal and state databases, EDR contacts the appropriate governmental agency on a monthly or quarterly basis, as required.

Number of Days to Update: Provides confirmation that EDR is reporting records that have been updated within 90 days from the date the government agency made the information available to the public.

STANDARD ENVIRONMENTAL RECORDS

Federal NPL site list

NPL: National Priority List

National Priorities List (Superfund). The NPL is a subset of CERCLIS and identifies over 1,200 sites for priority cleanup under the Superfund Program. NPL sites may encompass relatively large areas. As such, EDR provides polygon coverage for over 1,000 NPL site boundaries produced by EPA's Environmental Photographic Interpretation Center (EPIC) and regional EPA offices.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 26

Source: EPA
Telephone: N/A
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

NPL Site Boundaries

Sources:

EPA's Environmental Photographic Interpretation Center (EPIC)
Telephone: 202-564-7333

EPA Region 1
Telephone 617-918-1143

EPA Region 3
Telephone 215-814-5418

EPA Region 4
Telephone 404-562-8033

EPA Region 5
Telephone 312-886-6686

EPA Region 10
Telephone 206-553-8665

EPA Region 6
Telephone: 214-655-6659

EPA Region 7
Telephone: 913-551-7247

EPA Region 8
Telephone: 303-312-6774

EPA Region 9
Telephone: 415-947-4246

Proposed NPL: Proposed National Priority List Sites

A site that has been proposed for listing on the National Priorities List through the issuance of a proposed rule in the Federal Register. EPA then accepts public comments on the site, responds to the comments, and places on the NPL those sites that continue to meet the requirements for listing.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 26

Source: EPA
Telephone: N/A
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

NPL LIENS: Federal Superfund Liens

Federal Superfund Liens. Under the authority granted the USEPA by CERCLA of 1980, the USEPA has the authority to file liens against real property in order to recover remedial action expenditures or when the property owner received notification of potential liability. USEPA compiles a listing of filed notices of Superfund Liens.

Date of Government Version: 10/15/1991
Date Data Arrived at EDR: 02/02/1994
Date Made Active in Reports: 03/30/1994
Number of Days to Update: 56

Source: EPA
Telephone: 202-564-4267
Last EDR Contact: 08/15/2011
Next Scheduled EDR Contact: 11/28/2011
Data Release Frequency: No Update Planned

Federal Delisted NPL site list

Delisted NPL: National Priority List Deletions

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) establishes the criteria that the EPA uses to delete sites from the NPL. In accordance with 40 CFR 300.425.(e), sites may be deleted from the NPL where no further response is appropriate.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 26

Source: EPA
Telephone: N/A
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

Federal CERCLIS list

FEDERAL FACILITY: Federal Facility Site Information listing

A listing of National Priority List (NPL) and Base Realignment and Closure (BRAC) sites found in the Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) Database where EPA Federal Facilities Restoration and Reuse Office is involved in cleanup activities.

Date of Government Version: 04/03/2019
Date Data Arrived at EDR: 04/05/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 39

Source: Environmental Protection Agency
Telephone: 703-603-8704
Last EDR Contact: 07/03/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Varies

SEMS: Superfund Enterprise Management System

SEMS (Superfund Enterprise Management System) tracks hazardous waste sites, potentially hazardous waste sites, and remedial activities performed in support of EPA's Superfund Program across the United States. The list was formerly know as CERCLIS, renamed to SEMS by the EPA in 2015. The list contains data on potentially hazardous waste sites that have been reported to the USEPA by states, municipalities, private companies and private persons, pursuant to Section 103 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This dataset also contains sites which are either proposed to or on the National Priorities List (NPL) and the sites which are in the screening and assessment phase for possible inclusion on the NPL.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 35

Source: EPA
Telephone: 800-424-9346
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

Federal CERCLIS NFRAP site list

SEMS-ARCHIVE: Superfund Enterprise Management System Archive

SEMS-ARCHIVE (Superfund Enterprise Management System Archive) tracks sites that have no further interest under the Federal Superfund Program based on available information. The list was formerly known as the CERCLIS-NFRAP, renamed to SEMS ARCHIVE by the EPA in 2015. EPA may perform a minimal level of assessment work at a site while it is archived if site conditions change and/or new information becomes available. Archived sites have been removed and archived from the inventory of SEMS sites. Archived status indicates that, to the best of EPA's knowledge, assessment at a site has been completed and that EPA has determined no further steps will be taken to list the site on the National Priorities List (NPL), unless information indicates this decision was not appropriate or other considerations require a recommendation for listing at a later time. The decision does not necessarily mean that there is no hazard associated with a given site; it only means that. based upon available information, the location is not judged to be potential NPL site.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 35

Source: EPA
Telephone: 800-424-9346
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

Federal RCRA CORRACTS facilities list

CORRACTS: Corrective Action Report
CORRACTS identifies hazardous waste handlers with RCRA corrective action activity.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: EPA
Telephone: 800-424-9346
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

Federal RCRA non-CORRACTS TSD facilities list

RCRA-TSDF: RCRA - Treatment, Storage and Disposal
RCRAInfo is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The database includes selective information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA). Transporters are individuals or entities that move hazardous waste from the generator offsite to a facility that can recycle, treat, store, or dispose of the waste. TSDFs treat, store, or dispose of the waste.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: (212) 637-3660
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

Federal RCRA generators list

RCRA-LQG: RCRA - Large Quantity Generators
RCRAInfo is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The database includes selective information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA). Large quantity generators (LQGs) generate over 1,000 kilograms (kg) of hazardous waste, or over 1 kg of acutely hazardous waste per month.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: (212) 637-3660
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

RCRA-SQG: RCRA - Small Quantity Generators

RCRAInfo is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The database includes selective information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA). Small quantity generators (SQGs) generate between 100 kg and 1,000 kg of hazardous waste per month.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: (212) 637-3660
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

RCRA-CESQG: RCRA - Conditionally Exempt Small Quantity Generators

RCRAInfo is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The database includes selective information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA). Conditionally exempt small quantity generators (CESQGs) generate less than 100 kg of hazardous waste, or less than 1 kg of acutely hazardous waste per month.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: (212) 637-3660
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

Federal institutional controls / engineering controls registries

LUCIS: Land Use Control Information System

LUCIS contains records of land use control information pertaining to the former Navy Base Realignment and Closure properties.

Date of Government Version: 02/22/2019
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 41

Source: Department of the Navy
Telephone: 843-820-7326
Last EDR Contact: 05/10/2019
Next Scheduled EDR Contact: 08/26/2019
Data Release Frequency: Varies

US ENG CONTROLS: Engineering Controls Sites List

A listing of sites with engineering controls in place. Engineering controls include various forms of caps, building foundations, liners, and treatment methods to create pathway elimination for regulated substances to enter environmental media or effect human health.

Date of Government Version: 01/31/2019
Date Data Arrived at EDR: 02/04/2019
Date Made Active in Reports: 03/08/2019
Number of Days to Update: 32

Source: Environmental Protection Agency
Telephone: 703-603-0695
Last EDR Contact: 05/29/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Varies

US INST CONTROL: Sites with Institutional Controls

A listing of sites with institutional controls in place. Institutional controls include administrative measures, such as groundwater use restrictions, construction restrictions, property use restrictions, and post remediation care requirements intended to prevent exposure to contaminants remaining on site. Deed restrictions are generally required as part of the institutional controls.

Date of Government Version: 01/31/2019
Date Data Arrived at EDR: 02/04/2019
Date Made Active in Reports: 03/08/2019
Number of Days to Update: 32

Source: Environmental Protection Agency
Telephone: 703-603-0695
Last EDR Contact: 05/29/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Varies

Federal ERNS list

ERNS: Emergency Response Notification System
Emergency Response Notification System. ERNS records and stores information on reported releases of oil and hazardous substances.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/26/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 36

Source: National Response Center, United States Coast Guard
Telephone: 202-267-2180
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

State- and tribal - equivalent CERCLIS

SHWS: This state does not maintain a SHWS list. See the Federal CERCLIS list and Federal NPL list.
State Hazardous Waste Sites. State hazardous waste site records are the states' equivalent to CERCLIS. These sites may or may not already be listed on the federal CERCLIS list. Priority sites planned for cleanup using state funds (state equivalent of Superfund) are identified along with sites where cleanup will be paid for by potentially responsible parties. Available information varies by state.

Date of Government Version: N/A
Date Data Arrived at EDR: N/A
Date Made Active in Reports: N/A
Number of Days to Update: N/A

Source: Environmental Quality Board
Telephone: 787-767-8181
Last EDR Contact: 08/22/2005
Next Scheduled EDR Contact: 11/21/2005
Data Release Frequency: N/A

State and tribal leaking storage tank lists

LUST: Leaking Underground Storage Tanks
Leaking Underground Storage Tank Incident Reports. LUST records contain an inventory of reported leaking underground storage tank incidents. Not all states maintain these records, and the information stored varies by state.

Date of Government Version: 07/27/2018
Date Data Arrived at EDR: 11/08/2018
Date Made Active in Reports: 01/03/2019
Number of Days to Update: 56

Source: Environmental Quality Board
Telephone: 787-767-8056
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R10: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in Alaska, Idaho, Oregon and Washington.

Date of Government Version: 10/17/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 10
Telephone: 206-553-2857
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R9: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in Arizona, California, New Mexico and Nevada

Date of Government Version: 10/10/2018
Date Data Arrived at EDR: 03/08/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 54

Source: Environmental Protection Agency
Telephone: 415-972-3372
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R8: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming.

Date of Government Version: 10/16/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 8
Telephone: 303-312-6271
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R7: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in Iowa, Kansas, and Nebraska

Date of Government Version: 02/19/2019
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 7
Telephone: 913-551-7003
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R6: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in New Mexico and Oklahoma.

Date of Government Version: 11/01/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 6
Telephone: 214-665-6597
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R4: Leaking Underground Storage Tanks on Indian Land
LUSTs on Indian land in Florida, Mississippi and North Carolina.

Date of Government Version: 09/24/2018
Date Data Arrived at EDR: 03/12/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 50

Source: EPA Region 4
Telephone: 404-562-8677
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R1: Leaking Underground Storage Tanks on Indian Land
A listing of leaking underground storage tank locations on Indian Land.

Date of Government Version: 10/13/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 1
Telephone: 617-918-1313
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN LUST R5: Leaking Underground Storage Tanks on Indian Land
Leaking underground storage tanks located on Indian Land in Michigan, Minnesota and Wisconsin.

Date of Government Version: 10/12/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA, Region 5
Telephone: 312-886-7439
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

State and tribal registered storage tank lists

FEMA UST: Underground Storage Tank Listing
A listing of all FEMA owned underground storage tanks.

Date of Government Version: 05/15/2017
Date Data Arrived at EDR: 05/30/2017
Date Made Active in Reports: 10/13/2017
Number of Days to Update: 136

Source: FEMA
Telephone: 202-646-5797
Last EDR Contact: 07/10/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Varies

UST: Underground Storage Tank Facilities
Underground storage tank site locations.

Date of Government Version: 01/01/2008
Date Data Arrived at EDR: 03/26/2008
Date Made Active in Reports: 04/23/2008
Number of Days to Update: 28

Source: Environmental Quality Board
Telephone: 787-767-8056
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Semi-Annually

INDIAN UST R5: Underground Storage Tanks on Indian Land
The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 5 (Michigan, Minnesota and Wisconsin and Tribal Nations).

Date of Government Version: 10/12/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 5
Telephone: 312-886-6136
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R4: Underground Storage Tanks on Indian Land
The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 4 (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee and Tribal Nations)

Date of Government Version: 09/24/2018
Date Data Arrived at EDR: 03/12/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 50

Source: EPA Region 4
Telephone: 404-562-9424
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R1: Underground Storage Tanks on Indian Land
The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont and ten Tribal Nations).

Date of Government Version: 10/03/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA, Region 1
Telephone: 617-918-1313
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R6: Underground Storage Tanks on Indian Land
The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 6 (Louisiana, Arkansas, Oklahoma, New Mexico, Texas and 65 Tribes).

Date of Government Version: 11/01/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 6
Telephone: 214-665-7591
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R10: Underground Storage Tanks on Indian Land
The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 10 (Alaska, Idaho, Oregon, Washington, and Tribal Nations).

Date of Government Version: 10/17/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 10
Telephone: 206-553-2857
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R7: Underground Storage Tanks on Indian Land

The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 7 (Iowa, Kansas, Missouri, Nebraska, and 9 Tribal Nations).

Date of Government Version: 11/07/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 7
Telephone: 913-551-7003
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R8: Underground Storage Tanks on Indian Land

The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 8 (Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming and 27 Tribal Nations).

Date of Government Version: 10/16/2018
Date Data Arrived at EDR: 03/07/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 55

Source: EPA Region 8
Telephone: 303-312-6137
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

INDIAN UST R9: Underground Storage Tanks on Indian Land

The Indian Underground Storage Tank (UST) database provides information about underground storage tanks on Indian land in EPA Region 9 (Arizona, California, Hawaii, Nevada, the Pacific Islands, and Tribal Nations).

Date of Government Version: 10/10/2018
Date Data Arrived at EDR: 03/08/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 54

Source: EPA Region 9
Telephone: 415-972-3368
Last EDR Contact: 04/26/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

State and tribal voluntary cleanup sites

INDIAN VCP R1: Voluntary Cleanup Priority Listing

A listing of voluntary cleanup priority sites located on Indian Land located in Region 1.

Date of Government Version: 07/27/2015
Date Data Arrived at EDR: 09/29/2015
Date Made Active in Reports: 02/18/2016
Number of Days to Update: 142

Source: EPA, Region 1
Telephone: 617-918-1102
Last EDR Contact: 06/20/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Varies

INDIAN VCP R7: Voluntary Cleanup Priority Lisitng

A listing of voluntary cleanup priority sites located on Indian Land located in Region 7.

Date of Government Version: 03/20/2008
Date Data Arrived at EDR: 04/22/2008
Date Made Active in Reports: 05/19/2008
Number of Days to Update: 27

Source: EPA, Region 7
Telephone: 913-551-7365
Last EDR Contact: 04/20/2009
Next Scheduled EDR Contact: 07/20/2009
Data Release Frequency: Varies

ADDITIONAL ENVIRONMENTAL RECORDS

Local Brownfield lists

US BROWNFIELDS: A Listing of Brownfields Sites

Brownfields are real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant. Cleaning up and reinvesting in these properties takes development pressures off of undeveloped, open land, and both improves and protects the environment. Assessment, Cleanup and Redevelopment Exchange System (ACRES) stores information reported by EPA Brownfields grant recipients on brownfields properties assessed or cleaned up with grant funding as well as information on Targeted Brownfields Assessments performed by EPA Regions. A listing of ACRES Brownfield sites is obtained from Cleanups in My Community. Cleanups in My Community provides information on Brownfields properties for which information is reported back to EPA, as well as areas served by Brownfields grant programs.

Date of Government Version: 12/17/2018	Source: Environmental Protection Agency
Date Data Arrived at EDR: 12/18/2018	Telephone: 202-566-2777
Date Made Active in Reports: 01/11/2019	Last EDR Contact: 06/04/2019
Number of Days to Update: 24	Next Scheduled EDR Contact: 09/30/2019
	Data Release Frequency: Semi-Annually

Local Lists of Landfill / Solid Waste Disposal Sites

INDIAN ODI: Report on the Status of Open Dumps on Indian Lands
Location of open dumps on Indian land.

Date of Government Version: 12/31/1998	Source: Environmental Protection Agency
Date Data Arrived at EDR: 12/03/2007	Telephone: 703-308-8245
Date Made Active in Reports: 01/24/2008	Last EDR Contact: 04/26/2019
Number of Days to Update: 52	Next Scheduled EDR Contact: 08/12/2019
	Data Release Frequency: Varies

DEBRIS REGION 9: Torres Martinez Reservation Illegal Dump Site Locations
A listing of illegal dump sites location on the Torres Martinez Indian Reservation located in eastern Riverside County and northern Imperial County, California.

Date of Government Version: 01/12/2009	Source: EPA, Region 9
Date Data Arrived at EDR: 05/07/2009	Telephone: 415-947-4219
Date Made Active in Reports: 09/21/2009	Last EDR Contact: 04/22/2019
Number of Days to Update: 137	Next Scheduled EDR Contact: 08/05/2019
	Data Release Frequency: No Update Planned

ODI: Open Dump Inventory
An open dump is defined as a disposal facility that does not comply with one or more of the Part 257 or Part 258 Subtitle D Criteria.

Date of Government Version: 06/30/1985	Source: Environmental Protection Agency
Date Data Arrived at EDR: 08/09/2004	Telephone: 800-424-9346
Date Made Active in Reports: 09/17/2004	Last EDR Contact: 06/09/2004
Number of Days to Update: 39	Next Scheduled EDR Contact: N/A
	Data Release Frequency: No Update Planned

IHS OPEN DUMPS: Open Dumps on Indian Land
A listing of all open dumps located on Indian Land in the United States.

Date of Government Version: 04/01/2014	Source: Department of Health & Human Serivces, Indian Health Service
Date Data Arrived at EDR: 08/06/2014	Telephone: 301-443-1452
Date Made Active in Reports: 01/29/2015	Last EDR Contact: 04/23/2019
Number of Days to Update: 176	Next Scheduled EDR Contact: 08/12/2019
	Data Release Frequency: Varies

Local Lists of Hazardous waste / Contaminated Sites

US HIST CDL: National Clandestine Laboratory Register
A listing of clandestine drug lab locations that have been removed from the DEAs National Clandestine Laboratory Register.

Date of Government Version: 02/24/2019	Source: Drug Enforcement Administration
Date Data Arrived at EDR: 02/26/2019	Telephone: 202-307-1000
Date Made Active in Reports: 04/17/2019	Last EDR Contact: 05/24/2019
Number of Days to Update: 50	Next Scheduled EDR Contact: 09/09/2019
	Data Release Frequency: No Update Planned

US CDL: Clandestine Drug Labs
A listing of clandestine drug lab locations. The U.S. Department of Justice ("the Department") provides this web site as a public service. It contains addresses of some locations where law enforcement agencies reported they found chemicals or other items that indicated the presence of either clandestine drug laboratories or dumpsites. In most cases, the source of the entries is not the Department, and the Department has not verified the entry and does not guarantee its accuracy. Members of the public must verify the accuracy of all entries by, for example, contacting local law enforcement and local health departments.

Date of Government Version: 02/24/2019
Date Data Arrived at EDR: 02/26/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 50

Source: Drug Enforcement Administration
Telephone: 202-307-1000
Last EDR Contact: 05/24/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Quarterly

Local Land Records

LIENS 2: CERCLA Lien Information

A Federal CERCLA ('Superfund') lien can exist by operation of law at any site or property at which EPA has spent Superfund monies. These monies are spent to investigate and address releases and threatened releases of contamination. CERCLIS provides information as to the identity of these sites and properties.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 35

Source: Environmental Protection Agency
Telephone: 202-564-6023
Last EDR Contact: 07/02/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Semi-Annually

Records of Emergency Release Reports

HMIRS: Hazardous Materials Information Reporting System

Hazardous Materials Incident Report System. HMIRS contains hazardous material spill incidents reported to DOT.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/26/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 49

Source: U.S. Department of Transportation
Telephone: 202-366-4555
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

Other Ascertainable Records

RCRA NonGen / NLR: RCRA - Non Generators / No Longer Regulated

RCRAInfo is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The database includes selective information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA). Non-Generators do not presently generate hazardous waste.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/27/2019
Date Made Active in Reports: 04/17/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: (212) 637-3660
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

FUDS: Formerly Used Defense Sites

The listing includes locations of Formerly Used Defense Sites properties where the US Army Corps of Engineers is actively working or will take necessary cleanup actions.

Date of Government Version: 03/07/2019
Date Data Arrived at EDR: 04/03/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 50

Source: U.S. Army Corps of Engineers
Telephone: 202-528-4285
Last EDR Contact: 05/21/2019
Next Scheduled EDR Contact: 09/02/2019
Data Release Frequency: Varies

DOD: Department of Defense Sites

This data set consists of federally owned or administered lands, administered by the Department of Defense, that have any area equal to or greater than 640 acres of the United States, Puerto Rico, and the U.S. Virgin Islands.

Date of Government Version: 12/31/2005
Date Data Arrived at EDR: 11/10/2006
Date Made Active in Reports: 01/11/2007
Number of Days to Update: 62

Source: USGS
Telephone: 888-275-8747
Last EDR Contact: 07/09/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Semi-Annually

FEDLAND: Federal and Indian Lands

Federally and Indian administrated lands of the United States. Lands included are administrated by: Army Corps of Engineers, Bureau of Reclamation, National Wild and Scenic River, National Wildlife Refuge, Public Domain Land, Wilderness, Wilderness Study Area, Wildlife Management Area, Bureau of Indian Affairs, Bureau of Land Management, Department of Justice, Forest Service, Fish and Wildlife Service, National Park Service.

Date of Government Version: 12/31/2005
Date Data Arrived at EDR: 02/06/2006
Date Made Active in Reports: 01/11/2007
Number of Days to Update: 339

Source: U.S. Geological Survey
Telephone: 888-275-8747
Last EDR Contact: 07/10/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: N/A

SCRD DRYCLEANERS: State Coalition for Remediation of Drycleaners Listing

The State Coalition for Remediation of Drycleaners was established in 1998, with support from the U.S. EPA Office of Superfund Remediation and Technology Innovation. It is comprised of representatives of states with established drycleaner remediation programs. Currently the member states are Alabama, Connecticut, Florida, Illinois, Kansas, Minnesota, Missouri, North Carolina, Oregon, South Carolina, Tennessee, Texas, and Wisconsin.

Date of Government Version: 01/01/2017
Date Data Arrived at EDR: 02/03/2017
Date Made Active in Reports: 04/07/2017
Number of Days to Update: 63

Source: Environmental Protection Agency
Telephone: 615-532-8599
Last EDR Contact: 05/13/2019
Next Scheduled EDR Contact: 08/26/2019
Data Release Frequency: Varies

US FIN ASSUR: Financial Assurance Information

All owners and operators of facilities that treat, store, or dispose of hazardous waste are required to provide proof that they will have sufficient funds to pay for the clean up, closure, and post-closure care of their facilities.

Date of Government Version: 03/25/2019
Date Data Arrived at EDR: 03/26/2019
Date Made Active in Reports: 05/07/2019
Number of Days to Update: 42

Source: Environmental Protection Agency
Telephone: 202-566-1917
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Quarterly

EPA WATCH LIST: EPA WATCH LIST

EPA maintains a "Watch List" to facilitate dialogue between EPA, state and local environmental agencies on enforcement matters relating to facilities with alleged violations identified as either significant or high priority. Being on the Watch List does not mean that the facility has actually violated the law only that an investigation by EPA or a state or local environmental agency has led those organizations to allege that an unproven violation has in fact occurred. Being on the Watch List does not represent a higher level of concern regarding the alleged violations that were detected, but instead indicates cases requiring additional dialogue between EPA, state and local agencies - primarily because of the length of time the alleged violation has gone unaddressed or unresolved.

Date of Government Version: 08/30/2013
Date Data Arrived at EDR: 03/21/2014
Date Made Active in Reports: 06/17/2014
Number of Days to Update: 88

Source: Environmental Protection Agency
Telephone: 617-520-3000
Last EDR Contact: 05/06/2019
Next Scheduled EDR Contact: 08/19/2019
Data Release Frequency: Quarterly

2020 COR ACTION: 2020 Corrective Action Program List

The EPA has set ambitious goals for the RCRA Corrective Action program by creating the 2020 Corrective Action Universe. This RCRA cleanup baseline includes facilities expected to need corrective action. The 2020 universe contains a wide variety of sites. Some properties are heavily contaminated while others were contaminated but have since been cleaned up. Still others have not been fully investigated yet, and may require little or no remediation. Inclusion in the 2020 Universe does not necessarily imply failure on the part of a facility to meet its RCRA obligations.

Date of Government Version: 09/30/2017	Source: Environmental Protection Agency
Date Data Arrived at EDR: 05/08/2018	Telephone: 703-308-4044
Date Made Active in Reports: 07/20/2018	Last EDR Contact: 05/10/2019
Number of Days to Update: 73	Next Scheduled EDR Contact: 08/19/2019
	Data Release Frequency: Varies

TSCA: Toxic Substances Control Act

Toxic Substances Control Act. TSCA identifies manufacturers and importers of chemical substances included on the TSCA Chemical Substance Inventory list. It includes data on the production volume of these substances by plant site.

Date of Government Version: 12/31/2016	Source: EPA
Date Data Arrived at EDR: 06/21/2017	Telephone: 202-260-5521
Date Made Active in Reports: 01/05/2018	Last EDR Contact: 06/18/2019
Number of Days to Update: 198	Next Scheduled EDR Contact: 09/30/2019
	Data Release Frequency: Every 4 Years

TRIS: Toxic Chemical Release Inventory System

Toxic Release Inventory System. TRIS identifies facilities which release toxic chemicals to the air, water and land in reportable quantities under SARA Title III Section 313.

Date of Government Version: 12/31/2016	Source: EPA
Date Data Arrived at EDR: 01/10/2018	Telephone: 202-566-0250
Date Made Active in Reports: 01/12/2018	Last EDR Contact: 05/24/2019
Number of Days to Update: 2	Next Scheduled EDR Contact: 09/02/2019
	Data Release Frequency: Annually

SSTS: Section 7 Tracking Systems

Section 7 of the Federal Insecticide, Fungicide and Rodenticide Act, as amended (92 Stat. 829) requires all registered pesticide-producing establishments to submit a report to the Environmental Protection Agency by March 1st each year. Each establishment must report the types and amounts of pesticides, active ingredients and devices being produced, and those having been produced and sold or distributed in the past year.

Date of Government Version: 12/31/2009	Source: EPA
Date Data Arrived at EDR: 12/10/2010	Telephone: 202-564-4203
Date Made Active in Reports: 02/25/2011	Last EDR Contact: 04/24/2019
Number of Days to Update: 77	Next Scheduled EDR Contact: 08/05/2019
	Data Release Frequency: Annually

ROD: Records Of Decision

Record of Decision. ROD documents mandate a permanent remedy at an NPL (Superfund) site containing technical and health information to aid in the cleanup.

Date of Government Version: 04/11/2019	Source: EPA
Date Data Arrived at EDR: 04/18/2019	Telephone: 703-416-0223
Date Made Active in Reports: 05/23/2019	Last EDR Contact: 07/01/2019
Number of Days to Update: 35	Next Scheduled EDR Contact: 09/16/2019
	Data Release Frequency: Annually

RMP: Risk Management Plans

When Congress passed the Clean Air Act Amendments of 1990, it required EPA to publish regulations and guidance for chemical accident prevention at facilities using extremely hazardous substances. The Risk Management Program Rule (RMP Rule) was written to implement Section 112(r) of these amendments. The rule, which built upon existing industry codes and standards, requires companies of all sizes that use certain flammable and toxic substances to develop a Risk Management Program, which includes a(n): Hazard assessment that details the potential effects of an accidental release, an accident history of the last five years, and an evaluation of worst-case and alternative accidental releases; Prevention program that includes safety precautions and maintenance, monitoring, and employee training measures; and Emergency response program that spells out emergency health care, employee training measures and procedures for informing the public and response agencies (e.g the fire department) should an accident occur.

Date of Government Version: 04/25/2019
Date Data Arrived at EDR: 05/02/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 21

Source: Environmental Protection Agency
Telephone: 202-564-8600
Last EDR Contact: 04/22/2019
Next Scheduled EDR Contact: 08/05/2019
Data Release Frequency: Varies

RAATS: RCRA Administrative Action Tracking System

RCRA Administration Action Tracking System. RAATS contains records based on enforcement actions issued under RCRA pertaining to major violators and includes administrative and civil actions brought by the EPA. For administration actions after September 30, 1995, data entry in the RAATS database was discontinued. EPA will retain a copy of the database for historical records. It was necessary to terminate RAATS because a decrease in agency resources made it impossible to continue to update the information contained in the database.

Date of Government Version: 04/17/1995
Date Data Arrived at EDR: 07/03/1995
Date Made Active in Reports: 08/07/1995
Number of Days to Update: 35

Source: EPA
Telephone: 202-564-4104
Last EDR Contact: 06/02/2008
Next Scheduled EDR Contact: 09/01/2008
Data Release Frequency: No Update Planned

PRP: Potentially Responsible Parties

A listing of verified Potentially Responsible Parties

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 35

Source: EPA
Telephone: 202-564-6023
Last EDR Contact: 07/01/2019
Next Scheduled EDR Contact: 08/19/2019
Data Release Frequency: Quarterly

PADS: PCB Activity Database System

PCB Activity Database. PADS Identifies generators, transporters, commercial storers and/or brokers and disposers of PCB's who are required to notify the EPA of such activities.

Date of Government Version: 03/20/2019
Date Data Arrived at EDR: 04/10/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 34

Source: EPA
Telephone: 202-566-0500
Last EDR Contact: 04/10/2019
Next Scheduled EDR Contact: 07/22/2019
Data Release Frequency: Annually

ICIS: Integrated Compliance Information System

The Integrated Compliance Information System (ICIS) supports the information needs of the national enforcement and compliance program as well as the unique needs of the National Pollutant Discharge Elimination System (NPDES) program.

Date of Government Version: 11/18/2016
Date Data Arrived at EDR: 11/23/2016
Date Made Active in Reports: 02/10/2017
Number of Days to Update: 79

Source: Environmental Protection Agency
Telephone: 202-564-2501
Last EDR Contact: 07/03/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Quarterly

GOVERNMENT RECORDS SEARCHED / DATA CURRENCY TRACKING

FTTS: FIFRA/ TSCA Tracking System - FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act)/TSCA (Toxic Substances Control Act)
FTTS tracks administrative cases and pesticide enforcement actions and compliance activities related to FIFRA, TSCA and EPCRA (Emergency Planning and Community Right-to-Know Act). To maintain currency, EDR contacts the Agency on a quarterly basis.

Date of Government Version: 04/09/2009	Source: EPA/Office of Prevention, Pesticides and Toxic Substances
Date Data Arrived at EDR: 04/16/2009	Telephone: 202-566-1667
Date Made Active in Reports: 05/11/2009	Last EDR Contact: 08/18/2017
Number of Days to Update: 25	Next Scheduled EDR Contact: 12/04/2017
	Data Release Frequency: No Update Planned

FTTS INSP: FIFRA/ TSCA Tracking System - FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act)/TSCA (Toxic Substances Control Act)
A listing of FIFRA/TSCA Tracking System (FTTS) inspections and enforcements.

Date of Government Version: 04/09/2009	Source: EPA
Date Data Arrived at EDR: 04/16/2009	Telephone: 202-566-1667
Date Made Active in Reports: 05/11/2009	Last EDR Contact: 08/18/2017
Number of Days to Update: 25	Next Scheduled EDR Contact: 12/04/2017
	Data Release Frequency: No Update Planned

MLTS: Material Licensing Tracking System
MLTS is maintained by the Nuclear Regulatory Commission and contains a list of approximately 8,100 sites which possess or use radioactive materials and which are subject to NRC licensing requirements. To maintain currency, EDR contacts the Agency on a quarterly basis.

Date of Government Version: 08/30/2016	Source: Nuclear Regulatory Commission
Date Data Arrived at EDR: 09/08/2016	Telephone: 301-415-7169
Date Made Active in Reports: 10/21/2016	Last EDR Contact: 04/22/2019
Number of Days to Update: 43	Next Scheduled EDR Contact: 08/05/2019
	Data Release Frequency: Quarterly

COAL ASH DOE: Steam-Electric Plant Operation Data
A listing of power plants that store ash in surface ponds.

Date of Government Version: 12/31/2005	Source: Department of Energy
Date Data Arrived at EDR: 08/07/2009	Telephone: 202-586-8719
Date Made Active in Reports: 10/22/2009	Last EDR Contact: 06/07/2019
Number of Days to Update: 76	Next Scheduled EDR Contact: 09/16/2019
	Data Release Frequency: Varies

COAL ASH EPA: Coal Combustion Residues Surface Impoundments List
A listing of coal combustion residues surface impoundments with high hazard potential ratings.

Date of Government Version: 07/01/2014	Source: Environmental Protection Agency
Date Data Arrived at EDR: 09/10/2014	Telephone: N/A
Date Made Active in Reports: 10/20/2014	Last EDR Contact: 06/07/2019
Number of Days to Update: 40	Next Scheduled EDR Contact: 09/16/2019
	Data Release Frequency: Varies

PCB TRANSFORMER: PCB Transformer Registration Database
The database of PCB transformer registrations that includes all PCB registration submittals.

Date of Government Version: 05/24/2017	Source: Environmental Protection Agency
Date Data Arrived at EDR: 11/30/2017	Telephone: 202-566-0517
Date Made Active in Reports: 12/15/2017	Last EDR Contact: 04/26/2019
Number of Days to Update: 15	Next Scheduled EDR Contact: 08/05/2019
	Data Release Frequency: Varies

RADINFO: Radiation Information Database
The Radiation Information Database (RADINFO) contains information about facilities that are regulated by U.S. Environmental Protection Agency (EPA) regulations for radiation and radioactivity.

Date of Government Version: 04/02/2019
Date Data Arrived at EDR: 04/02/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 42

Source: Environmental Protection Agency
Telephone: 202-343-9775
Last EDR Contact: 07/01/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Quarterly

HIST FTTS: FIFRA/TSCA Tracking System Administrative Case Listing

A complete administrative case listing from the FIFRA/TSCA Tracking System (FTTS) for all ten EPA regions. The information was obtained from the National Compliance Database (NCDB). NCDB supports the implementation of FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) and TSCA (Toxic Substances Control Act). Some EPA regions are now closing out records. Because of that, and the fact that some EPA regions are not providing EPA Headquarters with updated records, it was decided to create a HIST FTTS database. It included records that may not be included in the newer FTTS database updates. This database is no longer updated.

Date of Government Version: 10/19/2006
Date Data Arrived at EDR: 03/01/2007
Date Made Active in Reports: 04/10/2007
Number of Days to Update: 40

Source: Environmental Protection Agency
Telephone: 202-564-2501
Last EDR Contact: 12/17/2007
Next Scheduled EDR Contact: 03/17/2008
Data Release Frequency: No Update Planned

HIST FTTS INSP: FIFRA/TSCA Tracking System Inspection & Enforcement Case Listing

A complete inspection and enforcement case listing from the FIFRA/TSCA Tracking System (FTTS) for all ten EPA regions. The information was obtained from the National Compliance Database (NCDB). NCDB supports the implementation of FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) and TSCA (Toxic Substances Control Act). Some EPA regions are now closing out records. Because of that, and the fact that some EPA regions are not providing EPA Headquarters with updated records, it was decided to create a HIST FTTS database. It included records that may not be included in the newer FTTS database updates. This database is no longer updated.

Date of Government Version: 10/19/2006
Date Data Arrived at EDR: 03/01/2007
Date Made Active in Reports: 04/10/2007
Number of Days to Update: 40

Source: Environmental Protection Agency
Telephone: 202-564-2501
Last EDR Contact: 12/17/2008
Next Scheduled EDR Contact: 03/17/2008
Data Release Frequency: No Update Planned

DOT OPS: Incident and Accident Data

Department of Transporation, Office of Pipeline Safety Incident and Accident data.

Date of Government Version: 12/03/2018
Date Data Arrived at EDR: 01/29/2019
Date Made Active in Reports: 03/21/2019
Number of Days to Update: 51

Source: Department of Transporation, Office of Pipeline Safety
Telephone: 202-366-4595
Last EDR Contact: 04/30/2019
Next Scheduled EDR Contact: 08/12/2019
Data Release Frequency: Quarterly

CONSENT: Superfund (CERCLA) Consent Decrees

Major legal settlements that establish responsibility and standards for cleanup at NPL (Superfund) sites. Released periodically by United States District Courts after settlement by parties to litigation matters.

Date of Government Version: 03/31/2019
Date Data Arrived at EDR: 04/23/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 30

Source: Department of Justice, Consent Decree Library
Telephone: Varies
Last EDR Contact: 07/08/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Varies

BRS: Biennial Reporting System

The Biennial Reporting System is a national system administered by the EPA that collects data on the generation and management of hazardous waste. BRS captures detailed data from two groups: Large Quantity Generators (LQG) and Treatment, Storage, and Disposal Facilities.

Date of Government Version: 12/31/2015
Date Data Arrived at EDR: 02/22/2017
Date Made Active in Reports: 09/28/2017
Number of Days to Update: 218

Source: EPA/NTIS
Telephone: 800-424-9346
Last EDR Contact: 06/26/2019
Next Scheduled EDR Contact: 10/07/2019
Data Release Frequency: Biennially

INDIAN RESERV: Indian Reservations

This map layer portrays Indian administered lands of the United States that have any area equal to or greater than 640 acres.

Date of Government Version: 12/31/2014
Date Data Arrived at EDR: 07/14/2015
Date Made Active in Reports: 01/10/2017
Number of Days to Update: 546

Source: USGS
Telephone: 202-208-3710
Last EDR Contact: 07/10/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Semi-Annually

FUSRAP: Formerly Utilized Sites Remedial Action Program

DOE established the Formerly Utilized Sites Remedial Action Program (FUSRAP) in 1974 to remediate sites where radioactive contamination remained from Manhattan Project and early U.S. Atomic Energy Commission (AEC) operations.

Date of Government Version: 08/08/2017
Date Data Arrived at EDR: 09/11/2018
Date Made Active in Reports: 09/14/2018
Number of Days to Update: 3

Source: Department of Energy
Telephone: 202-586-3559
Last EDR Contact: 05/02/2019
Next Scheduled EDR Contact: 08/19/2019
Data Release Frequency: Varies

UMTRA: Uranium Mill Tailings Sites

Uranium ore was mined by private companies for federal government use in national defense programs. When the mills shut down, large piles of the sand-like material (mill tailings) remain after uranium has been extracted from the ore. Levels of human exposure to radioactive materials from the piles are low; however, in some cases tailings were used as construction materials before the potential health hazards of the tailings were recognized.

Date of Government Version: 06/23/2017
Date Data Arrived at EDR: 10/11/2017
Date Made Active in Reports: 11/03/2017
Number of Days to Update: 23

Source: Department of Energy
Telephone: 505-845-0011
Last EDR Contact: 05/24/2019
Next Scheduled EDR Contact: 09/02/2019
Data Release Frequency: Varies

LEAD SMELTER 1: Lead Smelter Sites

A listing of former lead smelter site locations.

Date of Government Version: 04/11/2019
Date Data Arrived at EDR: 04/18/2019
Date Made Active in Reports: 05/14/2019
Number of Days to Update: 26

Source: Environmental Protection Agency
Telephone: 703-603-8787
Last EDR Contact: 07/01/2019
Next Scheduled EDR Contact: 10/14/2019
Data Release Frequency: Varies

LEAD SMELTER 2: Lead Smelter Sites

A list of several hundred sites in the U.S. where secondary lead smelting was done from 1931and 1964. These sites may pose a threat to public health through ingestion or inhalation of contaminated soil or dust

Date of Government Version: 04/05/2001
Date Data Arrived at EDR: 10/27/2010
Date Made Active in Reports: 12/02/2010
Number of Days to Update: 36

Source: American Journal of Public Health
Telephone: 703-305-6451
Last EDR Contact: 12/02/2009
Next Scheduled EDR Contact: N/A
Data Release Frequency: No Update Planned

US AIRS (AFS): Aerometric Information Retrieval System Facility Subsystem (AFS)

The database is a sub-system of Aerometric Information Retrieval System (AIRS). AFS contains compliance data on air pollution point sources regulated by the U.S. EPA and/or state and local air regulatory agencies. This information comes from source reports by various stationary sources of air pollution, such as electric power plants, steel mills, factories, and universities, and provides information about the air pollutants they produce. Action, air program, air program pollutant, and general level plant data. It is used to track emissions and compliance data from industrial plants.

Date of Government Version: 10/12/2016
Date Data Arrived at EDR: 10/26/2016
Date Made Active in Reports: 02/03/2017
Number of Days to Update: 100

Source: EPA
Telephone: 202-564-2496
Last EDR Contact: 09/26/2017
Next Scheduled EDR Contact: 01/08/2018
Data Release Frequency: Annually

US AIRS MINOR: Air Facility System Data
A listing of minor source facilities.

Date of Government Version: 10/12/2016
Date Data Arrived at EDR: 10/26/2016
Date Made Active in Reports: 02/03/2017
Number of Days to Update: 100

Source: EPA
Telephone: 202-564-2496
Last EDR Contact: 09/26/2017
Next Scheduled EDR Contact: 01/08/2018
Data Release Frequency: Annually

US MINES: Mines Master Index File
Contains all mine identification numbers issued for mines active or opened since 1971. The data also includes violation information.

Date of Government Version: 11/27/2018
Date Data Arrived at EDR: 02/27/2019
Date Made Active in Reports: 04/01/2019
Number of Days to Update: 33

Source: Department of Labor, Mine Safety and Health Administration
Telephone: 303-231-5959
Last EDR Contact: 05/29/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Semi-Annually

US MINES 2: Ferrous and Nonferrous Metal Mines Database Listing
This map layer includes ferrous (ferrous metal mines are facilities that extract ferrous metals, such as iron ore or molybdenum) and nonferrous (Nonferrous metal mines are facilities that extract nonferrous metals, such as gold, silver, copper, zinc, and lead) metal mines in the United States.

Date of Government Version: 12/05/2005
Date Data Arrived at EDR: 02/29/2008
Date Made Active in Reports: 04/18/2008
Number of Days to Update: 49

Source: USGS
Telephone: 703-648-7709
Last EDR Contact: 05/31/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Varies

US MINES 3: Active Mines & Mineral Plants Database Listing
Active Mines and Mineral Processing Plant operations for commodities monitored by the Minerals Information Team of the USGS.

Date of Government Version: 04/14/2011
Date Data Arrived at EDR: 06/08/2011
Date Made Active in Reports: 09/13/2011
Number of Days to Update: 97

Source: USGS
Telephone: 703-648-7709
Last EDR Contact: 05/31/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Varies

ABANDONED MINES: Abandoned Mines
An inventory of land and water impacted by past mining (primarily coal mining) is maintained by OSMRE to provide information needed to implement the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The inventory contains information on the location, type, and extent of AML impacts, as well as, information on the cost associated with the reclamation of those problems. The inventory is based upon field surveys by State, Tribal, and OSMRE program officials. It is dynamic to the extent that it is modified as new problems are identified and existing problems are reclaimed.

Date of Government Version: 03/27/2019
Date Data Arrived at EDR: 03/28/2019
Date Made Active in Reports: 05/01/2019
Number of Days to Update: 34

Source: Department of Interior
Telephone: 202-208-2609
Last EDR Contact: 06/19/2019
Next Scheduled EDR Contact: 09/23/2019
Data Release Frequency: Quarterly

FINDS: Facility Index System/Facility Registry System

Facility Index System. FINDS contains both facility information and 'pointers' to other sources that contain more detail. EDR includes the following FINDS databases in this report: PCS (Permit Compliance System), AIRS (Aerometric Information Retrieval System), DOCKET (Enforcement Docket used to manage and track information on civil judicial enforcement cases for all environmental statutes), FURS (Federal Underground Injection Control), C-DOCKET (Criminal Docket System used to track criminal enforcement actions for all environmental statutes), FFIS (Federal Facilities Information System), STATE (State Environmental Laws and Statutes), and PADS (PCB Activity Data System).

Date of Government Version: 02/15/2019
Date Data Arrived at EDR: 03/05/2019
Date Made Active in Reports: 03/15/2019
Number of Days to Update: 10

Source: EPA
Telephone: (212) 637-3000
Last EDR Contact: 06/05/2019
Next Scheduled EDR Contact: 09/16/2019
Data Release Frequency: Quarterly

DOCKET HWC: Hazardous Waste Compliance Docket Listing

A complete list of the Federal Agency Hazardous Waste Compliance Docket Facilities.

Date of Government Version: 05/31/2018
Date Data Arrived at EDR: 07/26/2018
Date Made Active in Reports: 10/05/2018
Number of Days to Update: 71

Source: Environmental Protection Agency
Telephone: 202-564-0527
Last EDR Contact: 05/24/2019
Next Scheduled EDR Contact: 09/09/2019
Data Release Frequency: Varies

ECHO: Enforcement & Compliance History Information

ECHO provides integrated compliance and enforcement information for about 800,000 regulated facilities nationwide.

Date of Government Version: 04/07/2019
Date Data Arrived at EDR: 04/09/2019
Date Made Active in Reports: 05/23/2019
Number of Days to Update: 44

Source: Environmental Protection Agency
Telephone: 202-564-2280
Last EDR Contact: 07/09/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Quarterly

UXO: Unexploded Ordnance Sites

A listing of unexploded ordnance site locations

Date of Government Version: 12/31/2017
Date Data Arrived at EDR: 01/17/2019
Date Made Active in Reports: 04/01/2019
Number of Days to Update: 74

Source: Department of Defense
Telephone: 703-704-1564
Last EDR Contact: 04/15/2019
Next Scheduled EDR Contact: 07/29/2019
Data Release Frequency: Varies

FUELS PROGRAM: EPA Fuels Program Registered Listing

This listing includes facilities that are registered under the Part 80 (Code of Federal Regulations) EPA Fuels Programs. All companies now are required to submit new and updated registrations.

Date of Government Version: 02/19/2019
Date Data Arrived at EDR: 02/21/2019
Date Made Active in Reports: 04/01/2019
Number of Days to Update: 39

Source: EPA
Telephone: 800-385-6164
Last EDR Contact: 05/21/2019
Next Scheduled EDR Contact: 09/02/2019
Data Release Frequency: Quarterly

EDR HIGH RISK HISTORICAL RECORDS

EDR Exclusive Records

EDR MGP: EDR Proprietary Manufactured Gas Plants

The EDR Proprietary Manufactured Gas Plant Database includes records of coal gas plants (manufactured gas plants) compiled by EDR's researchers. Manufactured gas sites were used in the United States from the 1800's to 1950's to produce a gas that could be distributed and used as fuel. These plants used whale oil, rosin, coal, or a mixture of coal, oil, and water that also produced a significant amount of waste. Many of the byproducts of the gas production, such as coal tar (oily waste containing volatile and non-volatile chemicals), sludges, oils and other compounds are potentially hazardous to human health and the environment. The byproduct from this process was frequently disposed of directly at the plant site and can remain or spread slowly, serving as a continuous source of soil and groundwater contamination.

Date of Government Version: N/A	Source: EDR, Inc.
Date Data Arrived at EDR: N/A	Telephone: N/A
Date Made Active in Reports: N/A	Last EDR Contact: N/A
Number of Days to Update: N/A	Next Scheduled EDR Contact: N/A
	Data Release Frequency: No Update Planned

EDR Hist Auto: EDR Exclusive Historical Auto Stations

EDR has searched selected national collections of business directories and has collected listings of potential gas station/filling station/service station sites that were available to EDR researchers. EDR's review was limited to those categories of sources that might, in EDR's opinion, include gas station/filling station/service station establishments. The categories reviewed included, but were not limited to gas, gas station, gasoline station, filling station, auto, automobile repair, auto service station, service station, etc. This database falls within a category of information EDR classifies as "High Risk Historical Records", or HRHR. EDR's HRHR effort presents unique and sometimes proprietary data about past sites and operations that typically create environmental concerns, but may not show up in current government records searches.

Date of Government Version: N/A	Source: EDR, Inc.
Date Data Arrived at EDR: N/A	Telephone: N/A
Date Made Active in Reports: N/A	Last EDR Contact: N/A
Number of Days to Update: N/A	Next Scheduled EDR Contact: N/A
	Data Release Frequency: Varies

EDR Hist Cleaner: EDR Exclusive Historical Cleaners

EDR has searched selected national collections of business directories and has collected listings of potential dry cleaner sites that were available to EDR researchers. EDR's review was limited to those categories of sources that might, in EDR's opinion, include dry cleaning establishments. The categories reviewed included, but were not limited to dry cleaners, cleaners, laundry, laundromat, cleaning/laundry, wash & dry etc. This database falls within a category of information EDR classifies as "High Risk Historical Records", or HRHR. EDR's HRHR effort presents unique and sometimes proprietary data about past sites and operations that typically create environmental concerns, but may not show up in current government records searches.

Date of Government Version: N/A	Source: EDR, Inc.
Date Data Arrived at EDR: N/A	Telephone: N/A
Date Made Active in Reports: N/A	Last EDR Contact: N/A
Number of Days to Update: N/A	Next Scheduled EDR Contact: N/A
	Data Release Frequency: Varies

EDR RECOVERED GOVERNMENT ARCHIVES

Exclusive Recovered Govt. Archives

RGA LUST: Recovered Government Archive Leaking Underground Storage Tank

The EDR Recovered Government Archive Leaking Underground Storage Tank database provides a list of LUST incidents derived from historical databases and includes many records that no longer appear in current government lists. Compiled from Records formerly available from the Environmental Quality Board in Puerto Rico.

Date of Government Version: N/A	Source: Environmental Quality Board
Date Data Arrived at EDR: 07/01/2013	Telephone: N/A
Date Made Active in Reports: 01/04/2014	Last EDR Contact: 06/01/2012
Number of Days to Update: 187	Next Scheduled EDR Contact: N/A
	Data Release Frequency: Varies

OTHER DATABASE(S)

Depending on the geographic area covered by this report, the data provided in these specialty databases may or may not be complete. For example, the existence of wetlands information data in a specific report does not mean that all wetlands in the area covered by the report are included. Moreover, the absence of any reported wetlands information does not necessarily mean that wetlands do not exist in the area covered by the report.

NJ MANIFEST: Manifest Information
Hazardous waste manifest information.

Date of Government Version: 12/31/2018
Date Data Arrived at EDR: 04/10/2019
Date Made Active in Reports: 05/16/2019
Number of Days to Update: 36

Source: Department of Environmental Protection
Telephone: N/A
Last EDR Contact: 07/09/2019
Next Scheduled EDR Contact: 10/21/2019
Data Release Frequency: Annually

RI MANIFEST: Manifest information
Hazardous waste manifest information

Date of Government Version: 12/31/2017
Date Data Arrived at EDR: 02/23/2018
Date Made Active in Reports: 04/09/2018
Number of Days to Update: 45

Source: Department of Environmental Management
Telephone: 401-222-2797
Last EDR Contact: 05/17/2019
Next Scheduled EDR Contact: 09/02/2019
Data Release Frequency: Annually

Oil/Gas Pipelines
Source: PennWell Corporation
Petroleum Bundle (Crude Oil, Refined Products, Petrochemicals, Gas Liquids (LPG/NGL), and Specialty Gases (Miscellaneous)) N = Natural Gas Bundle (Natural Gas, Gas Liquids (LPG/NGL), and Specialty Gases (Miscellaneous)). This map includes information copyrighted by PennWell Corporation. This information is provided on a best effort basis and PennWell Corporation does not guarantee its accuracy nor warrant its fitness for any particular purpose. Such information has been reprinted with the permission of PennWell.

Electric Power Transmission Line Data
Source: PennWell Corporation
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Sensitive Receptors: There are individuals deemed sensitive receptors due to their fragile immune systems and special sensitivity to environmental discharges. These sensitive receptors typically include the elderly, the sick, and children. While the location of all sensitive receptors cannot be determined, EDR indicates those buildings and facilities - schools, daycares, hospitals, medical centers, and nursing homes - where individuals who are sensitive receptors are likely to be located.

AHA Hospitals:
Source: American Hospital Association, Inc.
Telephone: 312-280-5991
The database includes a listing of hospitals based on the American Hospital Association's annual survey of hospitals.

Medical Centers: Provider of Services Listing
Source: Centers for Medicare & Medicaid Services
Telephone: 410-786-3000
A listing of hospitals with Medicare provider number, produced by Centers of Medicare & Medicaid Services, a federal agency within the U.S. Department of Health and Human Services.

Nursing Homes
Source: National Institutes of Health
Telephone: 301-594-6248
Information on Medicare and Medicaid certified nursing homes in the United States.

Public Schools
Source: National Center for Education Statistics
Telephone: 202-502-7300
The National Center for Education Statistics' primary database on elementary and secondary public education in the United States. It is a comprehensive, annual, national statistical database of all public elementary and secondary schools and school districts, which contains data that are comparable across all states.

Private Schools
Source: National Center for Education Statistics
Telephone: 202-502-7300
The National Center for Education Statistics' primary database on private school locations in the United States.

GOVERNMENT RECORDS SEARCHED / DATA CURRENCY TRACKING

Flood Zone Data: This data was obtained from the Federal Emergency Management Agency (FEMA). It depicts 100-year and 500-year flood zones as defined by FEMA. It includes the National Flood Hazard Layer (NFHL) which incorporates Flood Insurance Rate Map (FIRM) data and Q3 data from FEMA in areas not covered by NFHL.

Source: FEMA
Telephone: 877-336-2627
Date of Government Version: 2003, 2015

NWI: National Wetlands Inventory. This data, available in select counties across the country, was obtained by EDR in 2002, 2005 and 2010 from the U.S. Fish and Wildlife Service.

Current USGS 7.5 Minute Topographic Map
Source: U.S. Geological Survey

STREET AND ADDRESS INFORMATION

GEOCHECK ® - PHYSICAL SETTING SOURCE ADDENDUM

TARGET PROPERTY ADDRESS

AASF ISLA GRANDE
600-600 CALLE LINDBERGH
SAN JUAN, PR 00907

TARGET PROPERTY COORDINATES

Latitude (North):	18.455264 - 18˚ 27’ 18.95’’
Longitude (West):	66.096015 - 66˚ 5’ 45.65’’
Universal Tranverse Mercator:	Zone 19
UTM X (Meters):	806735.1
UTM Y (Meters):	2042894.9
Elevation:	10 ft. above sea level

USGS TOPOGRAPHIC MAP

Target Property Map:	5964476 SAN JUAN, PR
Version Date:	2013

EDR’s GeoCheck Physical Setting Source Addendum is provided to assist the environmental professional in forming an opinion about the impact of potential contaminant migration.

Assessment of the impact of contaminant migration generally has two principle investigative components:

1. Groundwater flow direction, and
2. Groundwater flow velocity.

Groundwater flow direction may be impacted by surface topography, hydrology, hydrogeology, characteristics of the soil, and nearby wells. Groundwater flow velocity is generally impacted by the nature of the geologic strata.

GEOCHECK® - PHYSICAL SETTING SOURCE SUMMARY

GROUNDWATER FLOW DIRECTION INFORMATION

Groundwater flow direction for a particular site is best determined by a qualified environmental professional using site-specific well data. If such data is not reasonably ascertainable, it may be necessary to rely on other sources of information, such as surface topographic information, hydrologic information, hydrogeologic data collected on nearby properties, and regional groundwater flow information (from deep aquifers).

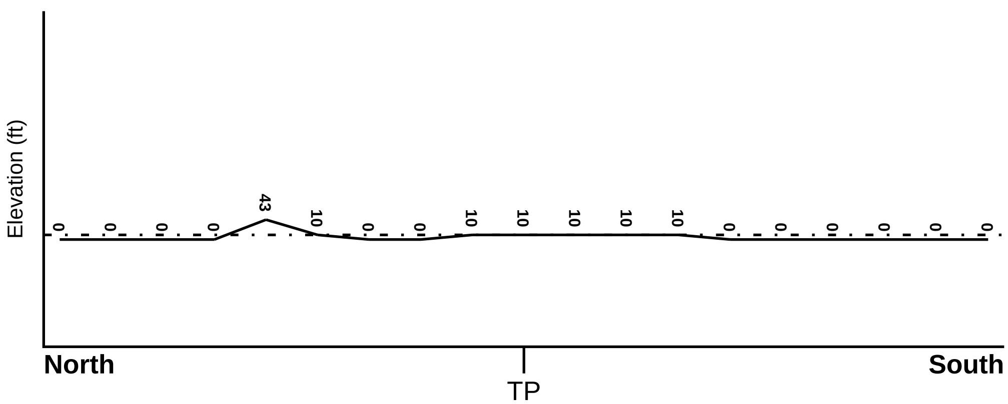
TOPOGRAPHIC INFORMATION

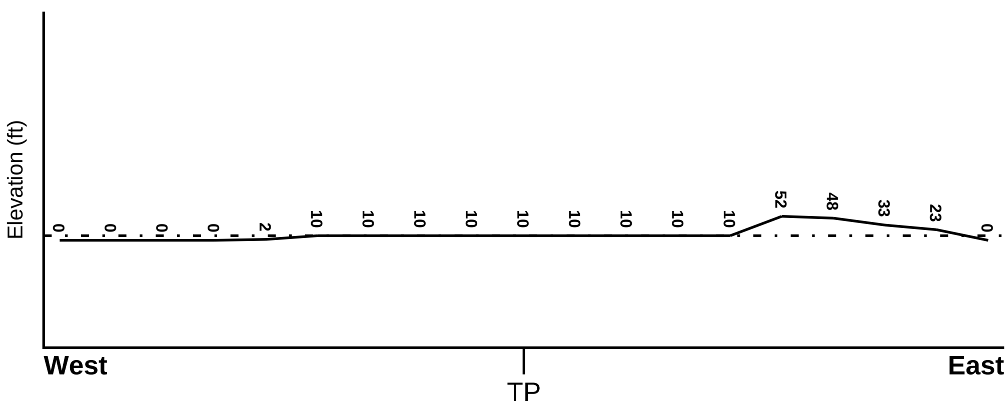
Surface topography may be indicative of the direction of surficial groundwater flow. This information can be used to assist the environmental professional in forming an opinion about the impact of nearby contaminated properties or, should contamination exist on the target property, what downgradient sites might be impacted.

TARGET PROPERTY TOPOGRAPHY

General Topographic Gradient: General North

SURROUNDING TOPOGRAPHY: ELEVATION PROFILES





Target Property Elevation: 10 ft.

0 1/2 1 Miles

Source: Topography has been determined from the USGS 7.5' Digital Elevation Model and should be evaluated on a relative (not an absolute) basis. Relative elevation information between sites of close proximity should be field verified.

GEOCHECK® - PHYSICAL SETTING SOURCE SUMMARY

HYDROLOGIC INFORMATION

Surface water can act as a hydrologic barrier to groundwater flow. Such hydrologic information can be used to assist the environmental professional in forming an opinion about the impact of nearby contaminated properties or, should contamination exist on the target property, what downgradient sites might be impacted.

Refer to the Physical Setting Source Map following this summary for hydrologic information (major waterways and bodies of water).

FEMA FLOOD ZONE

Flood Plain Panel at Target Property	FEMA Source Type
7200000051C	FEMA Q3 Flood data

Additional Panels in search area:	FEMA Source Type
Not Reported	

NATIONAL WETLAND INVENTORY

NWI Quad at Target Property	NWI Electronic Data Coverage
NOT AVAILABLE	YES - refer to the Overview Map and Detail Map

HYDROGEOLOGIC INFORMATION

Hydrogeologic information obtained by installation of wells on a specific site can often be an indicator of groundwater flow direction in the immediate area. Such hydrogeologic information can be used to assist the environmental professional in forming an opinion about the impact of nearby contaminated properties or, should contamination exist on the target property, what downgradient sites might be impacted.

AQUIFLOW®

Search Radius: 1.000 Mile.

EDR has developed the AQUIFLOW Information System to provide data on the general direction of groundwater flow at specific points. EDR has reviewed reports submitted by environmental professionals to regulatory authorities at select sites and has extracted the date of the report, groundwater flow direction as determined hydrogeologically, and the depth to water table.

MAP ID	LOCATION FROM TP	GENERAL DIRECTION GROUNDWATER FLOW
Not Reported		

GROUNDWATER FLOW VELOCITY INFORMATION

Groundwater flow velocity information for a particular site is best determined by a qualified environmental professional using site specific geologic and soil strata data. If such data are not reasonably ascertainable, it may be necessary to rely on other sources of information, including geologic age identification, rock stratigraphic unit and soil characteristics data collected on nearby properties and regional soil information. In general, contaminant plumes move more quickly through sandy-gravelly types of soils than silty-clayey types of soils.

GEOLOGIC INFORMATION IN GENERAL AREA OF TARGET PROPERTY

Geologic information can be used by the environmental professional in forming an opinion about the relative speed at which contaminant migration may be occurring.

ROCK STRATIGRAPHIC UNIT

Era:	-
System:	-
Series:	-
Code:	N/A *(decoded above as Era, System & Series)*

GEOLOGIC AGE IDENTIFICATION

Category: -

Geologic Age and Rock Stratigraphic Unit Source: P.G. Schruben, R.E. Arndt and W.J. Bawiec, Geology of the Conterminous U.S. at 1:2,500,000 Scale - a digital representation of the 1974 P.B. King and H.M. Beikman Map, USGS Digital Data Series DDS - 11 (1994).

DOMINANT SOIL COMPOSITION IN GENERAL AREA OF TARGET PROPERTY

The U.S. Department of Agriculture’s (USDA) Soil Conservation Service (SCS) leads the National Cooperative Soil Survey (NCSS) and is responsible for collecting, storing, maintaining and distributing soil survey information for privately owned lands in the United States. A soil map in a soil survey is a representation of soil patterns in a landscape. Soil maps for STATSGO are compiled by generalizing more detailed (SSURGO) soil survey maps. The following information is based on Soil Conservation Service STATSGO data.

Soil Component Name:	URBAN LAND
Soil Surface Texture:	variable
Hydrologic Group:	Not reported
Soil Drainage Class:	Not reported

Hydric Status: Soil does not meet the requirements for a hydric soil.

Corrosion Potential - Uncoated Steel:	Not Reported
Depth to Bedrock Min:	> 10 inches
Depth to Bedrock Max:	> 10 inches

Soil Layer Information							
	Boundary			Classification			
Layer	Upper	Lower	Soil Texture Class	AASHTO Group	Unified Soil	Permeability Rate (in/hr)	Soil Reaction (pH)
1	0 inches	6 inches	variable	Not reported	Not reported	Max: 0.00 Min: 0.00	Max: 0.00 Min: 0.00

OTHER SOIL TYPES IN AREA

Based on Soil Conservation Service STATSGO data, the following additional subordinant soil types may appear within the general area of target property.

Soil Surface Textures: sandy loam
loamy sand

Surficial Soil Types: sandy loam
loamy sand

Shallow Soil Types: No Other Soil Types

Deeper Soil Types: clay
sand

LOCAL / REGIONAL WATER AGENCY RECORDS

EDR Local/Regional Water Agency records provide water well information to assist the environmental professional in assessing sources that may impact ground water flow direction, and in forming an opinion about the impact of contaminant migration on nearby drinking water wells.

WELL SEARCH DISTANCE INFORMATION

DATABASE	SEARCH DISTANCE (miles)
Federal USGS	1.000
Federal FRDS PWS	Nearest PWS within 1 mile

FEDERAL USGS WELL INFORMATION

MAP ID	WELL ID	LOCATION FROM TP
1	USGS40001046406	1/2 - 1 Mile SE
2	USGS40001046633	1/2 - 1 Mile NW

FEDERAL FRDS PUBLIC WATER SUPPLY SYSTEM INFORMATION

MAP ID	WELL ID	LOCATION FROM TP

GEOCHECK® - PHYSICAL SETTING SOURCE SUMMARY

FEDERAL FRDS PUBLIC WATER SUPPLY SYSTEM INFORMATION

MAP ID	WELL ID	LOCATION FROM TP
No PWS System Found		

Note: PWS System location is not always the same as well location.

PHYSICAL SETTING SOURCE MAP - 5714997.2s

County Boundary
Major Roads
Contour Lines
Airports
Earthquake epicenter, Richter 5 or greater
Water Wells
Public Water Supply Wells
Cluster of Multiple Icons

0 1/4 1/2 1 Miles

Groundwater Flow Direction
GI Indeterminate Groundwater Flow at Location
GV Groundwater Flow Varies at Location

SITE NAME: AASF Isla Grande	CLIENT: AECOM
ADDRESS: 600-600 Calle Lindbergh San Juan PR 00907	CONTACT: Hans Sund
	INQUIRY #: 5714997.2s
LAT/LONG: 18.455264 / 66.096015	DATE: July 12, 2019 2:41 pm

Map ID Direction Distance Elevation	Database	EDR ID Number
1 **SE** **1/2 - 1 Mile** **Lower**	**FED USGS**	**USGS40001046406**

Organization ID:	USGS-PR		
Organization Name:	USGS Puerto Rico Water Science Center		
Monitor Location:	LATHAM WELL, SAN JUAN, PR	Type:	Well
Description:	Not Reported	HUC:	21010005
Drainage Area:	Not Reported	Drainage Area Units:	Not Reported
Contrib Drainage Area:	Not Reported	Contrib Drainage Area Unts:	Not Reported
Aquifer:	Not Reported	Formation Type:	Not Reported
Aquifer Type:	Not Reported	Construction Date:	19400101
Well Depth:	Not Reported	Well Depth Units:	Not Reported
Well Hole Depth:	50	Well Hole Depth Units:	ft

Map ID Direction Distance Elevation	Database	EDR ID Number
2 **NW** **1/2 - 1 Mile** **Higher**	**FED USGS**	**USGS40001046633**

Organization ID:	USGS-PR		
Organization Name:	USGS Puerto Rico Water Science Center		
Monitor Location:	IPLA WELL, SAN JUAN, PR	Type:	Well
Description:	Not Reported	HUC:	21010005
Drainage Area:	Not Reported	Drainage Area Units:	Not Reported
Contrib Drainage Area:	Not Reported	Contrib Drainage Area Unts:	Not Reported
Aquifer:	Not Reported	Formation Type:	Not Reported
Aquifer Type:	Not Reported	Construction Date:	19260101
Well Depth:	Not Reported	Well Depth Units:	Not Reported
Well Hole Depth:	710	Well Hole Depth Units:	ft

AREA RADON INFORMATION

Not Reported

PHYSICAL SETTING SOURCE RECORDS SEARCHED

TOPOGRAPHIC INFORMATION

USGS 7.5' Digital Elevation Model (DEM)
Source: United States Geologic Survey
EDR acquired the USGS 7.5' Digital Elevation Model in 2002 and updated it in 2006. The 7.5 minute DEM corresponds to the USGS 1:24,000- and 1:25,000-scale topographic quadrangle maps. The DEM provides elevation data with consistent elevation units and projection.

Current USGS 7.5 Minute Topographic Map
Source: U.S. Geological Survey

HYDROLOGIC INFORMATION

Flood Zone Data: This data was obtained from the Federal Emergency Management Agency (FEMA). It depicts 100-year and 500-year flood zones as defined by FEMA. It includes the National Flood Hazard Layer (NFHL) which incorporates Flood Insurance Rate Map (FIRM) data and Q3 data from FEMA in areas not covered by NFHL.
Source: FEMA
Telephone: 877-336-2627
Date of Government Version: 2003, 2015

NWI: National Wetlands Inventory. This data, available in select counties across the country, was obtained by EDR in 2002, 2005 and 2010 from the U.S. Fish and Wildlife Service.

HYDROGEOLOGIC INFORMATION

AQUIFLOW[R] Information System
Source: EDR proprietary database of groundwater flow information
EDR has developed the AQUIFLOW Information System (AIS) to provide data on the general direction of groundwater flow at specific points. EDR has reviewed reports submitted to regulatory authorities at select sites and has extracted the date of the report, hydrogeologically determined groundwater flow direction and depth to water table information.

GEOLOGIC INFORMATION

Geologic Age and Rock Stratigraphic Unit
Source: P.G. Schruben, R.E. Arndt and W.J. Bawiec, Geology of the Conterminous U.S. at 1:2,500,000 Scale - A digital representation of the 1974 P.B. King and H.M. Beikman Map, USGS Digital Data Series DDS - 11 (1994).

STATSGO: State Soil Geographic Database
Source: Department of Agriculture, Natural Resources Conservation Service (NRCS)
The U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) leads the national Conservation Soil Survey (NCSS) and is responsible for collecting, storing, maintaining and distributing soil survey information for privately owned lands in the United States. A soil map in a soil survey is a representation of soil patterns in a landscape. Soil maps for STATSGO are compiled by generalizing more detailed (SSURGO) soil survey maps.

SSURGO: Soil Survey Geographic Database
Source: Department of Agriculture, Natural Resources Conservation Service (NRCS)
Telephone: 800-672-5559
SSURGO is the most detailed level of mapping done by the Natural Resources Conservation Service, mapping scales generally range from 1:12,000 to 1:63,360. Field mapping methods using national standards are used to construct the soil maps in the Soil Survey Geographic (SSURGO) database. SSURGO digitizing duplicates the original soil survey maps. This level of mapping is designed for use by landowners, townships and county natural resource planning and management.

PHYSICAL SETTING SOURCE RECORDS SEARCHED

LOCAL / REGIONAL WATER AGENCY RECORDS

FEDERAL WATER WELLS

PWS: Public Water Systems
Source: EPA/Office of Drinking Water
Telephone: 202-564-3750
Public Water System data from the Federal Reporting Data System. A PWS is any water system which provides water to at least 25 people for at least 60 days annually. PWSs provide water from wells, rivers and other sources.

PWS ENF: Public Water Systems Violation and Enforcement Data
Source: EPA/Office of Drinking Water
Telephone: 202-564-3750
Violation and Enforcement data for Public Water Systems from the Safe Drinking Water Information System (SDWIS) after August 1995. Prior to August 1995, the data came from the Federal Reporting Data System (FRDS).

USGS Water Wells: USGS National Water Inventory System (NWIS)
This database contains descriptive information on sites where the USGS collects or has collected data on surface water and/or groundwater. The groundwater data includes information on wells, springs, and other sources of groundwater.

OTHER STATE DATABASE INFORMATION

RADON

Area Radon Information
Source: USGS
Telephone: 703-356-4020
The National Radon Database has been developed by the U.S. Environmental Protection Agency (USEPA) and is a compilation of the EPA/State Residential Radon Survey and the National Residential Radon Survey. The study covers the years 1986 - 1992. Where necessary data has been supplemented by information collected at private sources such as universities and research institutions.

EPA Radon Zones
Source: EPA
Telephone: 703-356-4020
Sections 307 & 309 of IRAA directed EPA to list and identify areas of U.S. with the potential for elevated indoor radon levels.

OTHER

Airport Landing Facilities: Private and public use landing facilities
Source: Federal Aviation Administration, 800-457-6656

Epicenters: World earthquake epicenters, Richter 5 or greater
Source: Department of Commerce, National Oceanic and Atmospheric Administration

Earthquake Fault Lines: The fault lines displayed on EDR’s Topographic map are digitized quaternary faultlines, prepared in 1975 by the United State Geological Survey

STREET AND ADDRESS INFORMATION

AASF Isla Grande

600-600 Calle Lindbergh

San Juan, PR 00907

Inquiry Number: 5714997.6

July 15, 2019

The EDR Aerial Photo Decade Package

6 Armstrong Road, 4th floor
Shelton, CT 06484
Toll Free: 800.352.0050
www.edrnet.com

EDR Aerial Photo Decade Package

07/15/19

Site Name:	**Client Name:**
AASF Isla Grande	AECOM
600-600 Calle Lindbergh	12120 Shamrock Plaza
San Juan, PR 00907	Omaha, NE 68154
EDR Inquiry # 5714997.6	Contact: Hans Sund

Environmental Data Resources, Inc. (EDR) Aerial Photo Decade Package is a screening tool designed to assist environmental professionals in evaluating potential liability on a target property resulting from past activities. EDR's professional researchers provide digitally reproduced historical aerial photographs, and when available, provide one photo per decade.

Search Results:

Year	Scale	Details	Source
2004	1"=500'	Flight Date: January 15, 2004	USGS
1995	1"=500'	Acquisition Date: December 01, 1995	USGS/DOQQ
1993	1"=500'	Flight Date: December 17, 1993	USGS
1989	1"=500'	Flight Date: March 31, 1989	USGS
1983	1"=1000'	Flight Date: February 05, 1983	USGS
1977	1"=500'	Flight Date: March 22, 1977	USGS
1974	1"=500'	Flight Date: January 17, 1974	USGS
1967	1"=500'	Flight Date: September 25, 1967	USGS

When delivered electronically by EDR, the aerial photo images included with this report are for ONE TIME USE ONLY. Further reproduction of these aerial photo images is prohibited without permission from EDR. For more information contact your EDR Account Executive.

INQUIRY #: 5714997.6

YEAR: 2004

= 500'

N

EDR

INQUIRY #: 5714997.6

YEAR: 1995

= 500'

N

EDR

INQUIRY #: 5714997.6

YEAR: 1993

= 500'

N

EDR

INQUIRY #: 5714997.6

YEAR: 1989

= 500'

N

EDR

INQUIRY #: 5714997.6

YEAR: 1983

= 1000'

N

EDR

Subject boundary not shown because it exceeds image extent or image is not georeferenced.

INQUIRY #: 5714997.6

YEAR: 1977

= 500'

N

EDR

INQUIRY #: 5714997.6

YEAR: 1974

= 500'

N

INQUIRY #: 5714997.6

YEAR: 1967

= 500'

N

EDR

Subject boundary not shown because it exceeds image extent or image is not georeferenced.

AASF Isla Grande

600-600 Calle Lindbergh

San Juan, PR 00907

Inquiry Number: 5714997.3

July 12, 2019

Certified Sanborn® Map Report

EDR®

6 Armstrong Road, 4th floor
Shelton, CT 06484
Toll Free: 800.352.0050
www.edrnet.com

Certified Sanborn® Map Report

07/12/19

Site Name:

AASF Isla Grande
600-600 Calle Lindbergh
San Juan, PR 00907
EDR Inquiry # 5714997.3

Client Name:

AECOM
12120 Shamrock Plaza
Omaha, NE 68154
Contact: Hans Sund

The Sanborn Library has been searched by EDR and maps covering the target property location as provided by AECOM were identified for the years listed below. The Sanborn Library is the largest, most complete collection of fire insurance maps. The collection includes maps from Sanborn, Bromley, Perris & Browne, Hopkins, Barlow, and others. Only Environmental Data Resources Inc. (EDR) is authorized to grant rights for commercial reproduction of maps by the Sanborn Library LLC, the copyright holder for the collection. Results can be authenticated by visiting www.edrnet.com/sanborn.

The Sanborn Library is continually enhanced with newly identified map archives. This report accesses all maps in the collection as of the day this report was generated.

Certified Sanborn Results:

Certification # 3FA2-48BD-8217

PO # NA

Project AASF Isla Grande

UNMAPPED PROPERTY

This report certifies that the complete holdings of the Sanborn Library, LLC collection have been searched based on client supplied target property information, and fire insurance maps covering the target property were not found.

Sanborn® Library search results

Certification #: 3FA2-48BD-8217

The Sanborn Library includes more than 1.2 million fire insurance maps from Sanborn, Bromley, Perris & Browne, Hopkins, Barlow and others which track historical property usage in approximately 12,000 American cities and towns. Collections searched:

- ✓ Library of Congress
- ✓ University Publications of America
- ✓ EDR Private Collection

The Sanborn Library LLC Since 1866™

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AECOM (the client) is permitted to make up to FIVE photocopies of this Sanborn Map transmittal and each fire insurance map accompanying this report solely for the limited use of its customer. No one other than the client is authorized to make copies. Upon request made directly to an EDR Account Executive, the client may be permitted to make a limited number of additional photocopies. This permission is conditioned upon compliance by the client, its customer and their agents with EDR's copyright policy; a copy of which is available upon request.

Coastal Geology of Puerto Rico

By CLIFFORD A. KAYE

GEOLOGICAL SURVEY PROFESSIONAL PAPER 317

Prepared in cooperation with the Puerto Rico Water Resources Authority, Puerto Rico Economic Development Administration, Puerto Rico Aqueduct and Sewer Authority, and Puerto Rico Department of the Interior

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

Kaye, Clifford Alan, 1916–
Coastal geology of Puerto Rico. Washington, U.S. Govt. Print. Off., 1959.

iv, 178 p. illus., maps (1 col.) diagrs., tables. 30 cm. (U.S. Geological Survey. Professional paper 317)

Part of illustrative matter folded in pocket.
Prepared in cooperation with the Puerto Rico Water Resources Authority, Puerto Rico Economic Development Administration, Puerto Rico Aqueduct and Sewer Authority, and Puerto Rico Dept. of the Interior.
Includes bibliographies.

(Continued on next card)
G S 59–198

Kaye, Clifford Alan, 1916– Coastal geology of Puerto Rico. 1959. (Card 2)

CONTENTS.—Geology of the San Juan metropolitan area.—Shoreline features and Quaternary shoreline changes.—Geology of Isla Mona and notes on age of Mona Passage. With a section on The petrography of the phosphorites, by Zalman S. Altschuler.

1. Geology—Puerto Rico. 2. Coasts—Puerto Rico. I. Title. (Series)

[QE75.P9 no. 317] G S 59–198

CONTENTS

[The letters in parentheses preceding the titles designate separately published chapters]

ILLUSTRATIONS

[Plates 1, 2, and 10-12 are in pocket]

Geology of the San Juan Metropolitan Area Puerto Rico

By CLIFFORD A. KAYE

COASTAL GEOLOGY OF PUERTO RICO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 317-A

Prepared in cooperation with Puerto Rico Water Resources Authority, Puerto Rico Economic Development Administration, Puerto Rico Aqueduct and Sewer Authority, and Puerto Rico Department of the Interior

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

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Thomas B. Nolan, *Director*

The U. S. Geological Survey Library has cataloged this publication as follows:

Kaye, Clifford A 1916–

Geology of the San Juan metropolitan area, Puerto Rico. Prepared in cooperation with Puerto Rico Water Resources Authority, Puerto Rico Economic Development Administration, Puerto Rico Aqueduct and Sewer Authority, and Puerto Rico Dept. of the Interior. Washington, U. S. Govt. Print. Off., 1959.

Ix, 48 p. maps (2 fold., 1 col., in pocket) diagrs., tables. 30 cm. ([U. S.] Geological Survey. Professional paper 317–A. Coastal geology of Puerto Rico)

Bibliography: p. 45–46.

1. Geology—Puerto Rico-San Juan area. I. Title: San Juan metropolitan area, Puerto Rico. (Series: U. S. Geological Survey. Professional paper 317–A. Series: U. S. Geological Survey. Coastal geology of Puerto Rico)

557.295

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.

PREFACE TO "COASTAL GEOLOGY OF PUERTO RICO"

BACKGROUND

The varied geologic notes that are the subject of Professional Paper 317 represent field work done from March 1949 through September 1951, when the writer was the U. S. Geological Survey representative assigned to provide geologic advice of an engineering nature to four agencies of the Puerto Rican government, namely: the Puerto Rico Water Resources Authority, the Industrial Development Company (later the Puerto Rico Economic Development Administration), the Puerto Rico Aqueduct and Sewer Authority, and the Insular Department of the Interior. The field studies that make up this report, however, were largely carried on independent of, or incidental to, the specific consulting work that was the first responsibility of the Puerto Rican cooperative project. In 1954 the writer returned to Puerto Rico in order to conduct a field check.

ACKNOWLEDGMENTS

The cooperation of the Puerto Rico Water Resources Authority, the Puerto Rico Economic Development Administration, the Puerto Rico Aqueduct and Sewer Authority, and the Insular Department of the Interior is hereby gratefully acknowledged. Particularly thanks are due the following officials of the Puerto Rico Water Resources Authority for their continued interest and aid: Antonio Lucchetti, Executive Director (deceased); Carl A. Bock, Chief Engineer; Miguel Quiñones; Manuel Fidalgo; Xavier Cuevas; Pedro Colón; Rafael Reyes; and Alonso Aguilar.

Rafael Fernández García, Director of Industrial Research of the Puerto Rico Economic Development Administration, gave his interest and friendship, provided laboratory facilities, made available mineral-investigation files and reports, and even furnished transportation during the writer's visit to the island in 1954.

The interest and assistance on several occasions of Rafael Picó, Chairman of the Puerto Rico Planning Board, is acknowledged.

Enrique Rubio, Insular Department of the Interior, furnished aerial photographs, maps, and topographic information; and Guillermo Esteves, Puerto Rico Reconstruction Administration (PRRA), allowed the use of the photographic darkroom and the file of aerial photographs that were the property of that agency. Buenaventura Quiñones Chacón and Miguel Meléndez, both of the Puerto Rico Department of Agriculture and Commerce, organized two trips to Isla Mona. Information on the soils of Puerto Rico was given by J. A. Bonnet, Insular Agricultural Experiment Station.

The writer also wishes to thank the University of Puerto Rico and the Insular Agricultural Experiment Station, both at Río Piedras, for granting him full library privileges.

Chemical analyses were made at the writer's request by the Industrial Research Laboratory of the Puerto Rico Economic Development Administration, the fertilizer laboratory of the Puerto Rico Department of Agriculture and Commerce, and the agronomic soils laboratory of the Insular Agricultural Experiment Station.

Historical and archeological information was provided by Adolpho de Hostos; Ricardo Allegría, University of Puerto Rico; Capt. Peter Verhoog; Adam Bishop; Rafael Ramírez, historian of San Juan; E. H. Wadsworth; and Irving Rouse, Yale University. Don U. Deere and J. L. Capaceti provided the writer with valuable subsurface data from their large file of boring records, and L. Antonsanti and Company of Ponce made available their records of water-well logs and well cuttings.

The assistance of the following agencies of the federal government in Puerto Rico is hereby acknowledged:

1. U. S. Coast Guard, for transportation to and from Isla Mona and Isla Caja de Muertos, and for rations and quarters for the writer at the lighthouses while he was visiting both places. The following members of the crew of the Isla Mona lighthouse acted as guides, drivers, cooks, and companions: Justo Gonzales, Nicolas Orlandi, Rafael Figueroa, and Ramón Cruz.

2. U. S. National Park Service, San Juan, for furnishing photocopies of their file of old maps.

3. U. S. Army Engineers, for logs of foundation borings and beach erosion information.

4. U. S. Army, for maps and photographs of Puerto Rico.

5. U. S. Navy Hydrographic Office, for charts of Caribbean waters.

6. U. S. Coast and Geodetic Survey Magnetic Observatory, Guaynabo, and its chief, Paul Ledig, for seismic data on the Caribbean region.

While it would be difficult to list all those who assisted the writer during his stay in Puerto Rico, it is only fitting to acknowledge a debt of gratitude to the following friends who were of inestimable help in facilitating arrangements, expediting contacts, and finding localities of geologic interest that normally might have been missed: Thomas Haydon, Rosa Haydon, and Heliodoro Blanco.

Of his many colleagues in the U. S. Geological Survey who in one way or another contributed to this study, the writer would like to acknowledge the special interest and help of Wendell P. Woodring, who, besides giving paleontological advice, also visited the project in the field.

Other paleontologists of the U. S. Geological Survey who devoted much of their time to Puerto Rican collections are: Esther Applin, W. Storrs Cole, C. Wythe Cooke, Jean Hough, John B. Reeside, Jr., I. G. Sohn, Ruth Todd, and John W. Wells. Advice on paleontology and taxonomy was also contributed by Alexander Wetmore, Smithsonian Institute; W. J. Clench, Harvard University; Francis Drouet, Chicago Natural History Museum; and H. A. Rehder and R. T. Abbot, U. S. National Museum.

Robert L. Smith, Richard C. Erd, and Fred Hildebrand, U. S. Geological Survey, are to be especially thanked for assistance on petrography and mineralogy, as is Zalman S. Altschuler for contributing the report on the Mona Island phosphorites that is included verbatim in Chapter C of this study.

SCOPE OF REPORT

The following pages consist of three separate, nonintegrated papers, all concerned primarily with coastal areas of Puerto Rico or with problems of coastal geology. Each study is published separately as a chapter of Professional Paper 317, and each is largely self-sufficient, thereby serving the specialized reader who may be interested in the subject matter of one chapter but who may not want to thread his way through the entire report.

The first paper (Chapter A) is the presentation of a geologic map of the city of San Juan and its environs. The mapped area, by most continental standards, is small; nevertheless it reveals several highly significant relations within the section of older rocks (older complex, as defined and used in this report), which form the main subject for discussion in this chapter.

Chapters B and C are concerned with geology of a type that is more usually implied by the term "coastal geology."

Chapter B discusses several shoreline forms and processes, including the formation of lunate shores, beachrock, cemented dunes, sea-level nips, tidal terraces, flat- and round-bottomed pits, oolite, and beach-faceted pebbles. The distribution of coral reefs and major shore features is also described. Chapter B also covers the following subjects: The Quaternary marine and eolian stratigraphy of the north coast, criteria for recognizing epeirogenic and eustatic sea levels, the age and stability of the present sea level, and a suggested correlation with the standard glacial section.

Chapter C is a general report in some detail of the geology of Isla Mona, situated off the west coast of Puerto Rico. The general stratigraphy is described and the geologic history and geomorphic implications of the caverns, sea cliffs, and surface forms are considered. The composition and origin of the cave phosphorites are reviewed in considerable detail. In addition an attempt is made to establish criteria for the age of the strait separating Puerto Rico from the Dominican Republic—Mona Passage.

TOPOGRAPHIC MAPS

Puerto Rico is entirely covered by modern U. S. Geological Survey topographic maps in four scales: 1:10,000, 1:30,000, 1:120,000, and 1:240,000. In addition to the geographic coordinates of the polyconic projection, the first two series of maps show the meter grid of the Puerto Rico plane-coordinate system, by which it is possible to relocate a position with accuracy. The last two maps are printed as single sheets.

CONVENTIONS USED IN THE REPORT

In citing localities, verbal descriptions are sometimes supplemented by notations in the plane-coordinate system, generally given in parentheses after a verbal location (185,630 m, 59,250 m). The first notation—the x coordinate—gives the position in meters east, and the second notation—the y coordinate—gives the position in meters north. This grid system makes it possible to relocate with precision. The locations can be plotted accurately by reference to the grid marks on the margins of the large-scale topographic maps. Because both a meter- and a yard-grid system have been constructed for Puerto Rico and are ticked on the margins of some maps, the reader must be careful to use the marks of the meter system in plotting locations given in this report.

Measurements and distances are given in inches, feet, miles (either statute or nautical; if the latter, it is so designated), and fathoms. Where specific reference is made to the topographic maps, altitudes are given in meters to conform with the system employed on the maps. The Spanish geographic names used on the topographic maps are generally retained in the text. The numbering of roads is the official designation in late 1955. This fact may be of some importance, for the highway numbering system has undergone several changes and may do so again.

Verbal descriptions of rock colors in places are supplemented by the Munsell color system notation. The "Rock Color Chart" prepared by a committee of the National Research Council in 1948, was used for these color notations and should be referred to by the reader.

PUERTO RICO: A GENERAL DESCRIPTION

Puerto Rico was discovered by Christopher Columbus on November 19, 1493, as he sailed westward in the course of his second great voyage to the west. He named the island San Juan de Bautista. Curiously enough, with the passing of time the name of the island and the name of its principal port and capital, Puerto Rico, became reversed to the present usage. The island was governed as a Spanish Crown Colony from its discovery to 1898, when it was ceded to the United States at the conclusion of the Spanish-American War. The island has the status of a commonwealth and is governed in the framework of a constitution written by its own legislature.

Puerto Rico is the easternmost of the Greater Antilles (fig. 1), a chain of large islands which includes, from west to east, Cuba, Jamaica, Hispaniola (consisting of the Republic of Haiti and the Dominican Republic), and Puerto Rico. Immediately east of Puerto Rico are the U. S. Virgin Islands and the British Virgin Islands, a cluster of small islands that, although geologically related to the Greater Antilles, geographically are the northernmost of the Lesser Antilles. The latter constitute an archipelago of small islands that stretch southward in a

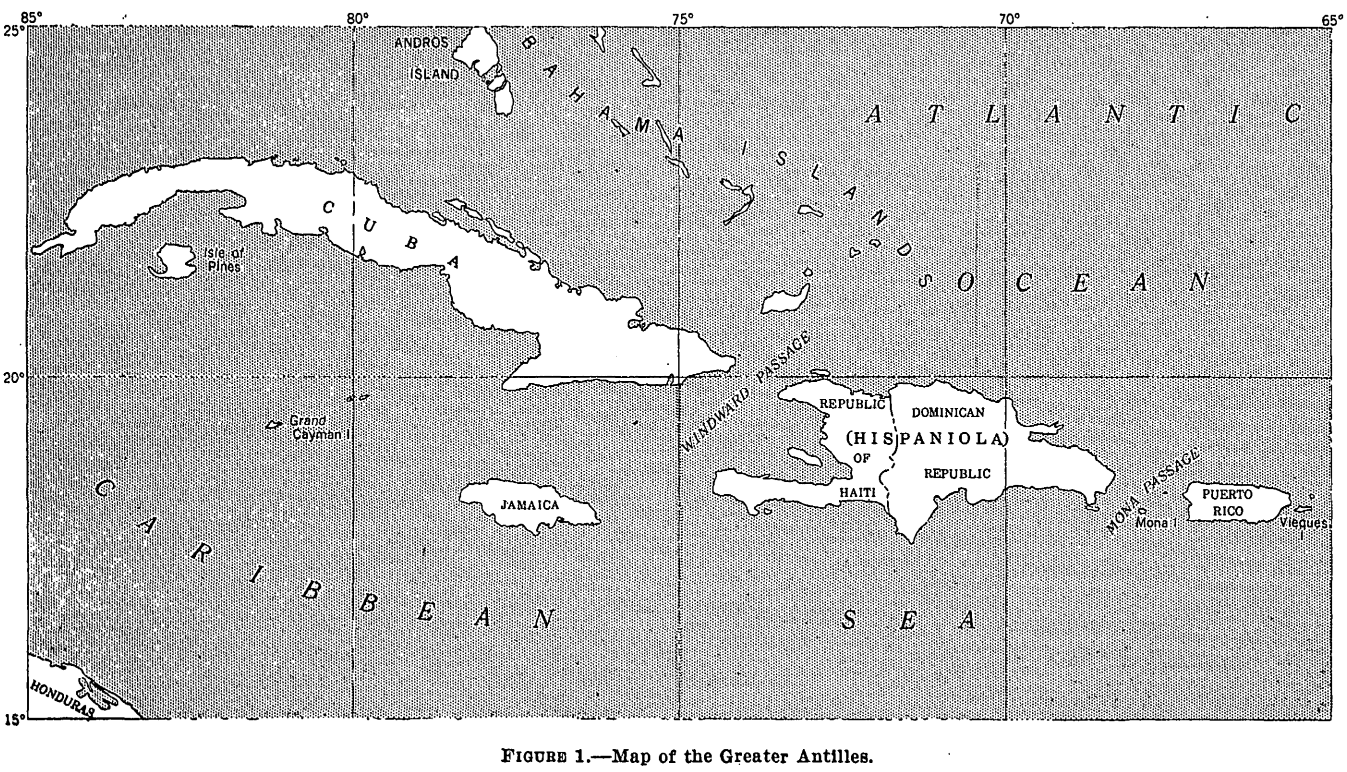

FIGURE 1.—Map of the Greater Antilles.

broad arc from the Virgin Islands to eastern Venezuela. The Greater and Lesser Antilles enclose the Caribbean Sea; waters outside this great island arc are referred to as the Atlantic Ocean.

Puerto Rico is roughly rectangular in shape (pl. 1) with its long dimension, or axis, oriented from east to west. It measures approximately 110 miles from east to west and 37 miles from north to south; its area is 3,421 square miles. Several small outlying islands are politically part of Puerto Rico. The largest of these are Isla de Vieques and Isla de Culebra off the east coast, Isla Caja de Muertos off the south coast, and Isla Mona and Isla Desecheo off the west coast.

The topography of Puerto Rico is extremely varied, but most of the island is hilly to mountainous, with the maximum relief generally in the interior. Very steep slopes and narrow valleys characterize most of the interior, though here and there one finds local widenings of the valleys and even broad interior basins, such as that at Cayey. The divide separating the Atlantic from the Caribbean drainage lies somewhat south of the geographic axis of the island, and in consequence the general orographic slope is steeper on the south side of the island.

The highest point on Puerto Rico is that of Cerro de Punta (altitude, 1,338 m or 4,390 feet), which is located on this divide. In addition to the high peaks along the principal insular divide, an isolated and very prominent cluster of peaks that attains a maximum altitude of 1,074 m (3,532 feet), the Sierra de Luquillo, occurs at the northeast corner of Puerto Rico.

A broad east-west belt of exceptionally rugged karst topography characterizes much of the north side of the island. Here one finds vertical to steeply conical knobs of Tertiary limestone rising abruptly from flat alluvium-covered plains or, where the weathering of the limestone is less advanced, from a plexus of deep sinkholes. When viewed from afar, the surface of this karst topography—with its wave on wave of sharp-crested limestone hills—strongly resembles a choppy sea. Except for the major rivers cutting across it, drainage in this limestone belt is underground.

Part of the north coastal area is low and swampy, indented, here and there, by small bays and lagoons and the well-protected harbor of San Juan. The east and west coasts of the island consist of alternating low alluvial plains and hilly headlands. The south coast of the island—except for the western part, which consists of low limestone hills, and for several miles near the eastern end, which is mountainous—is a low alluvial plain that fringes the foot of the steep-sloped upland.

Broadly viewed, the major geologic units of Puerto Rico are arranged in a simple pattern. Structurally, the island is a geanticline, or broad arch, whose axis is essentially the same as the geographical axis. Younger rocks crop out on both north and south coasts, where they dip gently north and south, respectively, away from the outcrop of the older rocks, which extends as a continuous belt from the west to the east coast and forms the more rugged interior of the island.

The older rocks, which are grouped together in this report under the term "older complex," consist of an unknown thickness of sedimentary and volcanic rocks of Late Cretaceous to Paleocene or early Eocene age. These rocks have been intruded by ultrabasic to acid magmas in bodies that range in size and shape from small sills and dikes to batholiths. The large area of plutonic rock in the southeastern part of the island is batholithic in size, but that in the central part of the island, around Utuado, is perhaps more suitably termed a large stock. This entire sequence of the older complex rocks is lithologically quite similar to rocks of the same age in the other islands of the Greater Antilles.

The older complex is much deformed by faulting and, to a lesser extent, by folding. Most fold axes are alined to the northwest. The principal exceptions to this are on the peripheries of the larger intrusions, where the strike of the beds tends to conform to the general outline of these bodies, and in the northeast and southwest corners of the island, where the strikes are more nearly east-west (chapter A).

On the north and south side of the island are limestones, marls, and some noncarbonate sediments of late Oligocene to early Miocene age. These overlie the older complex unconformably and dip at a prevailingly moderate inclination away from the axis of the island. These beds are locally folded (particularly on the south coast) and faulted but in general, when compared to the older complex, seem relatively undisturbed (Kaye, 1957).

The outcrop belt of middle Tertiary rocks on the north side of the island has a maximum width of 13 miles, measured across the strike. This belt extends for nearly the entire length of the coast. The corresponding outcrop belt of middle Tertiary rocks on the south coast is smaller, both in width and length.

Besides the older complex basement of the island and the middle Tertiary sedimentary blanket flanking it on the north and south coasts, the only other noteworthy rocks are marine and eolian deposits of Pleistocene age, which are mostly on the north coast and on some of the outlying islands, and alluvial deposits along the coasts and in the structural and erosional basins of the island's interior.

The climate of Puerto Rico is subtropical marine and is largely controlled by the northeast trade winds. Precipitation varies from high on the windward (north) side of the main insular divide to relatively low on the lee (south) side of the divide. The recorded extremes are the high peaks of the Sierra de Luquillo in the northeast corner of the island, which have an average annual precipitation of 196.63 inches at the La Mina station, and at Lajas, in the southwestern corner of the island, with an average annual precipitation of 28.82 inches. The temperature range is small and temperatures below 70° F. or above 90° F. are relatively rare. Seasons are poorly defined, both as to temperature and rainfall. Showers of short duration due to very local atmospheric convections occur during daylight hours throughout the year. Puerto Rico lies within the North Atlantic hurricane track but at the time of writing (1956) has been stricken directly only three times during the present century. However, near misses by hurricanes have been more numerous and these are generally accompanied by severe rains and floods.

The island is crisscrossed with roads. Indeed, from the point of view of both density and quality the road net is probably second to none in a terrain and climate of this type. Most of the island is readily accessible to the geologist by road or trail; there are only a few areas more than moderately difficult of access, and of these the badly dissected karst country northeast of Lares is probably the worst. The great density of population (628.13 per square mile) has necessitated the cultivation of almost all but the very poorest land, and in consequence habitations dot the highest hills.

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ILLUSTRATIONS

[Plates 1-2 are in pocket]

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THE COASTAL GEOLOGY OF PUERTO RICO

GEOLOGY OF THE SAN JUAN METROPOLITAN AREA

By **Clifford A. Kaye**

ABSTRACT

The San Juan area comprises about 80 square miles centered about the city of San Juan and includes the San Juan and the northern half of the Aguas Buenas topographic quadrangles. The area consists of a very gently sloping coastal plain in the northern part and a low to moderate hilly section on the south. The coast is marked mostly by sand beaches, but at the western end of the area eolianite crops out in the sea cliffs of San Juan and the adjoining low hills as well as in the chain of small rocks that rise offshore. Behind the coast occur several enclosed to nearly enclosed lagoons, including the admirably protected harbor of Bahía de San Juan. In the southern part of the coastal plain several hills and steep-sided rocky ridges of Miocene limestone rise abruptly from the featureless plain. To the south the uplands, which are underlain by rocks of Late Cretaceous to late Paleocene or early Eocene age, rise progressively and develop a rugged aspect only at the southern edge of the map area. The only sizeable river is the Río Grande de Loíza, the largest on the island, with almost 225 square miles of watershed. Its known rate of discharge varies from a minimum of 48 cubic feet per second to a maximum of 125,000 cubic feet per second. The river flows on rock and thin alluvial sand and gravel and has a valley over 650 feet deep in the southwestern corner of the area.

The uplands are underlain by a sequence of much-deformed rocks, the older complex, ranging in known age from Late Cretaceous to late Paleocene or early Eocene. It consists of volcanic, tuffaceous, and sedimentary rocks, of both marine and nonmarine facies, and shallow to hypabyssal intrusive rocks. The stratigraphic sequence, from oldest to youngest, is as follows: Hato Puerco tuff—prevailingly massive volcanics with some stratified ash. They show a somewhat higher grade of regional metamorphism than the younger rocks. Guaynabo formation—graywacke, conglomerate, and shale, which are probably nonmarine in origin. Tortugas andesite—augite andesite breccias and flows of local prominence. Frailes formation—a marine accumulation of shale, siltstone, and graywacke, with lenticular limestone in the lower part (La Muda limestone member), massive lapilli tuff in the middle, and well-bedded tuffaceous limestones (Leprocomio limestone member) in the upper part. Monacillo formation—predominantly graywacke and conglomerate, commonly red to purple in color and possibly nonmarine. Trujillo Alto limestone—medium-bedded to massive fossiliferous pure limestone. This formation probably marks the top of the Cretaceous section. Figuera volcanics—hornblende andesite breccia with minor flows. Tuffaceous limestone and derived limestone blocks occur in base. Fajardo formation—thin-bedded ashy siltstone and chert that grades laterally into coarse clastics.

Late Cretaceous marine fossils have been collected from the Frailes formation and the Trujillo Alto limestone. Although diagnostic fossils have not been found above the Trujillo Alto limestone, it is proposed that the Figuera volcanics correlate with the late Paleocene or early Eocene deposits of Loíza, to the east, and Corozal, to the west. It is estimated that the older complex in the San Juan area aggregates 16,000 feet or more in thickness.

Three types of intrusive rock are recognized in the older complex of the San Juan area. Biotite granodiorite porphyry, now albitized, crops out in the southern part of the area and seems to be the top of a large subjacent mass. Augite andesite porphyry occurs in tabular and irregular-shaped masses. This rock shows evidence of a certain amount of wallrock assimilation. Diabase dikes, sills, and pipes also occur fairly widely. From cross-cutting relations all three rock types are thought to be early Tertiary in age and to postdate the entire stratigraphic section.

Although megascopically none of the rocks of the San Juan area are metamorphic in aspect, all of them show secondary mineralogic changes indicative of low-grade regional metamorphism. This is more pronounced in some rocks than in others. Plagioclases, more often than not, have been partly or entirely altered to albite; and chlorite, epidote, clinozoisite, and calcite are common. Very fine grained amphibolites also occur. There is some basis for thinking, however, that the rocks have responded more to the introduction of new constituents and to heat than to pressure. The assimilation of wallrock by andesitic intrusion is indicated in many places by relict wallrock structures, textures, fragments, and the bulbous termination to andesitic dikes without the structural distortion of the surrounding wallrock (such as would result from dilation).

The middle Tertiary is separated from the older complex by an angular unconformity. Two formations, both probably early Miocene in age, are recognized in the San Juan area: the Aguada formation and the Aymamón limestone. The former consists principally of compact sand, silt, marl, and lenticular arenaceous limestone and is approximately 325 feet thick. The latter is medium- to thick-bedded, dense white to pink limestone with some interbedded marl and sand. The outcrops of the Aymamón limestone project through the coastal plain alluvium in steep-sided rocky hills. From surface evidence it is computed that roughly 950 feet of Aymamón limestone underlies San Juan, on the north

coast. Data from seismic work using reflection methods, however, indicate the occurrence of close to 3,000 feet of middle Tertiary sedimentary rocks and suggest a probable thickening of the middle Tertiary section to the north.

Older alluvium, consisting of thoroughly decomposed sands and gravels, blankets part of the upland and higher stream terraces and much of the coastal plain. Light gray and buff reticulations are rather characteristic and seem to be due to leaching by acidic subsurface water along fractures and roots. Littoral deposits of Pleistocene age, consisting of cemented dune sand (eolianite) with some interbedded shallow marine and beach deposits, crop out on Isla San Juan, Santurce, and the offshore islets. The Santurce sand is a medium-grained, well-sorted quartz sand and clayey sand that is particularly thick in Santurce and is widespread on the north coastal area of the island. The sand is probably mostly older alluvium that has been reworked by sheet erosion and then by wind. Much of the quartz was probably originally derived from the middle Tertiary limestones. The white coloration (lack of iron staining) that is rather characteristic of the deposit may again be due to leaching by acidic ground waters. Littoral deposits of Recent age consist of beach sands and associated dunes and sand aprons. The sand is generally medium to coarse grained and is made up of both mineral grains and shell fragments, in variable proportion. Bay mud, or muck, is the soft, highly organic clay that fringes San Juan Bay. It is 25 to 35 feet thick over most of this area. Alluvium of Recent age, consisting of gray to red clays, sands, and gravels occur on the poorly drained meadows flanking the bay and in the beds of the larger streams and rivers.

The rocks of the older complex are much deformed. In the San Juan area they have been folded into several large, fairly symmetrical flexures, which strike east for most of their length, and whose sides dip at moderate angles. High- and low-angle faults abound. A large thrust, which seems to vary along its strike from high to low angle and which dips north, crosses the entire area. Horizontal displacement along this fault is estimated to exceed 3 miles. The larger high-angle faults in the area form a conjugate pattern of two dominant trends: west-northwest and east-northeast. Some of these faults preceded the displacement of the large thrust and also the intrusion of the granodiorite porphyry. Others show later movement and a few were probably active in the late Tertiary or early Quaternary. Several eroded scarps may have been produced by this late movement. The middle Tertiary strata dip north at angles as large as 6°. Steplike structural undulations and possibly folds with very small closure occur. The middle Tertiary is broken by relatively few faults, which are mostly high-angle normal faults of small displacement.

At least the lower part of the older complex of the San Juan area probably represents accumulations on the flanks of a large volcanic cone. The Hato Puerco tuff is thought to have formed part of this cone. Higher stratigraphic units are either alluvial deposits on the flanks of the cone or their marine continuations. Interstratified volcanic rocks may have been derived from smaller local vents. The cone rested on a foundering crust, and so in time it was probably entirely overlapped by marine deposits. No evidence of an abyssal depositional environment for any of the rocks in the area has been recognized. The orogeny that deformed the older complex took place in the late Paleocene or the Eocene (probably the latter). The absence of signs of a dominant direction of tangential stress suggests deformation by sliding into a troughlike downwarp. The dominant northwest alinement of fold axes in the island points to a northwest orientation for this trough. The larger intrusive masses may have formed as a result of fusion of the roots of the downwarp followed by forceful injection of the magma into higher levels with continued foundering. The subsequent uplift of the downwarped rocks may have been chiefly an isostatic response to deeply infolded light crustal material. The coarse-grained alluvium of the basal middle Tertiary deposits show that Puerto Rico was characterized by a rugged topography in late Oligocene time. Downwarping on both the north and south of an east-west axis occurred at this time, and this broad geanticlinal structure has dominated the structural deformation of the island ever since. This east-west structural axis may be genetically related to the essentially east-west alinement of the Puerto Rican trough, the foredeep that lies north of the island. The island was apparently reduced to an old-age erosion surface by late Miocene or early Pliocene time. In late Pliocene or early Pleistocene time it was again re-arched along its east-west axis but mostly by the movement of fault blocks. Two such eroded scarps from this faulting occur in the San Juan area.

The engineering characteristics of the geologic materials of the area are briefly summarized. The older complex rocks are almost everywhere covered by a silty clay regolith of residual and alluvial origin. For most of the formational units, the physical properties of this clayey blanket seem to be much alike. Exceptions to this are the pure limestones, which are covered by clays of fairly high plasticity, and the graywackes of the Guaynabo formation, which yield a sandy regolith. Most of the heavy structures in the San Juan area are built on older alluvium, Santurce sand, the bay mud, and Recent alluvium. The Santurce sand has varied though generally low strength for footings. Construction on bay muds generally requires piles to the underlying older alluvium; undue settlement of roads has been eliminated in one instance by the use of vertical sand drains. The older alluvium is generally quite compact and has moderate bearing strength. Formations most used for crushed rock, building stone, and general fill are the Hato Puerco tuff, Tortugas andesite, the La Munda and Leprocomio limestone members of the Frailes formation, the Trujillo Alto limestone, the ashy siltstone of the Fajardo formation, and the Aymamón limestone. The Recent alluvium of the Río Grande de Loíza is the largest source of gravel for concrete aggregate. The site of the dam across this river is briefly described. The rock is a very fine grained amphibolite, a metavolcanic component of the Hato Puerco(?) tuff, hornblende diorite, and aplite. The rock was sound, massive, and unusually fresh close to the surface, so that very little stripping was required. The dam had a minimum of foundation problems.

INTRODUCTION

The geologist working in the older deformed rocks of Puerto Rico sooner or later comes to realize that the structural and stratigraphic complexities are too great to permit a satisfactory synthesis of the island's geologic history on the basis of reconnaissance, or small-scale, mapping. Stratigraphic ambiguities in particular seem at first an insurmountable barrier to a proper understanding of past events; in consequence, the need for detailed large-scale mapping becomes strongly manifest. It was with the purpose therefore of making such a map that the area about the capital city of San Juan was studied at irregular intervals during the period 1949–51.

The San Juan area is particularly well chosen for such a study. Although the area is small, it encompasses nearly the full range of geology known on Puerto Rico; and, owing mostly to man's engineering activities, it provides an exceptional wealth of rock exposures for a region generally characterized by thick soils and few outcrops. The many road cuts, quarries, and excavations for buildings and small houses provide the geologist with advantages not found in such profusion elsewhere in Puerto Rico.

Field mapping was done on the published topographic map (scale 1:10,000) and on aerial photographs (scale about 1:18,000). Geologic mapping was completed for the San Juan 7°30′ quadrangle, which includes all the San Juan metropolitan area, and the northwest and a part of the northeast quarters of the Aguas Buenas 7°30′ quadrangle, which adjoins on the south. The San Juan quadrangle and the northern half of Aguas Buenas quadrangle have been combined and printed as one sheet (scale 1:30,000) in this report for presentation of the geologic map (pl. 2).

LOCATION AND GEOGRAPHIC SETTING

The San Juan area includes the capital city of San Juan and its environs and encompasses a land area of about 80 square miles. The city of San Juan is located on the eastern part of the north coast of Puerto Rico, and the mapped area (pl. 2) is bounded by the geographic coordinates: latitude 18°18′45″ N. to latitude 18°30′ N.; longitude 66°00′ W. to longitude 66° 7′30″ W.

The northern part of the area is a very gently sloping coastal plain indented by several large lagoons and the semienclosed embayment of Bahía de San Juan. South of Río Piedras the land is hilly, becoming progressively more so as one penetrates deeper into the island interior.

The entire area is densely populated in both the urban and the rural sections, attaining a maximum concentration on the coastal plain in the city of San Juan (a political unification of now coalesced but formerly separate communities of San Juan, Santurce, Hato Rey, and Río Piedras). Surrounding the city itself are numerous suburbs, settlements, roadside communities, and hamlets that are all economic appendages to the city.

At the time the study was made, a building boom, unprecedented for the island, was spreading the edges of the urban area at a rapid rate, and in consequence the culture shown on the topographic base map of plate 2 is obsolete. The city has grown from its original site on the narrow island on the north side of the bay to encompass not only much of the better drained alluvial ground of the coastal plain but also to infringe on the extensive salt marshes surrounding the bay and the adjoining lagoons.

Where slopes are not too steep the rural areas are mainly given over to sugarcane cultivation. Steep slopes are used mostly for tobacco, small root crops, fruits, and minor coffee cultivation. Most of the original forest cover has been stripped, and such trees as one sees are generally flowering ornamental trees, the many tropical fruit-bearing species, and the shade trees of coffee plantations. The poorly drained alluvial land of the coastal plain is used almost exclusively for dairying.

PREVIOUS WORK

The area covered by this study lies within areas designated as the San Juan and the Fajardo districts in the "Scientific Survey of Porto Rico and the Virgin Islands," by the New York Academy of Science, a scientific survey of broad scope initiated in the early part of the twentieth century (fig. 2). Maps of both these districts were published in separate geologic reports (Semmes, 1919; Meyerhoff and Smith, 1931) of this early survey. The geologic map (scale 1:62,500) accompanying Semmes' report on the San Juan district includes a strip along the west margin of the present study, and Meyerhoff and Smith's map (scale 1 inch to 1 mile) includes the entire area of the present study.

A. K. Lobeck (1922) included the San Juan area in his study of the physiography of Puerto Rico, as did C. P. Berkey (1915) in his reconnaissance of Puerto Rican geology. Several of the formational names used by Meyerhoff and Smith and in this report were first proposed by Berkey.

It would be well at the outset to recall some of the conditions under which these earlier geologic studies were made in order to explain the basis for certain differences between the maps of Semmes (1919) and Meyerhoff and Smith (1931) and that

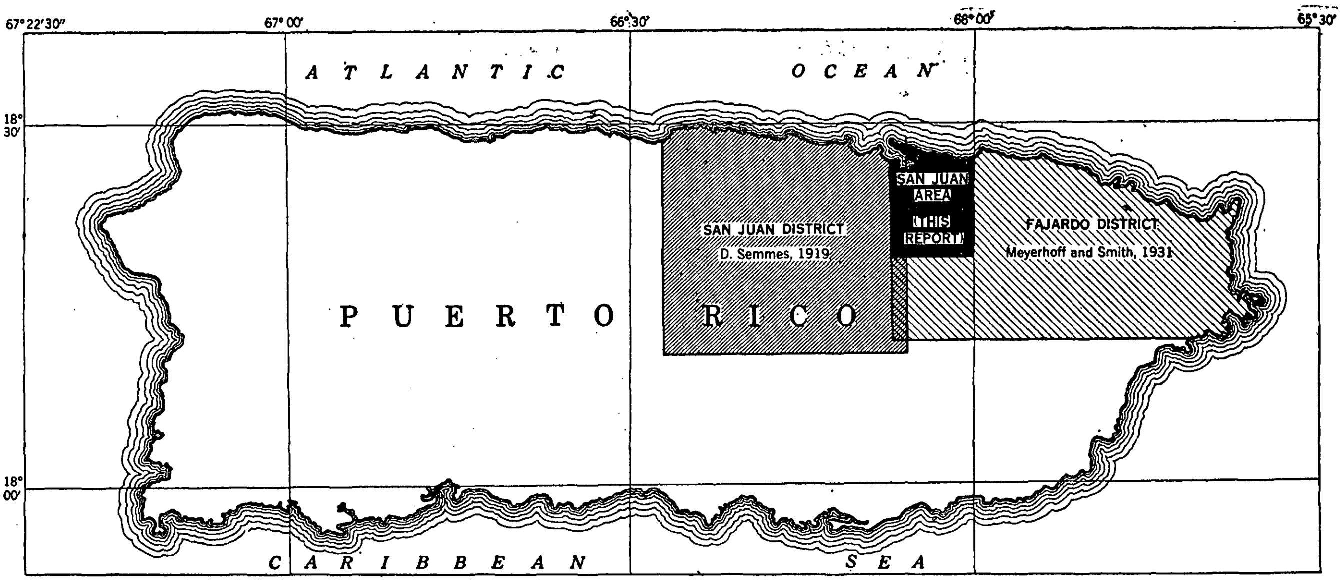

FIGURE 2.—Index map of Puerto Rico, showing the San Juan area of this report, and the San Juan and Fajardo districts of earlier authors.

which accompanies this report (pl. 2). The areas involved in both the San Juan and Fajardo districts of the New York Academy of Science reports were large, about 500 square miles each. The field work for both reports was of a reconnaissance nature and was done during the course of one or two summer seasons. The several authors were obliged to make their own base maps in addition to doing the geology of these broad tracts. Roads were fewer than they were in 1951 and many man-made exposures provided by the modern road net were not yet in existence. In the light of these handicaps, the quality of both reports is outstanding and differences between the earlier and the present map become understandable.

PHYSICAL FEATURES

The San Juan area lies on the north of Puerto Rico and includes parts of the low-lying coastal plain on the north and of the hilly uplands of the Puerto Rican interior on the south. Several topographic features, including the coastal plain and the uplands, merit separate descriptions. The shore is mostly low lying, with sandy beaches and, here and there, small rocky headlands. Off the coast there are small rocks and rock reefs, which are for the most part cemented sand dunes now partly or entirely inundated. Other cemented dunes form the hill of Santurce and the narrow island of the old city of San Juan. Behind the coastal strip with its belt of cemented dunes are two large lagoons, fringed by tracts of mangrove swamp; one of the lagoons, Bahía de San Juan, has a broad, deep-water mouth. Rising gently southward from the lagoons is a coastal plain made up of alluvial sediments, through which, at several places, project ridges and bosses of Miocene rock. The coastal plain terminates to the south against hills of the uplands, which tend to increase in altitude southward as one approches the interior of the island. The largest river in the area is the Río Grande de Loíza, which empties into the Atlantic Ocean east of the San Juan area.

OFFSHORE ROCKS

At several places off the north coast there are small rocky islets, notably: Isla Verde, off Punta el Medio; Isla Piedra, about a mile off Punta Las Marías; and three groups, including the large Peñon de San Jorge off the island of San Juan. The latter rocks exhibit very well the east-west alinement that is common to these features along much of the north coast of Puerto Rico. The rocks are small, generally considerably less than an acre in area, and consist of eolianite (cemented dune sand). Except for Isla Verde, which supports a lone coconut palm growing from a thin sandy cover, the islets are without soil. The rocks—again except for Isla Verde, which apparently is a fragment of a former shore isolated by beach erosion—are the tops of sand dunes, now cemented into a friable sandstone and partly inundated by the sea (see chapter B, "Shoreline Features and Quarternary Shoreline Changes"). They vary in form, some possessing a humped profile, relict of the original dune shape, whereas others, which have been reduced by pitting and wave erosion, are simply flat platforms at hightide level. These offshore rocks receive the full force of the Atlantic waves and even the highest of them, the Peñon de San Jorge, is more often than not completely bathed with spray.

REEF

A narrow belt of shoal water and reef extends westward, from the east edge of the map, through the offshore rocks. Although in places the reef is marked by growths of true reef organisms, the feature is interpreted as being primarily a line of submerged cemented sand dunes. The shallow bench formed by these submerged sand dunes form both a rocky barrier (a rock reef) and a platform on which reef corals are able to thrive.

SHORELINE

Except for the island of the old city of San Juan, the shoreline is low. Broad sandy beaches extend nearly the entire length of the shore east of Punta Piedrita. The beaches, with the exception of the lunate beach between Punta Las Marías and Punta El Medio, are characterized by an intermittent pavement of cemented beach sand, or beach rock, at intertidal levels. Behind most of the beaches are low sand ridges that generally rise no higher than 10 feet above sea level. Low ridges of eolianite crop out at several places on the shoreline between Punta Piedrita and the mouth of the Laguna del Condado.

Although the coast is ordinarily somewhat protected by the reef, large waves are able to carry much of their energy to the shore, and in recent decades beach erosion has been particularly severe between Punta Las Marías and Punta El Medio (U. S. Beach Erosion Board, 1948). Moreover, the width of the sand beaches is delicately adjusted to the size and character of the surf. During intervals of large waves, beaches not infrequently recede 100 or more feet in a few days, only to advance the same distance during the ensuing intervals of normal surf.

ISLA SAN JUAN

The old city of San Juan (or Puerto Rico, as it was first called) was established in 1521 on the elongated island forming the north side of Bahía de San Juan. The island is tied to the mainland by two short bridges and a causeway, in consequence of which some of its insular characteristics have been lost and local residents are inclined to think of it as a peninsula. The island extends to the west edge of the San Juan quadrangle. West of this is the narrow harbor mouth that connects the bay with the ocean.

Except at its eastern end, the ocean side of the island is a steep cliff that ranges from 30 feet to about 100 feet in height. From about the midpoint of the island, or at the old fortress of San Cristóbal, and continuing westward to the El Morro fortification at the harbor mouth, the cliff is cut mainly in eolianite and is encumbered by houses and colonial fortifications down to the water's edge. East of the San Cristóbal battlements, the cliff face is mostly very friable eolianite and uncemented sand, and the slope is not marred by manmade structures.

The highest point on the island lies in the western part and is shown on the topographic map as enclosed by the 35-meter contour line. The ridge drops off steeply to the south and is partly terminated by a high retaining wall built during colonial times.

The narrow port and warehousing area along the southern edge of the island is mostly reclaimed marshland.

SANTURCE

Physiographically, the broad low hill on which much of Santurce is built is a continuation of the eolianite ridge that forms Isla San Juan. In Santurce the ridge is about 2½ miles long and about three-fourths mile wide and trends west-northwest. The highest point is encircled by the 35-meter contour line. In places near the crest hard eolianite crops out, although for the most part the ridge is blanketed by loose sand and clayey sand. Because the entire area is heavily built up, the topographic form is somewhat obscured and altered by construction.

BAHÍA DE SAN JUAN AND LAGOONS

In the San Juan quadrangle a nearly continuous belt of salt marshes and lagoons separates the narrow coastal plain and the shoreline proper. The Laguna San José and its appendage, Laguna Los Corozos, have no direct outlet to the ocean; both are blocked at their seaward end by low beach ridges. They connect, however, with Bahía de San Juan (or, as it is called in this report, simply the bay) by means of the narrow overflow channel of Martín Peña. Circulation of water in the Laguna San José is sluggish, and there is little discharge when the water level of the bay is high for an extended period. The stagnation resulting from this impeded circulation has resulted in a considerable nuisance to the adjoining parts of the city, which are periodically bothered by strong miasmas.

The bay is fringed by a mangrove swamp, which is being rapidly reclaimed as the industrial hinterland of the city spreads. The low-lying peninsula on the northeast side of the bay, which is occupied by the U. S. Naval Reservation and the Isla Grande International Airport, is mostly made-land and reclaimed marshland.

The bay itself has a central dredged channel leading to the harbor mouth west of San Juan, which, according to U. S. Coast and Geodetic Survey Chart 908 (San Juan Harbor), attains a maximum depth of 38 feet. Most of the bay, however, is less than 16 feet deep.

COASTAL PLAIN

This is a plain that slopes very gently from the lagoons to the hilly upland. Its southern limit is approximately an east-west line passing through the town of Río Piedras. The plain has been built up by the accumulation of alluvial and colluvial sediments derived from the uplands to the south; it is, in fact, a series of coalesced alluvial fans which is slightly dissected by small streams and broken at several places by isolated low hills of lower Miocene rock.

PROMINENT HILLS IN COASTAL PLAIN AND MANGROVE SWAMPS

Several very prominent hills rise abruptly from the featureless coastal plain and from the mangrove swamps at the west edge of the Laguna San José. The largest of these hills, the Montes de Caneja, in the western part of the San Juan quadrangle, extends as an east-west ridge for 1½ miles and rises with steep rocky flanks out of the flat alluvial coastal plain to a maximum altitude of 330 feet. Less than half a mile to the east is a similar east-west ridge, the Montes de San Patricio, that rises to an altitude of 270 feet. Several smaller knobs crop out on the west shore of the Laguna San José, although at the time the present study was being made these were being rapidly destroyed by quarrying. These conspicuous hills are composed chiefly of thick-bedded, light-colored limestones, with lesser quantities of marl and sand, all of early Miocene age. The peculiar steep-sided shape assumed by these hills is typical of the karst topography that characterizes the outcrop of these rocks along much of the Puerto Rican north coast.

In contrast to the haystack hills formed by the dense limestone, the rather rounded, soil-covered low hills between Suchville and the Montes de Caneja, as well as the five small conical hills between the Montes de San Patricio and the east edge of the quadrangle, consist principally of sand, clay, and marl that stratigraphically underlie the dense limestone.

UPLANDS

All the area south of the coastal plain is included under this heading, although some of the land is of low altitude and there is considerable diversity of topography. The essential factor of the uplands is that the topography has been eroded in the deformed rocks of the older complex (see under "General geology"), which crop out in the hilly to mountainous interior of the island. The upland topography, in a general way, increases in relief and ruggedness to the south toward the insular divide. This tendency is expressed in the small area of upland encompassed in the San Juan area, where the topography exhibits many of the land forms and the steplike discordances that are characteristic of the island's topography as a whole.

East of Río Piedras the upland rises conspicuously from the coastal plain with the Montes de Hatillo. This mile-wide ridge, which extends to the west for over 5 miles ending abruptly at Río Piedras, is a cuesta composed chiefly of well-bedded ashy and siliceous rocks. A similarly constituted but northeast-trending cuesta is found along the western margin of the mapped area. Between these two ridges an expanse of low-lying, gently dissected "upland" forms a transition between the coastal plain on the north and the more hilly land to the south.

To the east the general surface rises gradually from this low area, and hills and ridges formed of more durable rock rise here and there above the general level. To the south, however, the hills start rather abruptly with the well-defined scarp of the Guaynabo fault (pl. 3*A*, 7*A*). This is the northernmost of several northwest-trending fault scarps which raise the general upland level in progressive steps southward. The Guaynabo fault scarp, though much dissected, presents a conspicuous front some 225 feet to 320 feet high. The highest points on this fault block lie at altitudes of about 590 feet. The Guaynabo fault block is separated by the northwest-trending valley of the Río Guaynabo from the next scarp to the south, which raises the general level by another 320 feet to altitudes of about 915 feet. This scarp is much dissected, and it is in this block that the rugged terrain typical of much of the interior of Puerto Rico is encountered. The slopes and stream gradients are steep, and the thickness of soil cover is variable. In many places extensive rock outcrops occur only in stream beds (pl. 9*A*), though outcrops are also scattered here and there on slopes and divides.

The topography of the upland is partly adjusted to the varied erodibility of the many rocks that make up the older complex. Outcrops of the granodiorite porphyry and the Trujillo Alto limestone particularly show a tendency to be marked by valleys or areas of low, subdued relief. Fault lines and zones of dense jointing have also been etched out by selective stream erosion, and the prevailing northwest alinement of stream valleys in the southern part of the mapped area is attributed to this type of control.

VALLEY OF THE RÍO GRANDE DE LOÍZA

The Río Grande de Loíza, rising south of the San Juan area at the island divide, is the largest river of Puerto Rico. Its watershed, of about 225 square miles, receives an average annual rainfall of about 76 inches. The river flows north along the eastern edge of the mapped area and leaves the Aguas Buenas quadrangle at Trujillo Alto, where it makes a sharp bend toward the east.

The valley sides are 650 feet and more high at the southern end of the mapped area and decrease rapidly in height downstream. The river is flanked by a narrow, slightly terraced, gravelly flood plain that widens considerably where the river course bends sharply eastward at the town of Trujillo Alto. This alluvium provides the principal source of construction gravel in the area.

The minimum recorded flow of the river, as compiled in studies for the new Loíza dam (p. 44), is 48 cubic feet per second. The maximum recorded flow is estimated at 125,000 cubic feet per second. This was attained for half an hour during the near-hurricane storm of August 4, 1945. The average flow of the river is probably somewhat more than 500 cubic feet per second (Fox, 1951, p. 33). Foundation excavation for the Loíza dam of the Puerto Rico Aqueduct and Sewer Authority, located 1¾ miles south of Trujillo Alto, showed that in this stretch the river flows on both a rocky bed and a thin deposit of sand and gravel that undoubtedly is moved as bed load during periods of higher river stage and greater flow velocity.

GENERAL GEOLOGY

The San Juan area of this report, though small, contains rocks representative of nearly the full range of geologic ages known on Puerto Rico. The rocks are of Late Cretaceous(?), Late Cretaceous, Paleocene or early Eocene, early Miocene, possibly Pliocene, Pleistocene, and Recent ages, as shown in the stratigraphic summary given below.

Stratigraphic summary of the San Juan area, Puerto Rico

General designation	Stratigraphic unit	Brief description	Approx. thickness (feet)	Age
	Made-ground and fill.			Recent
	Beachrock pavement	Carbonate-cemented beach sand. Some iron-oxide cementation		
	Recent littoral deposits	Beach sand and associated sand aprons; foredunes		
	Floodplain alluvium	Mostly silt and clay		
	Bay mud	Soft black mucky silt and clay		
	Pleistocene littoral deposits	Reef rock, eolianite, and paleosols		Pleistocene
	Santurce sand	Quartz sand and white clayey sand		Pleistocene and Pliocene (?)
	Older alluvium	Red silty to sandy clay		
	Unconformity			
Middle Tertiary sequence.	Aymamón limestone	Thick-bedded, light-colored, dense limestone	950+	early Miocene
	Aguada formation	Friable sandstone, clay, and concretionary limestone	325	
	Unconformity			
	Intrusive igneous rocks	Diabase, granodiorite porphyry, and augite andesite porphyry		early Eocene (?) or late Paleocene (?).
	Fajardo formation	Light-colored ashy siltstone, siliceous siltstone and chert, interfingering graywaycke, conglomerate, and impure limestone	3,000+	
	Figuera volcanics	Hornblende andesite breccia, minor flow, limestone member at base	>3,000	
	Local unconformity			
Older complex	Trujillo Alto limestone	Fossiliferous medium-bedded to massive limestone	900−	Late Cretaceous
	Monacillo formation	Graywacke and conglomerate; commonly red or purple	900	
	Frailes formation (Leprocomio limestone member and La Muda limestone member).	Massive lapilli tuff with some stratified shale, siltstone, and graywacke. Leprocomio limestone member at top and La Muda limestone member near base.	2,350	
	Tortugas andesite	Augite andesite breccia and flows	1,300	
	Guaynabo formation	Graywacke, conglomerate, and shale	4,500	Late Cretaceous (?)
	Hato Puerco tuff	Massive volcanics and metavolcanics and some stratified ash	(?)	

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The older rocks, that is to say, those of Cretaceous and early Tertiary age, are highly deformed and faulted. They comprise a sequence of volcanic flows, pyroclastics, and sedimentary rocks, but many of the last consist largely of reworked volcanic material. Into these rocks have been intruded plugs, dikes, sills, and larger subjacent bodies that range in composition from granodiorite porphyry to diabase.

Unconformably overlying the Upper Cretaceous and lower Tertiary complex in the San Juan area is a sequence of sands, clays, marls, and limestones of early Miocene age, which have been tilted to the north and faulted on a small scale but which are otherwise undeformed. These rocks probably underlie most of the coastal plain alluvium.

Many of the events following the deposition of the early Miocene sediments are difficult to reconstruct, but certainly both deposition and erosion occurred, brought about by fault-block movement and crustal warping as well as by eustatic changes of sea level. Some of the sediments of the coastal plain and the old alluvial blanket of parts of the uplands were undoubtedly genetically associated with late Tertiary tectonic movements. The rocks of San Juan island and the Santurce hills probably owe their origin in part to higher sea levels, whereas lower sea levels probably account for the deep erosion and alluvium shown by borings about the bay, and for the ancient sand dunes now preserved as offshore rocks (see chap. B).

OLDER COMPLEX

The much deformed rocks that crop out widely in the hilly and mountainous parts of Puerto Rico constitute the most interesting and challenging geological element in Puerto Rico. These are the oldest rocks in the island and record the longest and most varied history of crustal disturbances. Their story, if it could be told with certainty, would explain much of the geologic history of this segment of the Antilles.

The works of the several authors of the New York Academy of Science's "Scientific Survey of Porto Rico and the Virgin Islands" (Berkey, 1915; Fettke, 1924; Hodge, 1920; Hubbard, 1923; Mitchell, 1922; Semmes, 1919; Meyerhoff and Smith, 1931) treat the older rocks at some length and from somewhat diverse points of view; and the geologic maps of these reports (later compiled into a single geologic map of Puerto Rico by Meyerhoff, 1933) convey a general picture of their natural classification, distribution, and structural trends.

C. P. Berkey (1915) first referred to this complex of rocks as the "Older Series," and Fettke (1924), Meyerhoff and Smith (1931), and Semmes (1919) continued this usage, finding it a convenient term to distinguish these rocks from the clearly younger and relatively undisturbed rocks of middle Tertiary age, which they referred to as the "Younger Series." Hubbard (1923), on the other hand, preferred the terms "Cretaceous formations" and "Tertiary formations" to distinguish the two rock sequences, while Hodge (1920) and Mitchell (1922) used no group terms to separate the two sequences. It is, however, both convenient and desirable to distinguish between the two groups of rocks. Unfortunately Berkey's term, "Older Series," cannot be used because of the special connotation the word "series" has in stratigraphic nomenclature, while Hubbard's simple Cretaceous and Tertiary classification no longer pertains, now that the early Tertiary is known to be included in his Cretaceous (Kaye, 1956). The term "older complex" is therefore used in this paper as a substitute for Berkey's "Older Series."

The nomenclature adopted for this report differs considerably from that used by earlier writers on the area. The geologic map of Semmes (1919) includes a strip 2 miles wide within the western border of the area mapped in this study. In this area Semmes shows the older complex as several northeast-trending belts which he classifies according to lithologic types but to which he does not assign formational names. Meyerhoff and Smith's (1931) map of the Fajardo district includes the entire area of the present study and overlaps the narrow strip of Semmes' map. Both Meyerhoff and Smith's and Semmes' maps are essentially in accord in the overlapped strip. Meyerhoff and Smith gave their map units formational names (fig. 3), including several that were first proposed by Berkey (1915).

A comparison of plate 2 and the Meyerhoff and Smith geologic map of the Fajardo district reveal several profound differences in structure and the distribution of lithologic types. These divergencies are of such weight that many of Meyerhoff and Smith's formational units could not be identified or applied in the field. The fact that the terrain is badly fragmented by faults prevented the writer from constructing a stratigraphic classification of his own until the rather complete and apparently undis-

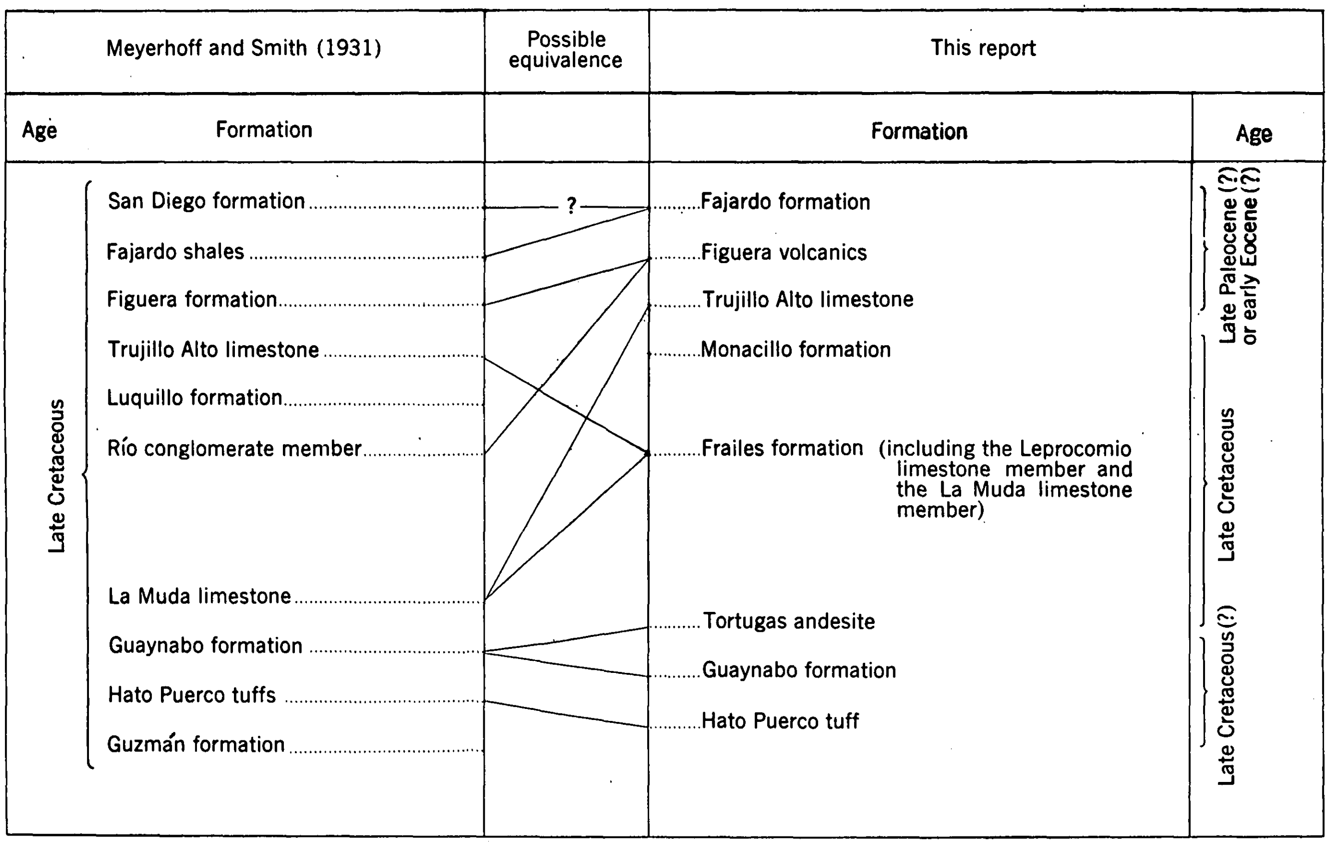


FIGURE 3.—Stratigraphic nomenclature of the older complex in the San Juan area.

turbed section in the eastern part of the area was studied. It is realized, however, that the formations finally adopted for use in this report, although considered valid for the San Juan area, may not apply in other sections of Puerto Rico.

The key to the stratigraphy of the older complex in the mapped area is considered to be the section exposed southeast of Río Piedras, in the Montes de Hatillo. Fortunately, this section is traversed by a road, the sides of which permit a fair picture to be had of the sequence of rock types. This road is Highway 181, which connects the town of Trujillo Alto and the eastern suburbs of Río Piedras, and Highway 175, which intersects Highway 181 on the north bank of the Río Grande de Loíza and follows the left bank of the river for several miles. Highway 181 crosses the cuesta of the Montes de Hatillo, and successively older rocks are exposed from north to south. In comparison with the terrain to the southwest, remarkably little faulting occurs along this traverse and the stratigraphic sequence is considered to be more or less intact.

The formational breakdown was made on the basis of (1) changes from continental to marine deposition or (2) marked lithologic breaks. The great variability in thickness and the similarities in lithologic types within the several formational units, however, often made their recognition in the field a matter of some uncertainty. The persistence of a rather monotonous suite of pyroclastic facies throughout the section and the difficulty of interpreting the nature of deeply weathered rocks proved particularly troublesome in mapping.

Before describing the individual map units a brief summary of the probable depositional history of the older complex in the San Juan area may be helpful in understanding the characteristics of the several formations and their stratigraphic relations. These rocks are thought (see p. 40 for discussion) to constitute an interfingering sequence of marine and nonmarine deposits such as would occur at the edge of a volcanic island that is undergoing subsidence. Such an island probably marked eastern Puerto Rico in Late Cretaceous time (see Meyerhoff, 1933, p. 43-53). It consisted of a central core made up entirely of pyroclastic and flow rocks that were extruded during an early period of cone construction. Its broad flanks in places were covered with alluvial deposits and in others were dissected by erosion (fig. 4). Lapping onto the lower flanks of the cone were estuarine and marine sediments. Subsidence of the insular volcano, either steadily or sporadically, brought overlap of marine deposits onto the eroded and alluviated flanks of the cone, and for part of its history the entire cone may have foundered beneath the sea. Periodic eruptions furnished ash to the surrounding seas and built out the island's shores with new ejecta. Because of such a sequence of events an alternation of continental and marine deposits was produced. Moreover, occasional eruptions from submarine vents low on the flanks of the cone disrupted or shattered the blanket of marine sediments that had been quietly forming on the shallow sea floor, while farther away from the island, in deeper water, marine deposition may have continued uninterrupted during this long history of periodic eruption and quiescence that so effectively left their varied marks on the flanks of the cone.

Such a geological picture seems to explain best the older complex rocks in the San Juan area. The great thickness of volcanic rocks in the region about Caguas, well to the south of the San Juan area, may represent accumulation from a major vent and therefore the central part of the main cone. The rocks of the San Juan area give evidence of having been deposited approximately on the critical zone of marine and insular interfingering that possibly marked the oscillating edge of the "Caguas volcanic island". The thickening and thinning of the older complex deposits in the San Juan area and their rapid changes of facies can readily be explained by the presence of pronounced local erosional disconformities within the section and the instability of the depositional environment. The recurrence of lithologically similar rock types within the section is therefore possibly the expression of the recurrence of certain events and environments during the long history of the volcano and, more precisely, of

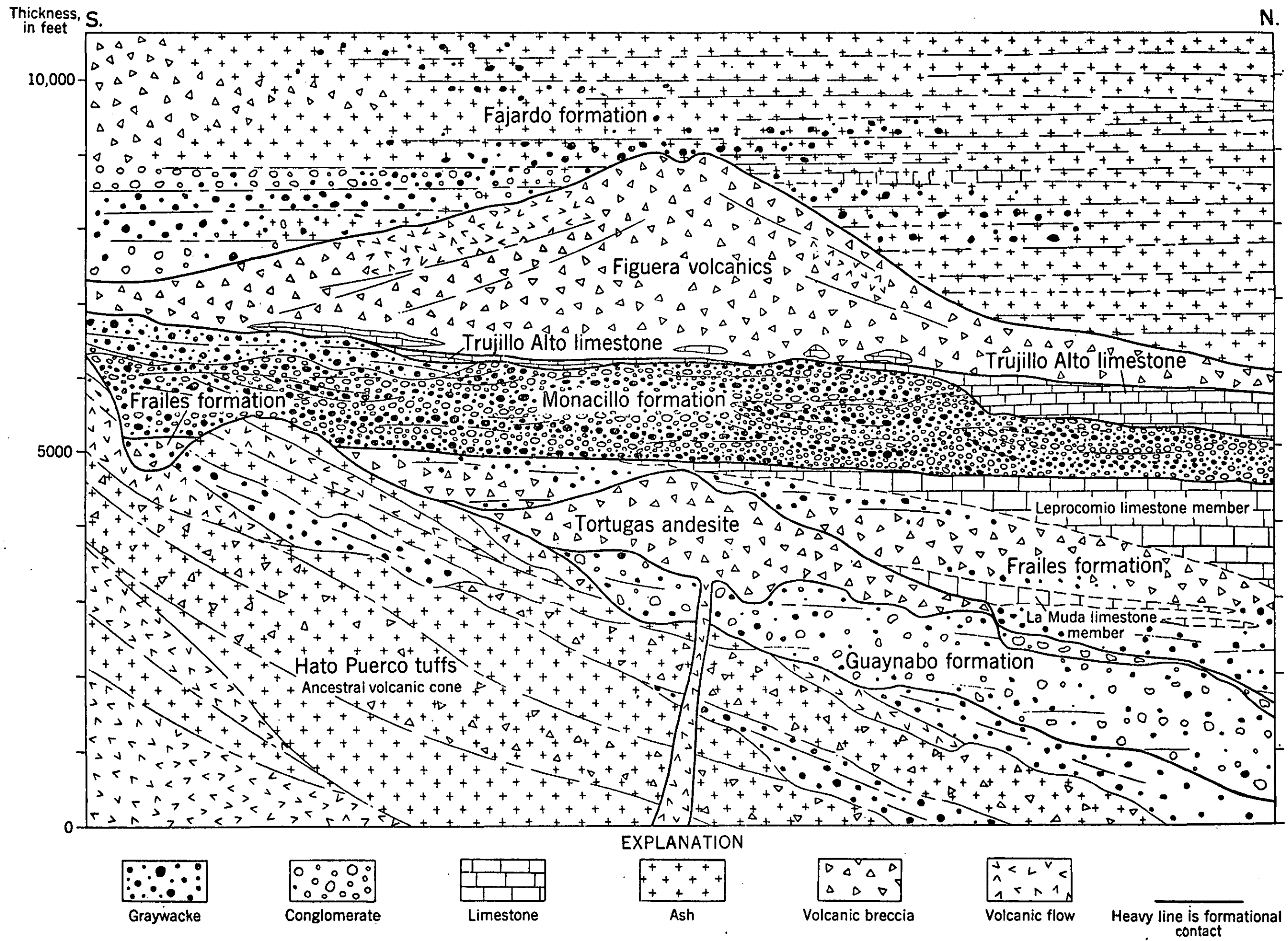


FIGURE 4.—Schematic reconstruction of depositional relations of the older complex in the San Juan area.

the periods of eruption and quiescence that characterize the later history of many volcanos.

HATO PUERCO TUFF

This formation was named by Meyerhoff and Smith (1931), who described it as a thick sequence of predominantly unstratified tuff and minor volcanic flows that lie between the Guzman formation and the Guaynabo formation in the western part of the Fajardo district. Although the Guzman formation does not crop out in the San Juan area and the Guaynabo formation is redefined in the present study, the identity of the Hato Puerco tuff was readily established in the area mapped.

The Hato Puerco tuff consists characteristically of massive pyroclastic rocks with some thick sections of flow rock. There are in addition some well-bedded to obscurely bedded tuffs. The whole section encompasses a very wide variety of rocks, although the general criteria for recognition are massiveness, a greater than usual density and toughness where not too greatly altered by weathering, a prevailing deep-green to dark-blue color, and a degree of regional metamorphism that is somewhat greater than that which characterizes most of the later rocks. The glasses seemed to have been entirely devitrified, the feldspars are invariably very much albitized or saussuritized, and the mineral components in general show various effects of low-grade regional metamorphism. The criterion of metamorphism in itself cannot be universally applied, for alteration similar to that of the Hato Puerco rocks can be found here and there throughout the section of the older complex.

The variability of the Hato Puerco tuff can be shown by a review of some of the types found in the San Juan area. Very dense, hard, dark blue-gray aphanitic to finely porphyritic rocks, which break into sharp angular fragments, occur in several places, perhaps most widely on the north side of the ridge that follows Highway 1 southeast of La Muda. Under the microscope this rock is seen to be a much altered tuff made up of both crystal and lithic fragments. It consists predominantly of angular broken crystals of chloritized andesine-laboradorite, scattered biotite and pyroxene, some nests and isolated grains of quartz, and a few subangular fragments of a much altered trachitic-textured rock. The interstitial material is a very fine aggregate of feldspar, quartz, and probably devitrified glass. Both the groundmass and the coarser fraction are much altered to chlorite. Clusters and randomly oriented needles of green clinoamphibole ($Z \vee c\ 21°$) are common in both the coarse fraction and the matrix.

An interesting altered tuff crops out southeast of La Muda (197,900 m, 54,430 m). This rock, a thin section of which was studied by Robert L. Smith of the U. S. Geological Survey, is a metamorphosed pumiceous tuff that was originally composed of small fragments of pumice, fragments of plagioclase crystals and scarce grains of pyroxene. According to Smith "the glass has been completely replaced by alkalic feldspar without loss of original pumiceous texture. The alkalic feldspar, as nearly as can be determined by optical and X-ray methods, is albite. The vesicles in the replaced glass are filled with chlorite. Chlorite also occurs, interstitial to the component fragments. The ubiquity of the chlorite together with the scarcity of relict ferromagnesian minerals or 'ghosts' of these minerals suggests that the original glass was rather basic in composition, and during its replacement by albite the ferromagnesian constituents went into chlorite. There are numerous tiny spherulitic grains of epidote scattered throughout the areas of chlorite. The plagioclase feldspar is partly altered to sericite mica and carbonate."

Stratified rocks of the Hato Puerco tuff are of a variety of types and in general seem to be relatively thin and nonpersistent. Laminated to thinly bedded light- and dark-gray tuff consisting of fine crystalline material, ranging in grain size from that of fine sand to silt (this textural classification is convenient for field description based on touch and hand-lens inspection), crop out widely in the southern part of the mapped area. Obscurely bedded ash that was weathered to a soft yellowish silty material wherever seen is another common type.

Coarse-grained volcanic breccias are common in the Hato Puerco tuff. Again, these rocks are dark green to blue gray, dense and tough. Matrix as well as fragments are equally indurated, and the rocks break across the constituent grain. Thin sections reveal that the more common lithic particles are subangular to subrounded fragments of dark-colored vitrophyres, now devitrified and variously altered to hematite. In addition there are fragments of very fine grained trachitic rocks and palagonite tuffs. The interstitial material contains broken albite crystals, quartz, and matter too finely comminuted to be identified under the petrographic microscope. Secondary zoisite and chlorite are common. Rocks of this type are found in several of the quarries along the valley of the Río Grande de Loíza south of Trujillo Alto.

Within the Hato Puerco tuff, thick sections of flow rock are not uncommon. The thickest development of these in the vicinity of San Juan occur along the valley of the Río Bayamón on the Naranjito quadrangle, just to the west of the southwestern part of the San Juan area. Here, several large quarries expose spilitic pillow lavas. In texture these rocks range from aphanitic to finely porphyritic amygdaloids, typically of a medium greenish-gray color (5*G* 5/1). A thin section of the porphyritic rock shows about 40 percent phenocrysts of zoned albite up to 3 mm in length and small stubby augite crystals. The groundmass consists of a felt of fine albite laths. Some glass may originally have been present in the groundmass, but it is now obscured by secondary chlorite and actinolite, which has replaced much of both the groundmass and the albite phenocrysts. Much ore dust is present throughout, as well as minute epidote clusters. The numerous vesicles in the thin sections studied are filled with chlorite, in radial arrangement, and prehnite.

Other metavolcanics of the Hato Puerco tuff are not too dissimilar in appearance and gross physical properties to these spilites. The tough, fine-grained dark-blue meta-andesites that crop out along the Río Grande de Loíza, about 1½ miles south of Trujillo Alto, are not, however, spilitic in composition. Here the phenocrysts are andesine, though the degree of alteration is so intense that the nature of the original groundmass is difficult to determine. The development of fine actinolite in this rock is particularly prominent. Samples of other dense, fine-grained dark bluish- to greenish-gray rocks of the Hato Puerco tuff show the same extensive development of green clinoamphibole ($Z \vee c$ $15° - 23°$) of metamorphic origin.

In the San Juan area the Hato Puerco tuff occurs in the south and southeast, in the area of more hilly topography. The formation appears to crop out widely to the south and east of the mapped area, and in it may probably be included many of the massive rocks that make up much of the central interior of the eastern part of Puerto Rico.

No estimate is made of the thickness of the Hato Puerco tuff exposed in the San Juan area, owing to the prevailing massiveness of the formation. Such attitudes as can be determined in the stratified members are considered unreliable structural guides, particularly in the absence of information on faults and of their displacement.

The Hato Puerco tuff probably formed the main mass of the volcanic cone or cone complex ("Caguas island") which has been discussed above. The position and approximate size of this volcanic island is suggested in a diagrammatic reconstruction by Meyerhoff (1933, p. 50). The volcanic cone origin of the Hato Puerco tuff probably accounts for both the unconformable and the conformable relations with the overlying formation (Meyerhoff and Smith, 1931, p. 272) and also for the fact that it is overlapped by rocks higher in the sequence. On the lowermost and, presumably, the flattest slopes, the thick sections of alluvium which make up most of the overlying Guaynabo formation may well have ben conformable with the thick ash deposits. Alluvial and marine sediments deposited against the eroded slopes, on the other hand, would for the most part be strongly unconformable with the stratification of the composite cone (fig. 4).

Age.—No fossils have been found in the Hato Puerco tuff. The entire older complex of Puerto Rico was thought to fall within the Upper Cretaceous by Meyerhoff and Smith (1931). More recent work has revealed, however, that Paleocene or early Eocene faunas, as well as Late Cretaceous faunas, occur in the older complex (Kaye, 1956). The rational basis for confining all older complex rocks to the Upper Cretaceous is therefore destroyed in one time direction, which raises some question as to the necessity of assigning a Late Cretaceous age to the oldest rocks in the section, particularly since they are unfossiliferous. At the present time, for want of any evidence to the contrary, the Hato Puerco tuff is designated Late Cretaceous(?) in age. It is possible, however, that they are Lower Cretaceous.

GUAYNABO FORMATION

The Guaynabo formation consists of several thousand feet of stratified tuffaceous sandstone or graywacke,[1] conglomerate and shale. Meyerhoff and Smith (1931, p. 275) define the Guaynabo formation as a ". . .succession of sediments which lie below the La Muda limestone and above the Hato Puerco tuffs in the northwestern part of the Fajardo district. The town of Guaynabo lies near the southwestern edge of the broad formational outcrop. . . ." This formation

[1] The term "graywacke" is used in this report to denote arenites that are of a rather varied mineralogic composition and that are generally shades of gray when unweathered. They may be marine or nonmarine in origin. For the most part the mineral components give evidence of volcanic origin. In some places these rocks could more aptly be called bedded tuffs. The term "graywacke," however, is preferred as a field term, because without the examination of thin sections it is difficult to assess the relative importance of the tuffaceous component.

is here redefined, however, inasmuch as the study of the section in the Trujillo Alto road and the distribution of rocks elsewhere in the San Juan area indicates: (1) that in several places these sediments are sharply terminated above by volcanic rocks (the Tortugas andesite); (2) that in the several places where it is recognized, the La Muda limestone, as defined on page 18, rests either on this volcanic sequence or is separated from the volcanic horizon by a varied thickness of noncarbonate beds (the Frailes formation); and (3) that the beds cropping out in the vicinity of the town of Guaynabo do not include sedimentary rocks having the stratigraphic position given by Meyerhoff and Smith. The limits of the Guaynabo formation are therefore drawn to include only the section of noncarbonate sediments overlying the Hato Puerco tuff and underlying the Tortugas andesite or, where this latter horizon is missing, the Frailes formation. The upper part of the Guaynabo formation is well exposed in the sides of Highway 175, across the Río Grande de Loíza from the town of Trujillo Alto. Here at least 550 feet of medium- to thick-bedded, gritty graywacke and intercalated gray shales and conglomerate are exposed.

The same beds crop out broadly in Barrio [2] Caimito and Barrio Cupey, northeast and west of the Escuela Segunda Unidad de Caimito, and are particularly well exposed in a deep road cut on the new Highway 1, a little more than half a mile south of El Minao. The road cut shows a plunging anticline in well-bedded, gritty graywacke with minor intercalated shale and fine-grained conglomerate. Flecks of carbonized plant remains are rather common throughout and locally are very abundant. In the creek bed close to the road cut where the graywacke is relatively fresh and unweathered, it is a tough rock, light to medium blue-gray in color; but in the road cut nearby, it is weathered to a brown very friable sandstone and even a loose sand.

In other places, the Guaynabo formation contains beds of very fine ash or siltstone, which break down on weathering to a yellowish soft punky silt. In fact, the rocks of this formation weather rather readily, the shales becoming light-gray to white clays and the sandstones becoming exceedingly friable. Bleached biotite flakes and flecks of carbonized wood are generally conspicuous in the weathered rock and aid in recognition of the formation.

[2] *Barrio* is the smallest of the Puerto Rican political units. It may be considered a district, ward, or precinct of a municipality (municipio).

A certain amount of current-bedding is noticeable in some exposures. Graded bedding is absent or not marked.

The contact of the Guaynabo formation with the Hato Puerco tuff was not knowingly observed by the writer; but this contact, where it occurs in the San Juan area, was inferred to be faulted. It is reported, however, by James P. Owens (written communication) to be exposed along the new section of the Caguas Highway (No. 1) where it is seen to be gradational.

The upper contact of the tuffaceous sandstone of the Guaynabo formation is variable. In the section along Highway 175, west of Trujillo Alto, the formation is overlain conformably by about 10 feet of andesitic conglomerate that is thought to represent the Tortugas andesite. A much thicker section of Tortugas andesite is found overlying the sedimentary rocks of the Guaynabo formation in the southern part of the mapped area, although in places the Tortugas andesite is replaced by an andesite porphyry sill. North of El Minao, the Tortugas andesite is either very thin or absent; and in places the Guaynabo formation is overlain by the Frailes formation.

The Guaynabo formation is possibly nonmarine in origin. Both in its somewhat irregular stratification and prevailingly coarse-grained composition it resembles an alluvial deposit, although, admittedly, the evidence is not conclusive.

The Guaynabo formation may attain a thickness of 4,500 feet in Barrio Cupey, although the lower contact of the formation is an inferred fault. Because the poor exposures in this area do not permit determination of the details of faulting, this thickness is only a rough estimate and may be excessive. It seems likely, however, that the Guaynabo formation partakes of the same variability in thickness as that which characterizes almost all of the formations of the older complex.

Age.—No identifiable fossils have been found in the Guaynabo formation. Since the formation in places seems to be conformable with the younger Frailes formation, which contains a late Upper Cretaceous fauna, it is probably not very much older than the latter rocks and is, therefore, designated as Late Cretaceous(?) in age.

TORTUGAS ANDESITE

The Tortugas andesite is named after Barrio Tortugas, lying north and east of La Muda, where it is well exposed. The formation consists of a nonpersistent horizon of flow rock, breccia, and, in places, conglomerate—all of a characteristic augite-andesite composition—lying between the Guaynabo formation, herein redefined, and the Frailes formation. The formation varies in thickness very rapidly, as for example at El Laberinto where probably over 1,300 feet of volcanic rocks of the Tortugas disappear almost abruptly along the strike and suggests a local vent accumulation at this place.

This stratigraphic unit was not recognized by Meyerhoff and Smith (1931). Its prominent outcrop in the vicinity of La Muda and Trujillo Alto are included in their Guaynabo, Luquillo, and Fajardo formations.

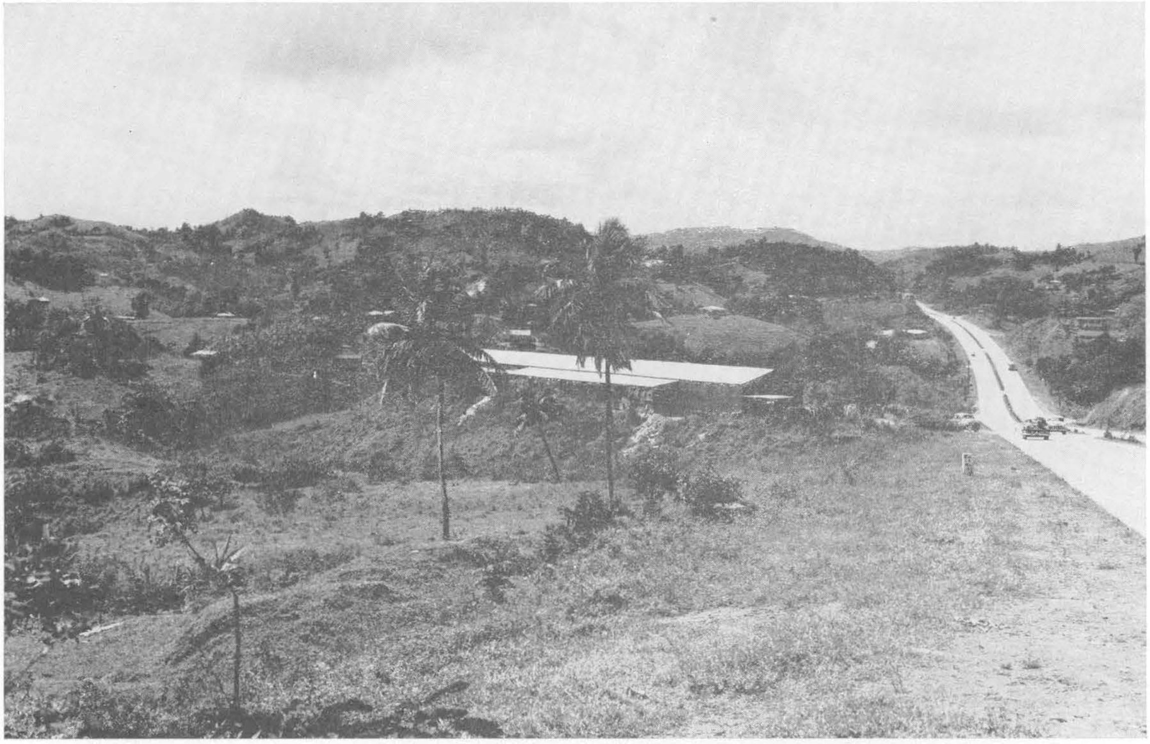
Blocks of sedimentary rock have been noted in the Tortugas andesite at two places southeast of La Muda. High on the side of the quarry, one-fourth mile north of the intersection of the Aguas Buenas road (Highway 173) and the Caguas road (Highway 1), is a large lens of sandstone and conglomerate entirely enclosed by massive andesite. At the road intersection itself (188,790 m, 53,410 m) there are many large and small blocks of a massive, finely crystalline limestone, which seem to be embedded in the andesite but which may possibly belong to a fault zone, as suggested by Mr. Owens (oral communication). These limestone blocks, which do not resemble the La Muda limestone member that crops out nearby just north of the Caguas road, contain abundant rudist fragments and provide the only known occurrence of rudists in the San Juan area. In addition, several mollusks were collected from these blocks. They were examined by John B. Reeside, Jr., who identified *Nerinea* (*Plesioptygmatis*) *burckhardti* Böse, *Trochactaeon* aff. *T. planilateris* Böse, and *Nerita* sp.. According to Mr. Reeside this fauna is certainly of Late Cretaceous age and appears to be close to that from Cardenas, Mexico, which Böse assigned to the lower Senonian (Santonian or Campanian). If the blocks are not due to fault displacement, they may represent ejected blocks of an older limestone; or they may represent limestones, more or less contemporary in age with the eruptions of the Tortugas andesite, that became incorporated in a flow.

The Tortugas andesite is particularly well exposed in several of the quarries that lie north of Highway 1 about a mile southeast of La Muda (189,000 m, 53,750 m) and in a quarry and a road cut about 1¼ miles north of La Muda (188,100 m, 56,800 m). The rocks are somewhat varied in texture and to a certain extent in composition; but they are almost always porphyritic, having small light-colored feldspar phenocrysts in a dark aphanitic groundmass. Mafic minerals, when visible in hand specimen, are generally augite, a feature which makes it possible to distinguish the rocks of this formation from the hornblende-bearing Figuera volcanics.

Fine-grained porphyries, which megascopically are similar to the volcanic rocks of the Tortugas andesite, are common in the conglomerates throughout the section of the older complex rocks in the San Juan area and occur widely throughout Puerto Rico. Whether this indicates that there was a long history of eruption of this type of lava throughout the course of deposition of the older complex, or whether the lavas represent a relatively short-lived, though widespread, eruptive cycle that provided sediment for all later deposition, is not known. In the San Juan area, however, there is evidence that a well-defined single interval of volcanic outpouring from several local vents accounted for the accumulation of the volcanics of the Tortugas andesite.

In the area to the north and east of El Laberinto, the Tortugas andesite is particularly thick and varied. In the several quarries north of Highway 1, two rocks of somewhat different textures occur. One is a light- to medium-gray porphyritic andesite in which nearly white plagioclase phenocrysts, ranging in size from 1 mm to 0.5 mm, make up about 30 percent of the rock, embedded in a gray finely crystalline groundmass. The other textural type is a somewhat denser andesite, in which the plagioclase phenocrysts are sparser and, because of their transparency, not readily discernible to the eye. The groundmass is a dark-bluish gray (5*B* 4/1). A thin section of the latter rocks shows that the feldspar phenocrysts, comprising about 25 percent of the rock, are calcic labradorite (An_{68}). Other phenocrysts are euhedral augite, making up about 5 percent of the rock and averaging 0.3 mm in size, and small euhedral grains of ore. The groundmass consists of minute oligoclase-andesine needles fluidly arranged in a glassy matrix containing abundant small zircons and much ore dust.

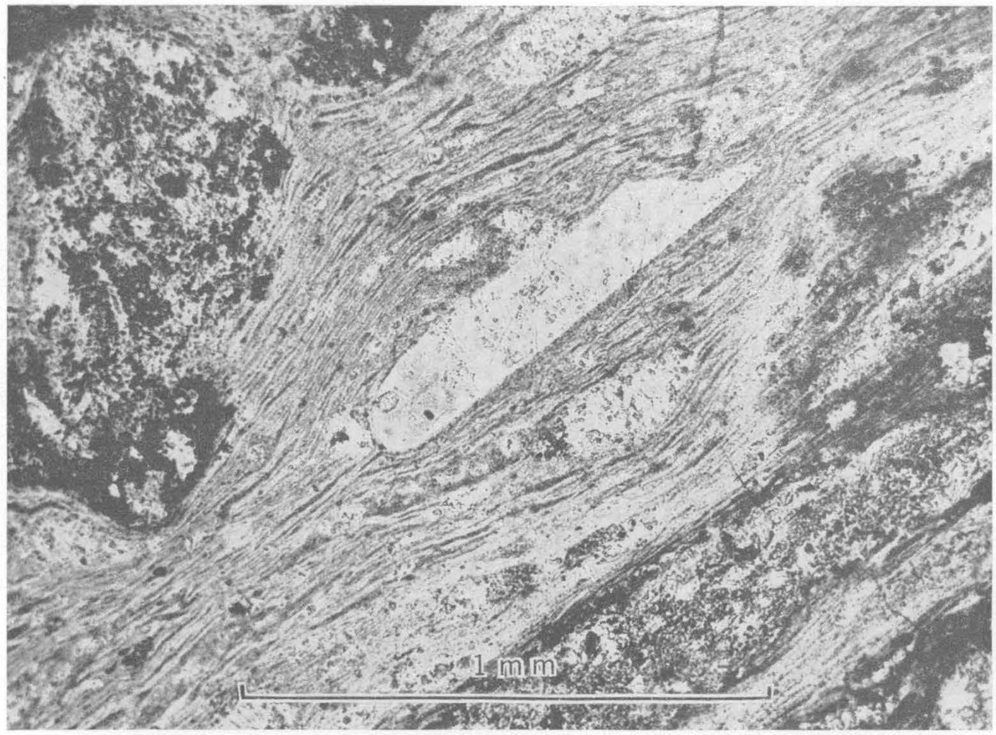
In cuts along the road to El Laberinto are exposed the same andesitic rocks as in the quarries to the north and east. Here interbedded breccias, conglomerates, and flow rocks, all of the same finely porphyritic augite andesite, crop out.



A. VIEW SOUTH ALONG RÍO PIEDRAS–LA MUDA HIGHWAY

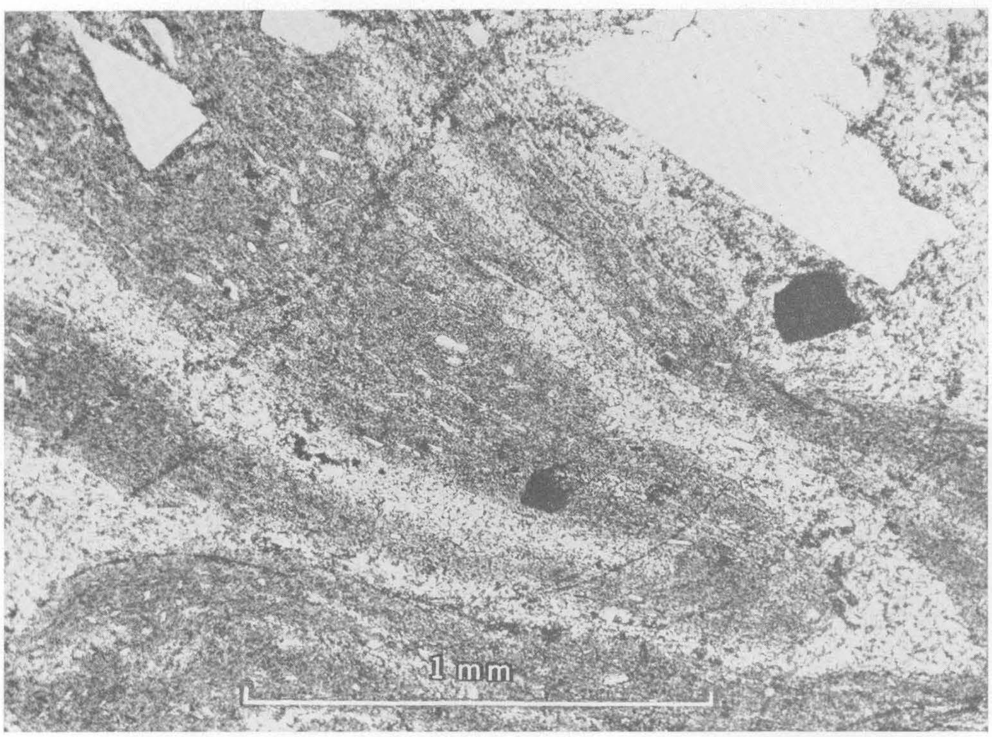
Guaynabo fault block shows in middle distance; just visible beyond is the higher fault block to the south

B. LARGE CONTORTED SHALE BLOCK IN LAPILLI TUFF OF THE FRAILES FORMATION, ABOUT ONE-FOURTH MILE SOUTH OF EL MINAO



A. BANDED RHYOLITIC VITROPHYRE (WELDED TUFF?) FROM BRECCIA IN THE FRAILES FORMATION

Large, broken and resorbed crystal is albite; clear areas are aggregates of xenomorphic granular quartz; banded material is glass; and finely divided hematite forms the darker streaks and the opaque areas. Magnification 69.9 ×, plane polarized light



B. VITROPHYRE FROM THE FIGUERA VOLCANICS, SHOWING FLOW STRUCTURE

Dark streaks are glass; light streaks are cryptocrystalline; crystals are plagioclase. Magnification 62 ×, plane polarized light

A particularly prominent development of the Tortugas andesite, including a thick section of conglomerate, occurs in an east-west belt over two miles in length and terminates about one-half mile southeast of Guaynabo. Judging from several thin sections, the rocks in this belt are variable in composition and are much altered. They are, however, fairly consistently dark gray with small white feldspar phenocrysts generally up to 2 mm in length. Variations include a somewhat coarser porphyry with labradorite (An_{66}) phenocrysts 3 mm in length in a grayish-purple (5*P* 4/2) groundmass that contains small crystals of copper-colored biotite. In thin sections the phenocrysts are seen to include, besides labradorite (An_{66}) phenocrysts 3 mm in length in small shreds, and olivine(?) in small crystals up to 0.01 mm in length. The groundmass consists of very fine needles of sodic andesine and a mesostasis of very low birefringence that possibly is a partly devitrified glass. Alteration of this rock is advanced, such that labradorite and augite are altered to very fine-grained chlorite and carbonate, and the olivine(?) is altered to chlorite and to carbonate with heavy rims of magnetite and goethite.

Another sample of flow rock showed 10 percent of zoned and twinned andesine-labradorite phenocrysts (An_{40}–An_{50}) up to 3 mm in length that were much altered to sericite, and about 3 percent of augite up to 0.7 mm in length, almost entirely replaced by quartz in aggregates of small crystals. Crystals of magnetite are plentiful and in places are large enough to be considered phenocrysts. The groundmass, which makes up about 80 percent of the rock, is a fine xenomorphic granular aggregate of albite and (or) orthoclase, and perhaps quartz with much ore dust. Very small crystals of apatite are abundant in both groundmass and phenocrysts.

A chemical analysis (given below) of a sample of Tortugas andesite from the quarry southeast of La Muda indicates that the composition of the rock is andesitic, although the low K_2O and MgO and the high CaO are all unusual for rocks with a comparable SiO_2 content. The composition, however, is not too dissimilar to Daly's (1933, p. 16) averages for both augite andesite and hypersthene andesite. It does not, however, accord too closely with the average andesite composition compiled more recently by Nockolds (1954).

Chemical analysis and parameters of Tortugas andesite, Puerto Rico, and related rocks

	Tortugas augite andersite from quarry 1 mile SE of La Muda [1] (weight percent)	Augite andesite; an average of 33 analyses [2] (weight percent)
A. Chemical analysis		
SiO_2	57.6	57.50
Al_2O_3	16.0	17.33
FeO	2.3	3.62
Fe_2O_3	4.3	3.78
MgO	3.2	3.28
CaO	7.2	5.83
Na_2O	3.0	3.53
K_2O	.94	2.36
TiO_2	.65	.79
P_2O_5	.29	.30
MnO	.17	.22
Ignition	[3] 3.4	(H_2O) 1.88
Total	99.05	100.42
B. CIPW norm		
Quartz	20.04	
Orthoclase	5.56	
Albite	25.10	
Anorthite	27.52	
Diopside	4.97	
Hypersthene	5.70	
Ilmenite	1.22	
Magnetite	6.03	
Hematite	.16	
Apatite	.67	
Total	96.97	
C. Mode		
Groundmass	55	
Plagioclase (An_{55})	33	
Augite	5	
Serpentine (ex-hypersthene?)	3	
Hornblende	Trace	
Ore	2	
Secondary chalcedony in shear zone	2	
Total	100	

[1] Chemical analysis by rapid methods; analysts, Frank S. Borris, Harry F. Phillips, and Katrine White.
[2] From Daly (1933).
[3] Includes gain due to oxidation of FeO.

Perhaps the closest norm in Nockolds' tables is that for dacites and dacite obsidians (combined). The high normative quartz (20.04 percent) indicates the bulk composition of a quartz andesite, although this is not reflected in the mode. Two thin sections of the analyzed sample failed to reveal any recognizable quartz, tridymite, or cristobalite except for a thin shear zone filled with minute chalcedonic spherulites. Most of the free silica indicated by the norm probably resides in the groundmass, which is too finely crystalline to permit mineral identification. The serpentine pseudomorphs reported in the mode are, from their outline, possibly alteration of hypersthene.

FRAILES FORMATION (INCLUDING THE LA MUDA AND LEPROCOMIO LIMESTONE MEMBERS)

The Frailes formation consists of sedimentary and pyroclastic rocks (particularly a massive lapilli tuff) with prominent limestones in the upper and lower parts. The formation is named after Barrio Frailes, east of Guaynabo, in which the formation is well developed.

A typical section of the Frailes formation is exposed in the road cuts on Highway 175 along the left bank of the Río Grande de Loíza west and north of Trujillo Alto, and along Highway 23 north of Trujillo Alto. Here it overlies an andesite porphyry sill. The contact of the Frailes formation with the underlying Tortugas andesite is, however, exposed in the La Muda area in a road cut on the west side of Highway 1, just west of the El Laberinto road crossing, and also in the immediate vicinity of this hamlet. The upper contact of the Frailes formation with the Monacillo formation is not clearly exposed in the shallow cuts along the road, where the rock is deeply weathered. The total thickness of the Frailes formation in this section is about 2,350 feet, scaled from the map.

Some idea of the wide range of lithologic types included in this formation can be had from the Highway 175 section, where from bottom to top the following rocks are exposed: rudely stratified fine conglomerate and lapilli tuff (about 80 ft); gray cherty shale (3 ft); thick-bedded graywacke with some interbedded tuffaceous shale (about 50 ft); massive lapilli tuff (about 20 ft); thick-bedded to thin-bedded, gritty to fine-grained, light-colored sandstone (about 59 ft.) with interbedded arenaceous fossiliferous limestone (La Muda limestone member); conglomerate (2 ft); light, dove-colored, fissile shale (about 13 ft.); thick-bedded graywacke with some interbedded thin tuffaceous shale (about 250 ft); massive lapilli tuff (about 12 ft); thin-bedded fine-grained graywacke; mottled and laminated porcelaneous shale (about 50 ft); massive lapilli tuff with some interbedded graywacke (about 800 ft); about 1,120 feet of thin- to thick-bedded tuffaceous limestone and interbedded tuffaceous sandstone (Leprocomio limestone member).

The color of the rocks is generally greenish gray when fresh and brown when weathered, although some of the shales are medium to light gray, and part of the massive lapilli tuff deposit northwest of El Laberinto is a very dusky red purple (5*RP* 2/2), although this is possibly the result of baking by one of several nearby intrusions.

Recognition features of this formation include the two limestone members, thick lapilli tuffs and fine conglomerates, well-bedded argillaceous and fine-grained sediments, and the presence of marine fossils.

Perhaps the most characteristic rock type of the Frailes formation is the dark-green lapilli tuff that occurs in the middle part, between the La Muda limestone member and the Leprocomio limestone member. The rock is well exposed along Highway 175 at Trujillo Alto (197,100 m, 58,250 m) and in several new road cuts just north of the Quebrada Frailes crossing on Highway 1 (188,700 m, 57,820 m). Other significant exposures can be found on a ridge about three-fourths mile east of Guaynabo and northeast of El Laberinto. All of these sections, except that northeast of El Laberinto, show a series of two or more lapilli tuff horizons separted by shale, siltstone and graywacke.

The pyroclastic section exposed in the cuts on Highway 1 north of the Quebrada Frailes crossing merits special description. The lowermost breccia crosses the highway at the El Minao intersection (unfortunately the interesting west side of this road cut has since been removed by the construction of the new Highway 1). Making allowances for the several faults that are present in this exposure, the following section was distinguished, from bottom to top: (1) Unknown thickness of interbedded gritty graywacke and olive-colored clay shales. (2) Fifteen feet of massive, very coarse breccia with angular fragments up to 6 feet across of banded rhyolitic vitrophyre with well-developed flow structure, coarse- to fine-grained dark porphyries resembling the Tortugas andesite, and pieces of shale and tuffaceous sandstone. The fragments are more rounded and smaller in size towards the top. (3) Approximately 2½ feet of bluish-gray gritty graywacke overlain by about 4 feet of olive-brown siltstone with marine fossils. (4) About 7 feet of massive lapilli tuff. (5) Four feet of gritty graywacke. (6) At least 18 feet of coarse volcanic breccia similar to bed 2, above. In the cut on the east side of the highway, the entire section above the base of the tuffaceous sandstone consists of coarse breccia.

The banded rhyolitic vitrophyre fragments (pl. 4*A*) found in the lower breccia in this exposure (see bed 2, above), may be of stratigraphic significance because massive deposits of similar rock have been noted at several places in Puerto Rico (Hodge, 1920, p. 171; Meyerhoff and Smith, 1931, p. 288; Semmes, 1919, p. 65; Smith and Hildebrand, 1953).

The dark-gray and light-pink (white on weathered surface) flow banding is particularly striking. The bands are generally 2 mm or less thick and the dark bands are discontinuous. Scattered through the rock are small subangular xenoliths, ranging in size up to about 2 mm, around which the dark bands inscribe regular flow lines. The long dimensions of these fragments are not everywhere parallel to the flow banding. In thin section the rock is seen to consist chiefly of slightly devitrified glass containing fluidly alined, fine threads that are richer in iron, and siliceous streaks and lenses made up mostly of spherulites with quartz and small sanidine crystals in the center of the broader lenses. About 5 percent of the rock consists of xenocrysts of fresh albite in somewhat broken crystals that not uncommonly have slightly resorbed edges. The xenoliths are mostly either of rocks possessing a fine-grained bostonitic texture or of rocks altered entirely to ore except for scattered small feldspar laths.

The possible stratigraphic importance of this rock is that it may represent a widespread and well-defined interval of rhyolitic outpouring. As such it would provide one of the few readily recognizable horizon markers in the older complex.

However, Smith and Hildebrand (1953, and written communication), in studying banded siliceous rocks south and southeast of the San Juan area, came to the conclusion that the fluidal banding in their rocks was secondary and was produced by the hydrothermal addition of silica in Eocene time. Yet, the fragments from the Frailes formation provide no evidence for doubting the primary nature of their flow banding, although it is possible that the quartzose streaks in this rock are deuteric, or even hydrothermal, as Smith and Hildebrand contend for the rocks east and west of Caguas. Even if this is so and even if one is not justified in hypothesizing a rhyolite interval as an islandwide stratigraphic marker, the El Minao road cut showed that this rock type already existed in Frailes time (Late Cretaceous) and refutes Smith and Hildebrand's (1953) conclusion that the alteration was of necessity Eocene in age.

The typical massive lapilli tuff of the Frailes formation is found in a deep road cut a few hundred yards to the south of the El Minao road cut just described. Here about 300 feet of massive well-cemented lapilli tuff is exposed, which consists of subangular to subrounded fragments, rarely exceeding 20 mm and averaging perhaps 5 mm in length, of dark aphanitic rocks embedded in a groundmass of dark, fine-grained material. White to light-pink zeolites are also common in the groundmass. The aphanitic texture of the lapilli is characteristic of these tuffs. The fresh rock is prevailingly dark greenish gray (5*G* 4/1) but many of the lapilli are shades of deep red and maroon. Where the rock is weathered it becomes varicolored, the lapilli fragments assuming various shades of green, purple, red, and brown. Although the tuff is dominantly massive there is a widely spaced rude stratification and some interbedded green siltstone and graywacke. Conspicuously though relatively sparsely imbedded in the breccia are angular masses up to 7 feet across of dark greenish-gray to dark maroon, thin-bedded shales (pl. 3*B*). The shale xenoliths tend to be concentrated in planes parallel to the rude bedding of the breccia. Many of the shale fragments are surrounded by thick rims of light-colored zeolites made up principally of laumontite.

Thin sections of the lapilli tuff show that the lapilli are mostly microcrystalline volcanic rocks whose textures range from pilotaxitic to bostonitic. In places these rocks are almost entirely opaque due to concentrations of magnetite and hematite. There are sparse broken crystals of sanidine, albite, and augite. The rock is very much altered. Zeolite minerals, chlorite, and very fine grained clayey(?) material makes up most of the matrix and replaces to varying degrees the lithic and crystal components.

Lapilli tuffs, identical to those described, crop out on the crest of the north-trending ridge about 0.7 miles southeast of Guaynabo, in a ridge 0.6 miles northwest of El Laberinto, and on Highway 175 northwest of Trujillo Alto. The coarse breccia in the El Minao road cut, however, is unique among the rocks examined in the San Juan area, both as to degree of coarseness and as to composition.

DISCUSSION

The occurrence of marine fossils in the Frailes formation shows that these rocks are at least partly of marine origin. The coarse breccia and the massive lapilli tuff are not incompatible with marine deposition. The coarse breccia may, for example, represent debris of submarine slides, and a somewhat similar origin for the lapilli tuff might account for the large angular blocks of shale embedded in it. Submarine sliding on a large scale is probably a normal ocurrence on the flanks of submarine volcanic cones, particularly during eruptions.

In several places in the San Juan area lapilli tuffs, somewhat similar in appearance to those in the

Frailes formation, have been provisionally included as part of the Hato Puerco tuff. A broad area of massive lapilli tuff surrounded by Hato Puerco rocks crops out south of the Escuela Segunda Unidad de Cupey (these have not been shown on the accompanying geologic map owing to the reconnaissance nature of the mapping in this area). A somewhat similar rock appears at the western edge of the area of this report, near the headwaters of the Quebrada Camerones. The lapilli tuffs of the Frailes and Hato Puerco formations are similar in the size, shape, and aphanitic composition of the lapilli constituents. But in all outcrops of the possible lapilli tuffs of the Hato Puerco that were examined by the writer, the rocks are very much better cemented than the Frailes formation, tending to break across the lapilli grains rather than around them as characterizes unquestionably the lapilli tuff of the Frailes, and suggesting thereby the somewhat greater degree of regional metamorphism that is characteristic of the Hato Puerco tuff. There is, however, the possibility that the lapilli tuff mapped within the Hato Puerco is simply an example of unconformable overlap of the younger Frailes formation onto the flanks of the subsiding Caguas volcano, a process that has already been discussed (p. 9) and that is graphically expressed in figure 4. Such an unconformable relationship might be preserved if the Frailes formation were concentrated in deep canyons or valleys (either submarine or subaerial) cut in the Hato Puerco tuff. The lapilli-tuff belt south of the Escuela Segunda Unidad de Cupey may therefore possibly be a Frailes outlier within the Hato Puerco tuff.

LA MUDA LIMESTONE MEMBER

Berkey (1915, p. 22) described the La Muda limestone as follows: "A rather heavy development of limestone in the vicinity of La Muda between Río Piedras and Caguas. . . . The rock is not prominently tuffaceous. . . . It has in places a coarse fragmental structure almost completely obscured by healing and it is, as usual, attacked by cave development. . . ." Meyerhoff and Smith (1931, p. 283), on the other hand, state: "Berkey was not aware of the presence of two limestone formations in the vicinity of La Muda, but his brief description applies more fully to the calcareous beds situated one mile north of the village than to the shaly, or tuffaceous, strata situated to the south. The latter have been correlated with the Trujillo Alto limestone, and the name La Muda will therefore be used for the more northerly of the two calcareous beds."

A comparison of Meyerhoff and Smith's map of the Fajardo district and the map accompanying this report will show that the distribution of the limestones shown in the vicinity of La Muda,[3] as well as along the Trujillo Alto section, are markedly different. The calcareous beds situated one mile north of the village of La Muda (Meyerhoff and Smith's La Muda limestone) is probably the local development of limestone that shown in this report about 0.6 miles north of the La Muda quarries and that is referred to the Trujillo Alto limestone (pl. 2). The limestone exposed, however, in the two quarries about 1½ miles southeast of the La Muda road fork and the limestone exposed to the southwest at El Laberinto are accurately described by Berkey, as to both location and lithology. There seems no reason therefore to redefine the name originally given to these rocks by Berkey, and in the present study the term is applied within the original guide lines established by him.

The La Muda limestone, which crops out in the quarries and their immediate vicinity, and to which Berkey apparently made reference in his original description, like almost all stratigraphic units in the San Juan area is somewhat variable in texture. The southeasternmost quarry exposes about 60 feet of thick-bedded, dark blue-gray to olive-gray, fine-grained, rather pure limestone. Solution openings and veins of coarsely crystalline calcite are common. Under the hand lens the limestone is seen to be made up of rounded to subrounded grains, resembling oolites in size and shape, and rounded to spindle-shaped black argillaceous grains, generally 1 to 2 mm in diameter. In thin sections the rock is seen to consist of a dense aggregate of Foraminifera, Radiolaria, and small broken grains of calcareous algae. Similar thick-bedded limestone crops out in the surrounding areas, although textures vary from that of a skeletal limestone made up almost exclusively of finely comminuted shell fragments to a very fine grained limestone in which poorly preserved corals are barely discernible. Adjacent to a diabase dike the limestone has been bleached white and is finely crystalline. At El Laberinto, at the top of the hill that lies across the valley, west of the quarries, about 35 feet of the same limestone crops out on the road, and an estimated 60 feet of

[3] La Muda is an ill-defined roadside settlement that fringes the highway for a mile or more southeast of the intersection of Highways 1 and 20.

limestone is exposed in the quarry southeast of this little community. Here the rock is finely crystalline and the fragmental texture is not evident.

In the type area around La Muda, the La Muda limestone directly overlies the Tortugas andesite in the vicinity of El Laberinto but rests on what seems to be the Guaynabo formation (without the intervening andesite) on the hilltop about a mile to the northeast. Moreover, the limestone at El Laberinto clearly lenses out not far north of the village. It seems reasonable to suspect therefore that the La Muda limestone forms lenticular limestones in the lower part of the Frailes formation and is not a single bed or stratigraphic horizon. In the type section of the Frailes formation along the Trujillo Alto road, the two thin limestone beds found at the bend of Highway 175, due west of Trujillo Alto, are good examples of lenticular limestone in the lower Frailes and as such are designated La Muda limestone. They consist of an 18-inch bed and a 20-inch bed of somewhat arenaceous gray limestone separated by 13 feet of thin-bedded, light-gray sandstone. In this locality the limestone is separated from the Tortugas andesite by about 200 feet of noncarbonate rock of the Frailes formation. The variable nature of the lower contact of the Frailes formation is taken in part to result from the lenticular nature of the La Muda limestone and in part the highly discordant and overlapping nature of the transgressing Frailes formation onto the eroded surface of the older rocks.

LEPROCOMIO LIMESTONE MEMBER

The Leprocomio limestone member designates the more or less limey, well-bedded, cuesta-forming sediments in the upper part of the Frailes formation. These rocks crop out north of the bend of the Río Grande de Loíza at Trujillo Alto and are well exposed in the several quarries east and west of Highway 181. The outcrops of these rocks are close to Leprocomio (Insular leper hospital), after which the member is named.

The rock is characteristically a light- to medium-gray impure limestone and fine-grained calcareous tuff and, in general, shows few if any effects of solution weathering. There is some interbedded graywacke, and the proportion of limestone to graywacke varies rapidly along the strike. The thickness of limey beds in this member is very variable and apparently reaches its maximum development in the Trujillo Alto area where it is approximately 1,120 feet thick. Weathering of these impure limestones results in a leached rock in which the volume of the original rock is retained although its specific gravity is reduced. The typical weathered impure limestone is therefore generally a well-stratified, somewhat punky tuffaceous (or argillaceous) rock without much or any carbonate. Alteration of this type can be easily observed about 1½ miles northeast of Guaynabo (188,780 m, 59,600 m) where over 30 feet of limey beds exposed in a small quarry grade laterally within 100 feet into a completely nonlimey section of well-stratified, porous, tuffaceous rock.

The Leprocomio limestone member of the Frailes formation is apparently the limestone referred to by Meyerhoff and Smith (1931, p. 283) when they applied the term Trujillo Alto limestone. Their description of a tuffaceous limestone cropping out north of Trujillo Alto, which showed few effects of solution-weathering and that graded downward to noncalcareous beds agrees exactly with the characteristics of the Leprocomio member of the Frailes formation as herein defined. Their geological map of the Trujillo Alto road section, however, shows this limestone in aproximately the position of a higher limestone, the Trujillo Alto limestone as used in this report. The confusion concerning the term Trujillo Alto limestone will be discussed under the description of that formation.

AGE AND CORRELATION

The fossil faunas grouped under the Frailes formation are of late Late Cretaceous age according to J. B. Reeside, Jr., and that of locality 23582 has affinities with a Haitian fauna of Santonian (earlier Senonian) age. The *Globator* sp. from the La Muda limestone member (identified by C. Wythe Cooke) may be the same as *"Echinoconus" antillensis* Cotteau which has been attributed to the Cretaceous at Cienfuegas, Cuba. According to Cooke, the only known species of *Globator* in the United States is *Globator parryi* (Hall), which is abundant in the Georgetown limestone (Washita group) of Early Cretaceous age of Texas. The weight of faunal evidence, and particularly the ammonites, shows, however, that the Frailes formation is of late Late Cretaceous age. The list of fossils is given on the following page.

MONACILLO FORMATION

The Monacillo formation seems to be predominantly a continental deposit, ranging in texture from siltstone to conglomerate, and lying between the Frailes formation and the Trujillo Alto limestone.

List of fossils from the Frailes formation

Species	Localities			
	26 La Muda limestone member	23193 [1]	23582 [1]	23192 [1] Lepro-comio limestone member
Pelecypods (identified by John B. Reeside, Jr.):				
Breviarca aff. *B. webbervillensis* Stephenson			X	
Inoceramus cf. *I. balticus* Boehm		X	X	X
Camptonectes sp			X	
Plicatula cf. *P. mullicaensis* Weller			X	
Anomia? sp			X	
Lima cf. *L. azteca* Böse			X	
Ostrea sp				X
Exogyra? sp				X
Pinna (*Atrina*) sp		X		
Lithophaga sp			X	
Cardita sp			X	
Cardium (*Granocardium*) sp. 1			X	
Cardium (*Granocardium*) sp. 2			X	
Linearia? sp			X	
Corbula cf. *C. paracrassa* Wade			X	
Gastropods (identified by John B. Reeside, Jr.):				
Aporrhais sp			X	
Pugnellus sp			X	
Actaeon? sp			X	
Turricula? sp			X	
Volutoderma? sp			X	
Cerithium? sp				X
Ammonites (identified by John B. Reeside, Jr.):				
Pachydiscus sp			X	
Texanites sp			X	
Echinoids (identified by C. Wythe Cooke):				
Schizaster (*Linthia*)? sp		X		
Linthia cf. *L. variabilis* Slocum			X	
Globator sp	X			
Comatulid crinoid, undetermined			X	
Serpula, unidentified species			X	
Crustacean fragments, undetermined			X	

[1] Five-digit numbers are U. S. Geological Survey localities; other is author's locality.

Locality descriptions

26 Aguas Buenas quadrangle; a hilltop 0.95 miles SE of La Muda road intersection (188,785 m, 54,095 m).
23193 Aguas Buenas quadrangle; road cut, east side of Highway 1 at El Minao (188,860 m, 58,263 m).
23582 Aguas Buenas quadrangle; approximately 1.25 miles SE of La Muda, in low road cut just N of intersection of old Caguas road and Highway 173. (188,732 m, 53,480 m).
23192 Aguas Buenas quadrangle; east side of Highway 181 about 0.75 miles north of Trujillo Alto (197,250 m, 58,880 m).

The formation has been named from Barrio Monacillo, southwest of Río Piedras, where it crops out widely. The lower contact of the formation was not observed, but from its field relations the formation seems to be conformable with the underlying Frailes formation and the overlying Trujillo Alto limestone.

This is perhaps the most difficult stratigraphic unit to identify in the field due to its extreme heterogeneity of composition and its marked changes in thickness. In general, however, it can be said that it consists of fine to coarse clastic beds (as usual, made up of tuffaceous or volcanic material), showing some crossbedding, local unconformities, and channel filling. The beds are in many places maroon in color. At least one predominantly pyroclastic horizon, consisting of purple ash and lapilli tuff, has been noted (187,820 m, 59,150 m). The formation is probably nonmarine in origin.

On Highway 181, the Monacillo formation is relatively thin and is intruded by several diabase sills and plugs. The part of the formation that is exposed consists of obscurely bedded weathered yellow siltstone, which may represent an ash deposit, underlain by at least several feet of deep reddish-maroon conglomerate with subrounded to subangular pebbles as large as 2 inches, mostly of dark fine-grained tuffaceous sandstone, ashy shales, and minor amounts of porphyry. There are interbedded fissile shales and obscurely bedded maroon medium-grained tuffaceous sandstone. Although a rather characteristic reddish or purplish coloration has been noticed in these beds at several places, it is not known how much of this along Highway 23 is a result of baking by the diabase intrusions.

The thickness of the Monacillo formation in the vicinity of the Trujillo Alto road has been scaled at about 900 feet. It is evidently very much thicker northeast of Guaynabo, although, due to the old alluvial soil cover in the area, a reliable estimate of thickness cannot be made.

Age and correlation—No fossils have been found in the Monacillo formation, but from fossils occurring in formations immediately above and below it there is no doubt that it is late Upper Cretaceous.

Berkey (1915, p. 21) described the Trujillo Alto limestone as follows:

TRUJILLO ALTO LIMESTONE

One [limestone member of the older complex] . . . has been observed only on the north side of the island in the vicinity north of Trujillo Alto and in the vicinity of Loíza. This is a very dense, fine bluish limestone made up wholly of fine microscopic organic growths. In some places it has a rough fragmental structure, but for the most part the rock is massive and the abundant organic content, largely algae, is its most striking characteristic. . . . It is affected by solution developing caves at the Trujillo Alto locality in much the same manner as is the Arecibo formation, but this rock is a much more compact type and its content and structure relations are quite distinct. It was probably of reef origin also, but is associated intimately wih the upper shale members of the older series rather than with the Tertiary series.

Berkey thus clearly described the broad belt of limestone that crosses Highway 181 at Pueblo Seco and can be traced as a continuous outcrop to the east and to the west for several miles. The width of the outcrop at Pueblo Seco indicates that the formation may be as much as 900 feet thick here, which is by far its maximum thickness.

The Trujillo Alto limestone appears to overlie the Monacillo formation conformably in the vicinity of Highway 181, north of Trujillo Alto, although the contact was not seen. In this area and north of La Muda, the limestone is conformably overlain by fine-grained tuffaceous rocks and breccias of the Figuera volcanics. The Trujillo Alto limestone is very possibly absent in the basin between Guaynabo and Río Piedras, where there are indications that the Figuera volcanics are separated from the older rocks by an angular unconformity.

Several quarries in the vicinity of Pueblo Seco permit a clear picture to be formed of the characteristics of at least part of the total thickness of limestone in this area. The lower part of the formation, but not the base, is well exposed in the Umpierre quarry at the headwater of Quebrada Cepero (194,700 m, 59,750 m). It is a blue-gray to light-gray massive limestone containing echinoid fragments and lesser thicknesses of dark blue-gray to nearly black, medium- to thick-bedded, highly argillaceous limestone containing Turritella, thin-shelled pelecypods, and fish scales. These beds are overlain by gray to light-gray, medium- to thick-bedded pure limestone that consists principally of finely comminuted calcareous algae and shell(?) material. In places this rock has a brecciated structure and forms large massive reeflike lenses. Higher in the section, the quarry at Pueblo Seco exposes massive, dense, fine-grained limestone that is varied in color from dark blue to very light gray. In places there is a conspicuous mottling of light and dark, suggesting that a sort of bleaching may have affected the rock. The rock contains a vast amount of skeletal detritus, principally small foraminifera, calcareous algae, small corals, echnoids and echnoid fragments, bryozoan, small mollusks shells, (mostly gastropods, oysters, and rock borers, such as small *Lithophaga*), and miscellaneous shell detritus. The stylolites, which are rather common in this limestone, are generally lined with a thin, flexible tissue of sepiolite (palygorskite? $N = 1.55$, positive elongation), associated with which are small seams of white, coarsely crystalline kaolinite. This is a very soluble and cavernous rock and its outcrops are generally fluted and deeply pitted. Formerly, a low "haystack" hill, similar in form to the larger karst features of the limestones of middle Tertiary age of the north coast, stood on the site of what is now the quarry at Pueblo Seco. It was this feature that probably inspired Berkey's comparison of the Pueblo Seco outcrop with the Arecibo formation (a formational name proposed by Berkey for all the middle Tertiary rocks of the north coast).

At the Pueblo Seco quarry the contact with the overlying Figuera volcanics is marked by about 20 feet of medium- to thin-bedded calcareous tuff, although the volcanics proper are not exposed in the quarry.

AGE AND CORRELATION

The Trujillo Alto limestone is rich in skeletal debris of many kinds, but it is not common to find fossils that are whole and sufficiently free of the dense limestone matrix to permit specific identification. Such indentifiable fossils as have been found by the writer indicate a late Late Cretaceous age. The following is a summary of the paleontologic findings on the Trujillo Alto limestone:

1. A collection from the black argillaceous limestone near the base of the formation in the Umpierre quarry was examined by John B. Reeside, Jr., who identified the following fossils, which he considered to be late Cretaceous:

    Lucina? n. sp.
    Venerid pelecypod
    Turritella n. sp., related to *T. tippana* Conrad
    Cassiope n. sp.
    Fish remains

2. The same carbonaceous facies from an outcrop about a mile to the west (192,550 m, 60,580 m) yielded a large number of poorly preserved ostracodes, "*Cythereis*" sp. and one or more smooth ostracode genera represented by internal casts. I. G. Sohn had suggested a probable Cretaceous age.

3. Foraminifera from the same rock that yielded the ostracodes were studied by Ruth Todd, who reported:

> The sample contains very abundant specimens of Foraminifera, all of minute size for this group, the largest less than 0.3 mm in greatest dimension . . . Some of the species appear to be very finely arenaceous, but others may be silicified. The composition of the fauna (rich in individuals but poor in species), the abundantly small size of all the species present, and the dominance of two arenaceous genera commonly found in shallow and brackish water, suggest deposition in a brackish environment. Identification is very difficult, even as to genus. No age assignment can be given other than post-Paleozoic.

Halophragmoides spp.	*Angulogerina?* sp.
Trochammina spp.	*Gyroidina?* sp.
Nonionella? sp.	*Cibicides?* spp.
Bolivina? sp.	

4. Very small echinoids, which weathered out of the massive limestone in the Pueblo Seco quarry in the upper part of the section, were identified by C. Wythe Cooke as *Magnosia?* n. sp. This genus,

known from the Jurassic (Bathonian) to the Upper Cretaceous (Cenomanian) of Europe and the circummediterranean countries, has not been noted before in the Western Hemisphere. The uncertainty, however, of the generic identification affects the usefulness of this fossil in dating the rock. The echinoid genus *Cidaris* occurs in abundance in the massive limestone, mostly as fragments.

5. A collection of corals from the same massive limestone in the Pueblo Seco quarry were studied by John W. Wells who judged them to be Late Cretaceous in age. The following species, all shallow water forms, were identified:

Elephantaria tottoni Wells
Actinacis sawkinsi Wells
Cladocora sp., cf. *C. jamaicensis* Vaughan
Monastrea sp., cf. *M. schindewolfi* Wells
Multicolumnastraea cyathiformis (Duncan)
Heliopora bennetti Wells

6. Well-preserved very small molluscan shells, which had weathered out of the massive limestone in the Pueblo Seco quarry and which are nondiagnostic insofar as separating the Upper Cretaceous from the Tertiary is concerned, consists of: *Ostrea* sp., *Lithophaga* sp., *Pseudomalaxis*? sp., *Capulus*? sp., and *Cerithiopsis*? sp. (the last three identified by Lloyd W. Stephenson).

Massive and thick-bedded limestone that is lithologically similar to the Trujillo Alto limestone crops out about 1½ miles west of the town of Loíza (206,-600 m, 59,900 m). It underlies tuffaceous beds containing large Foraminifera of Paleocene or early Eocene age (Kaye, 1956). In a quarry at the outskirts of the town of Corozal, west of the San Juan area (Kaye, 1956), a massive, dense limestone, rich in skeletal debris and containing a coral fauna somewhat related to that of the Trujillo Alto limestone, is found as exotic blocks embedded in rocks judged to be also of early Tertiary age. The Trujillo Alto limestone is possibly the equivalent of these limestones. Its stratigraphic position may therefore be at the top of the Upper Cretaceous section and immediately below the Paleocene or lower Eocene. Indeed, the overlying Figuera volcanics of the San Juan area has much in common with the lower Tertiary rocks at Loíza and at Corozal.

FIGUERA VOLCANICS

The Figuera volcanics of the San Juan area consist of pyroclastic rocks of a highly variable thickness with lenticular calcareous beds and included blocks of older limestone (the Trujillo Alto? limestone) in its basal part. The volcanic rocks are characteristically hornblende andesite of a mauve to greenish color. The Figuera volcanics are thought to be Paleocene or early Eocene in age.

Meyerhoff and Smith (1931, p. 284) describe a belt of fine-grained andesitic flow rocks in the eastern part of the island, south of Fajardo, under the term Figuera formation. This volcanic horizon was placed stratigraphically between the Trujillo Alto limestone and the Fajardo shales, although these authors noted that no outcrop of Trujillo Alto limestone was seen in the vicinity of the Figuera volcanics. The volcanic rocks in the San Juan area are probably the equivalent of the east-coast rocks, if the stratigraphic position of the latter has been correctly established. The absence, however, of a common contact with the Trujillo Alto limestone at the type locality and the uncertainty that the Fajardo shales of Meyerhoff and Smith at Fajardo and those in the San Juan area are stratigraphically identical raise an element of uncertainty as to the identity of the two volcanic sequences.

In the vicinities of Pueblo Seco and La Muda, the Figuera volcanics conformably overlie the Trujillo Alto limestone and, in fact, incorporate limestone similar to the Trujillo Alto in their basal part. In the lowland between Guaynabo and Río Piedras however, they apparently are separated from the underlying rocks by an angular unconformity, for north of Guaynabo they rest on the Monacillo formation, whereas to the south they rest on the Frailes formation. The Figuera volcanics are overlain by the well-bedded tuffaceous sediments of the Fajardo formation.

The Figuera volcanics are thickest and best exposed over an area of several square miles south and east of the town of Guaynabo, where it is estimated that they include more than 3,000 feet of breccia and minor intercalations of flow rock. The local thickening possibly represents a vent deposit or cinder cone (fig. 4). The thickness of Figuera volcanics on the Trujillo Alto road (Highway 181) is estimated to be about 600 feet, although the formation is very incompletely exposed at this place. The basal limey beds are represented by about 20 feet of thin-bedded nonfossiliferous calcareous tuff in the northernmost part of the quarry of Pueblo Seco. These beds rest on massive Trujillo Alto limestone. The more characteristic pyroclastic rocks can be seen in the sides of the road leading to the new filtration plant of the Puerto Rico Aqueduct and Sewer Authority, where a breccia with angular fragments up to 2 feet across of dark hornblende porphyry and minor amounts of red chert is exposed. With the exception of the chert fragments, the rock is completely weathered to clay, retaining, however, its variations in color and texture and its individual crystal outlines. Similar weathered breccias crop out in the vicinity of the Penitenciaría and Manicomio and were encountered in drilling at the Sanatorio Insular, west of Río Piedras. The same rock is also exposed in a road cut about a mile west of the last point. From these few exposures it is inferred that the Figuera volcanics strike west across the northern edge of the upland basin and then sharply bend to the southwest and follow along the base of the cuesta north of Guaynabo.

The andesite of the Figuera volcanics is one of the most striking and distinctive petrographic types in the San Juan area and can readily be recognized megascopically by the presence of abundant hornblende phenocrysts and the speckled drab purplish-gray to mauve groundmass. The typical mauve coloration is also imparted to the soil that develops on these rocks. In some places a blue-green color is prominent, resulting probably from the large amounts of fine-grained chloritic material it contains. The principal rock type is an albitized quartz-bearing hornblende andesite ("keratophyre" of some authors), occurring mostly as volcanic breccia, but also as flow rock, crystal tuff, and vitrophyre. The breccia typically consists of angular to subrounded fragments of fine-grained hornblende porphyry, which contains characteristically light colored albite phenocrysts embedded in a darker speckled matrix of somewhat fore fine grained hornblende andesite. Fine-grained white and pink laumontite, thomsonite, phillipsite, and apophyllite (identified petrographically) are common as veins, cavity fillings, and replacement of both feldspar phenocrysts and groundmass.

In hand specimen, the typical rock is a fine-grained porphyry with fluidly alined white feldspar laths up to 2 mm in length and shiny black hornblende crystals, generally up to 3 mm and rarely up to 5 mm, embedded in an aphanitic grayish-purple (5*P* 4/2) to medium dark-gray (*N* 4) groundmass. The white coloration of the feldspars apparently characterizes only albitized and zeolitized crystals. The relatively unaltered bytownite phenocrysts of the flow rock cropping out on the highway half a mile northeast of La Muda are dark in color. Under the microscope the rock is generally seen to consist of about 40 percent phenocrysts and 60 percent groundmass. Typically the feldspar phenocrysts are zoned and twinned albite, commonly with a certain amount of replacement by zeolite. The albite is probably secondary and some thin sections show relict fragments and zones of labradorite and bytownite within the essentially albite crystal. The relicts of the calcic feldspar also occur as somewhat broken outer zones about an albite core, though with some jagged embayments of albite. A few stubby crystals of adularia were noted in one thin section. The feldspar phenocrysts generally account for about 30 percent of the mass of the rock. Green hornblende euhedra make up as much as 12 percent of the rock mass and are of all sizes up to 3 mm. Pigeonite (light green, nonpleochroic, $2V$ about 30°, $Z \vee c = 34°$), in large crystals up to 3 mm, is ubiquitous but always less abundant than hornblende and amounts to about 7 percent of the rock in some sections. Both hornblende and pigeonite are generally unaltered, though one thin section showed strong hematite rims about the hornblende. In a few samples there was an intimate association of hornblende and pigeonite, the two minerals making up what appeared to be halves of twinned crystals, which suggests the possibility that at least some of the hornblende was secondary after pyroxene. Rounded and embayed crystals of magnetite make up as much as 2 percent of the rock. Apatite is a very important and ubiquitous accessory mineral, occurring as long slender prisms in the groundmass and as poikilitic inclusions in the phenocrysts. The groundmass is generally a fine-grained xenomorphic granular aggregate, which from its refractive indices is probably albite, perhaps some orthoclase, and small nests and ill-defined streaks of xenomorphic granular quartz possessing strained extinction. A highly birefringent bright blue-green chlorite commonly occurs as an alteration of other minerals and as a vesicle filling. A yellow fibrous vesicle filling, which may be nontronite, is also common.

Exposed in the low hill that forms the right bank of the Río Guaynabo, half a mile northwest of Guaynabo, is an unusual association of glassy rocks within the Figuera volcanics. These appear to be interbedded welded tuffs(?) and vitrophyres. Rocks of this type have not been observed elsewhere in the Figuera volcanics of the area, though it is possible that they are extensively developed to the northeast of this small hill, where the formation is mostly blanketed by thick soil.

The vitrophyre is dull brown, and its texture is pebbly on the weathered surface, reflective of a slightly perlitic structure. The fresh rock is a black pitchstone in which rather sparse small phenocrysts and lithic fragments are apparent to the naked eye. In thin section the rock is strongly banded with alternate dark-gray and light-pink bands (pl. 4*B*). The dark bands are glass ($n = 1.515$) densely packed with globulites and abundant oligoclase-andesine(?) microlites, fluidly alined. The light-pink bands are almost entirely devitrified glass and consist largely of crude rosette arrangements of small pinkish and greenish lath-shaped microlites of low birefringence, parallel extinction, and refractive indices less than balsam, and minute oligoclase-andesine laths. Scattered throughout both types of bands are phenocrysts of labradorite (An_{64}), generally in angular and broken fragments. These are varied in size up to 1 mm and make up an estimated 5 percent of the rock. The edges of the crystals show a certain amount of fusion and a few crystals are riddled with globules of glass. In addition to labradorite there are scattered and rather sparse augite crystals, generally less than 1 mm in size, that are spatially associated with the feldspar. Very small epidote spherulites(?) and fine apatite needles occur in the feldspar and augite.

A light brown aphanitic rock, sparsely speckled with fluidly alined cream-colored feldspar phenocrysts up to 2 mm in length and lithic fragments up to 5 mm, interfingers with the vitrophyre. The relation of the two rocks is not clear. From the limited exposure it seems that the vitrophyre occurs as streaks several feet or more thick in the brown aphanitic rock. The latter rock has some of the characteristics of a welded tuff.

In thin section the welded tuff(?) is seen to consist of a glassy groundmass containing a dense population of small orange-red shardlike glass forms, which exhibit excellent flow alinement. The glass has an index of refraction of approximately 1.535, which according to George (1924) suggests a basaltic composition. The red coloration of the shardlike forms is imparted by globulites of reddish color, possibly hematite. Embedded in the glass are broken and fractured albite crystals up to 2 mm in length, which rather commonly show the effects of partial fusion about the edges. The albite phenocrysts are rather densely speckled by very small rosettes of a secondary mineral that, from its optical properties, may be a hydromica, or even talc.

The xenoliths in the welded tuff(?) vary from angular fragments to almost completely fused schlieren and represent several rock types, conspicuous among which are dark devitrified glasses, probably related to the vitrophyre already described, and rocks with a very fine trachytic texture.

ANALYTIC DATA

A chemical analysis of the dense flow rock that crops out on the southwest side of Highway 20, about 0.6 miles northwest of the La Muda road fork, is rather similar to the analysis of the Tortugas andesite (p. 15). The Figuera volcanics, however, are notably higher in Al_2O_3 and CaO than the former and have an unusually low K_2O content. The high normative quartz is reflected in some thin sections by considerable xenomorphic granular quartz in the groundmass. The rock can be classified as a quartz andesite. The unusually low K_2O content of this sample is not so readily explained, nor is the marked difference between the normative and modal plagioclase compositions (norm, An_{55}; mode, An_{70-80}). The glassy groundmass of the rock is probably more siliceous and less calcic than the plagioclase phenocrysts.

A chemical analysis of the vitrophyre shows an intermediate composition. The composition, interestingly enough, is close to that of a Puerto Rican granodiorite collected by the writer from the central part of the island near Utuado, which in turn is close to the average composition of 56 basic granodiorites given by Johannsen (1932, p. 344) and of 65 hornblende-biotite granodiorites given by Nockolds (1954). The vitrophyre has therefore the composition of a rhyodacite, the extrusive equivalent of a basic granodiorite.

The discrepancy between the modal and normative constituents of the vitrophyre is interesting. The absence of recognizable silica and the rather calcic composition of the plagioclase phenocrysts (An_{45}) points to a discordance between the composition of the preponderant glassy matrix and the phenocrysts. This suggests that (1) the glass consists of fused rock of intermediate composition that had contaminated the magma (fused wall rock), or (2) the glass is a late differentiate, whereas the phenocrysts date from an earlier, less evolved magmatic state. Since glass and cryptocrystalline material make up 90 percent of the mode, the composition of this material predominates in the bulk analysis. The normative composition of the glass is confirmed by the refractive index of the glass ($n = 1.515$) which indicates an SiO_2 composition of about 65 percent (George, 1924).

Chemical analyses and parameters of hornblende andesite, vitrophyre, and granodiorite from Puerto Rico, and of related rocks.

[Weight percent]

	Hornblende andesite from the Figuera volcanics; S. side Highway 20, 0.6 miles NW of La Muda road intersection (187,280 m, 55,960 m).	Vitrophyre from the Figuera volcanics; 0.7 mile NW of Guaynabo (185,630 m, 59,250 m).	Granodiorite; left abutment Caonillas dam, Puerto Rico (128,750 m, 49,200 m).	Average composition of 56 more basic granodiorites [1]
A. Chemical analyses				
SiO_2	[2] 55.6	[2] 65.8	[2] 65.9	65.41
Al_2O_3	18.2	14.8	15.8	15.72
FeO	3.2	1.6	1.6	2.92
Fe_2O_3	3.9	1.8	2.2	1.57
MgO	2.7	1.0	1.9	1.88
CaO	8.8	3.8	4.4	4.08
Na_2O	3.2	4.2	3.9	3.66
K_2O	.35	2.0	2.8	2.99
TiO_2	.55	.66	.40	.58
P_2O_5	.32	.20	.17	.17
MnO	.25	.12	.08	.07
Ignition	[3] 2.7	[3] 4.1	[3] .84	(H_2O) .92
Total	99.77	100.08	99.99	99.97
B. CIPW norms				
Quartz	14.11	24.74	20.87	
Orthoclase	2.22	11.68	16.68	
Albite	27.25	35.63	33.01	
Anorthite	33.92	15.57	17.24	
Diopside	6.21	2.62	3.70	
Hypersthene	5.90	1.66	3.55	
Ilmenite	1.06	1.37	.76	
Magnetite	5.57	2.44	3.25	
Apatite	.67	Trace	Trace	
C. Mode				
Glass and crystallites	90			
Quartz		16		
Orthoclase		23		
Plagioclase (An_{45})	9	48		
Hornblende		8		
Augite	1			
Biotite		Trace		
Chlorite (ex biotite)		3		
Sphene		1		
Apatite		Trace		
Magnetite	Trace	Trace		
Epidote		1		
Total	100	100+		

[1] From Johannsen (1932, v. 2, table 175).
[2] Chemical analyses by rapid method; analysts, Frank S. Borris, Harry F. Phillips, and Katrine White, U. S. Geological Survey.
[3] Includes gain due to oxidation of FeO.

AGE AND CORRELATION

No diagnostic fossils have been found in the basal calcareous tuffs of the Figuera volcanics in the San Juan area, and the blocks of grey limestone embedded in the basal tuffs south and west of Guaynabo are probably fragments of the Trujillo Alto limestone. Nevertheless the Figuera volcanics are thought to be probably Paleocene or early Eocene in age. This age assignment is made on the basis of fossils found in rocks both east and west of the mapped area (Kaye, 1956), which exhibit certain stratigraphic similarities to the Figuera volcanics. One of these localities is 8½ miles east of Río Piedras and about 1 mile west of the town of Loíza. Here a thick-bedded limestone, similar in appearance to the Trujillo Alto limestone, is overlain by bedded tuffs containing calcareous algae and late Paleocene or early Eocene large Foraminifera. The Foraminifera were examined by W. Storrs Cole who identified *Operculinoides bermudezi* (D. K. Palmer), *Discocyclina (Discocyclina) barkeri* Vaughan and Cole, *Discocyclina (Discocyclina) grimsdalei* Vaughan and Cole, and *Pseudophraginina (Athecocyclina) soladensis calebardensis* Vaughan. The tuffs are overlain by amygdaloidal andesitic flow of aphanitic texture, which in turn is overlain by a relatively pure algal limestone, again richly studded with Paleocene or early Eocene large Foraminifera. This volcanic sequence may be the equivalent of the Figuera volcanics. Unfortunately no rocks stratigraphically higher than the upper limestone is exposed in the Loíza locality, nor are the lower Tertiary rocks directly traceable into the San Juan area.

The second Paleocene locality is at Corozal, about 18 miles west of Río Piedras. The stratigraphic succession there is somewhat more complex than that at Loíza but consists essentially of a series of limestones, volcanic breccias and well-bedded tuffs. At the western edge of the town of Corozal there is a very coarse breccia, which is made up mostly of blocks of nearly white dense coralliferous limestone up to 20 feet across but also some blocks of andesitic rock embedded in a tuffaceous matrix. This breccia is possibly the equivalent of the basal part of the Figuera volcanics in the San Juan area, which contains large blocks of reworked Trujillo Alto limestone. Cropping out for a distance of at least a mile east and south of the quarry at Corozal are well-bedded tuffaceous rocks, locally calcareous, and lenticular, somewhat tuffaceous limestones. The latter have also yielded faunas that are very probably of Paleocene age (Kaye, 1956). These beds may grade into the hornblende andesites similar to the andesite of the Figuera volcanics, which crop out several miles southeast of Corozal (see quarry at 168,800 m, 53,500 m). The field work necessary to prove this correlation has yet to be done.

DISCUSSION

If one is correct in correlating the Figuera volcanics with the fossiliferous lower Tertiary strata of Loíza and Corozal, then it appears that the Figuera volcanics represent a well-defined eruptive period that ushered in early Tertiary deposition. These eruptions may have been widespread throughout the region, if similar hornblende-quartz andesites found elsewhere in Puerto Rico and in Hispaniola (Woodring and others, 1924, p. 310) are contemporaneous.

In the San Juan area the pronounced local thickening southeast of Guaynabo suggests a cone that had formed about a local vent. Several or more vents might have existed in the region and pyroclastic debris from these eruptive centers might have formed this distinctive, though in places thin, stratigraphic marker.

The stratified tuffaceous limestone at the north end of the Pueblo Seco quarry and the foraminiferal tuff west of Loíza (Kaye, 1956) indicate that in places the basal part of the Figuera volcanics is marine. There is some question, however, whether or not the entire thickness of Figuera volcanics in the San Juan area represents marine deposition. Evidence that possibly argues against a marine environment for the entire thickness is the lack of any sign of marine sediments or bedding in the section other than at the base. A possible argument in favor, however, is the abundance of zeolites in these rocks. Park (1946), for example, discusses the significance of zeolites as an indication of saline interactions produced by the contact of marine waters on volcanic rock.

The nature and significance of the glassy rocks exposed in the small hill northwest of Guaynabo pose an interesting problem. The known distribution of these rocks is limited to the few acres of the hill itself, though it is possible they occur beneath the masking soil and alluvial cover to the north. The rocks consist of alternate streaks, or beds, of what appears to be a welded tuff and a black augite-labradorite vitrophyre, both showing very strong fluidal banding. A chemical analysis of a sample of the vitrophyre shows that it has the composition of a rhyodacite. The most important question raised by this rock is whether it is a product of the same eruptive cycle as that which produced the quartz-bearing hornblende andesites of the Figuera volcanics. It is noteworthy that almost all the essential mineralogic criteria of the Figuera volcanics—hornblende, pigeonite, and quartz—are missing in the vitrophyre.

The refractive index ($n = 1.535$) of the glass of the welded tuff(?) indicates that this rock has a bulk composition of basic andesite, or even basalt. The small glassy shardlike shapes, densely packed and fluidly alined, that make up much of this rock, are strongly suggestive of the glass shards of vitric tuffs. They lack, however, the sharp tricornered or arcuate shapes of normal glass shards but resemble rather, glass shards that have been very much softened, compacted, and thereby deformed. The glass of shard and matrix are alike except for the dark color of the shard forms, which is imparted by a dense conglomeration of red globulites—the same globulites that are found more sparsely distributed in the matrix glass. C. M. Gilbert (1938, pl. 3; figs. 3, 6) figures several thin sections of the welded Bishop tuff in eastern California that resemble the Puerto Rican rock, except that in the latter the shard shapes are dark rather than light. The more deeply buried Bishop tuff is described by Gilbert as a dense, glassy rock in which the intense compression suffered by the pumiceous glass fragments made it possible for the glassy material to enter into the small embayments of resorbed quartz crystals (p. 1842). This phenomenon is duplicated in the Puerto Rican rocks where the shardlike forms squeeze into narrow corroded embayments and fractures of the albite xenocrysts.

What is the origin of the welded tuff-vitrophyre association? The vitrophyre, which differs in mineralogy and chemical composition from the andesites of the Figuera volcanics, may possibly represent fused wall rock that was engulfed by the andesitic magma. Banded glass and pumice of different composition but resembling somewhat the Figuera volcanics in association have been described from the Mt. Katmai area of Alaska by Fenner (1950), among others. Fenner writes of large and small blocks in the incandescent tuff deposit of the Valley of Ten Thousand Smokes, consisting of bands of dark-colored basic glass ($n = 1.520–1.540$) and light-colored pumice and welded tuff. Similar banding also characterizes the dome of nearby Novarupta. Fenner considered the dark glass to be fused basic country rock that had been engulfed by the superheated rhyolitic lavas and retained as a somewhat immiscible phase in the acidic ejecta of the eruptions. The dark vitrophyre in the Figuera volcanics may by analogy represent such a fused wall rock, and its mineralogic composition may therefore reflect the composition of that rock rather than the composition of the Figuera lavas. But in the Puerto Rican association, unlike the Mt. Katmai occurrence, the fused wall rock appears to be the more silicic of the two components.

The question remains whether a welded tuff is an absolute criterion for the subaerial eruption of the Figuera volcanics—a question that has already been raised. Because so little is known about submarine volcanism, one is obliged to admit the possibility that welded tuffs can form beneath the sea. If they do, however, it seems most probable that they form very small deposits that are confined to the vicinity of the vent. High-temperature submarine eruptions may minimize the important cooling effect of the water environment, permitting the partial refusion of glassy ash. The extremely limited distribution of these rocks in the Figuera volcanics points to the possibility of such an interpretation.

FAJARDO FORMATION

Berkey (1919, p. 18) gave the name Fajardo shales to the blocky, well-bedded, ashy shales—or siltstones, as they are called in this report (see below)—that crop out in the vicinity of the town of Fajardo, in the northeastern corner of the island. Meyerhoff and Smith (1931) recognized the flows of the Figuera volcanics as forming the base of this formation in that area. Its upper limit they determined to be gradational with more coarse-grained beds, to which they applied the name San Diego formation. These authors included in the Fajardo shales all the blocky, well-bedded ashy siltstones in their district.

Although the ashy siltstone of the Fajardo formation at the type locality in the Fajardo area has not been traced to the San Juan area as a continuous outcrop, there is no denying that the lithologic similarity of the rocks in the two areas is strong. The name Fajardo has therefore been retained in this report for these rocks, but the descriptive term shale has been dropped because of the questionable appropriateness of the term to the prevalent lithology and because of the importance of other types of rock within the formation.

Most characteristic of the Fajardo formation is a relatively soft, very well bedded, light-colored, nonfissile aphanitic rock of a rather low density (pls. 7*B*, 8). The lithologic term shale that was applied to these rocks by the New York Academy of Science authors is not quite appropriate because the rocks lack fissility. According to Twenhofel's classification (Twenhofel, 1937) they might more fittingly be called claystone, siltstone, or even bedded marine ash or ashy claystones, inasmuch as they probably consist largely of very fine grained volcanic ash now variously altered to clay. The term ashy siltstone is preferred, however, to a clay designation because to the touch the texture is definitely silty. The color is light yellow, light tan, white, pink, and various shades of red. The beds vary from 1 inch to 6 inches but are generally about 2 inches thick. Small undecipherable vermicular surface markings that suggest an organic origin are common on the bedding surfaces, but otherwise the beds are unfossiliferous. Thin intercalations, usually less than 1 inch thick, of light-gray to white kaolinitic clay are common between the individual siltstone beds. The rock is everywhere well jointed, and it breaks readily into rhomboidal-shaped flagstones and blocky fragments bounded by smooth joints and bedding planes. In thin sections the rock is seen to consist of a porous, fine-grained, clayey aggregate. James P. Owen reports (written communication) that X-ray and petrographic study of these rocks shows that they consist of kaolinite and quartz. Berkey (1915, p. 31) suggested that the pores were molds of Foraminifera whose calcareous tests had been leached by weathering. Despite the fact that the rock seems to be deeply weathered, it does not decompose readily to soft clay but retains its cohesive strength and form even when wet. This peculiarity probably accounts for the fact that in the San Juan area its outcrops generally form prominent topographic highs. Most of the Montes de Hatillo, south and east of Río Piedras, and the north- to northeast-trending ridge west of Guaynabo, for example, are cuestas of these rocks.

Besides the rather soft ashy siltstone there is also cream-colored to white thin-bedded chert and a siliceous siltstone. The latter is a rock that seems to possess qualities of both chert and ashy siltstone.

Intercalated with these ashy siltstones and cherts are other sedimentary rocks, ranging from tuffaceous limestone to conglomerate, and including bedded tuffs and volcanic breccias. These rocks are best developed in the Fajardo outcrop in the vicinity of Guaynabo and are relatively scarce in the Montes de Hatillo, east of Río Piedras. They are clearly more abundant in the southwestern part of the area, where they aggregate over half the thickness of the formation. In the following cross section of the Fajardo formation where it is exposed on the north side of the cut made by the Río Guaynabo through the cuesta ridge northwest of Guaynabo, the ratio of coarse-clastic and nonashy beds to ashy siltstone is very much greater than where the formation crops out in the Río Piedras area.

A little more than a mile south of the Río Guaynabo section an important thickness of massive to stratified purplish-gray tuff is found interbedded in the clastic beds of the upper part of the section. These are possibly the equivalent of Meyerhoff and Smith's San Diego formation. They are here included in the Fajardo formation because it seems evident that the typical ashy siltstone is only a facies and that the formation consists of a wide range of rock types forming an interfingering sequence.

The contact of the Fajardo formation with the underlying Figuera volcanics seems essentially conformable in the few places where it was seen, although in the side of the road about two-thirds mile southwest of Guaynabo a decided angularity exists between the flow lineation of the phenocrysts in a 5-foot Figuera flow that is exposed there and the overlying ashy siltstone of the Fajardo formation. No formational unit of the older complex higher than the Fajardo formation has been recognized in the San Juan area. The maximum thickness of the formation was observed in the Trujillo Alto road traverse, where it is estimated that at least 3,000 feet of the Fajardo formation is exposed.

Section of part of the Fajardo formation exposed in north side of Río Guaynabo valley, northwest of Guaynabo

Unit	*Description*	*Approximate Thickness (feet)*
1.	Graywacke, gritty, well-jointed, thin- to medium-bedded; minor amounts of interbedded argillaceous sandstone and gray calcareous tuff and tuffaceous limestone. Graywacke is dark green when fresh, weathering to dark brown. Small pipes, resembling casts of worm tubes several inches long and one-half inch or less in diameter, of a dark green structureless material with a conchoidal fracture occur in this tuffaceous sandstone. The material was studied by Robert L. Smith, U. S. Geological Survey, who described it as a mineralogic anomaly possessing the crystalline structure of celadonite but occurring in a manner more typical of glauconite. It may be crystalline glauconite or an intermediate link between typical glauconite and typical celadonite	700
2.	Siltstone, ashy, thin-bedded, light-colored; and chert	250
3.	Conglomerate, fine, thin- to medium-bedded; and gray tuffaceous limestone, tuffaceous sandstone, and minor amounts of clay shale	175
4.	Well-bedded red, yellow, and white ashy siltstone and siliceous siltstone with some crossbedding and ripple-marking	285
5.	Interbedded, gritty, tuffaceous sandstone, fissile shale, and ashy siliceous siltstone. Siltstone makes up approximately 55 percent of total thickness	275
6.	Interbedded brownish-gray fissile arenaceous shale and greenish-gray fine-grained sandstone	200
	Total thickness of Fajardo formation exposed	1, 885

The Fajardo formation is considered to be marine, although no fossils have been found in it. The ashy siltstone probably accumulated from fine volcanic ash fallen directly into the sea and from detrital ash and land-derived sediment washed into the sea. The coarser grained and nonashy facies may have accumulated close to shore, possibly in a littoral environment. Following this line of reasoning, and considering the relative distribution of the sedimentary types, it appears that the parental land mass lay to the south and possibly west of the San Juan area. This agrees essentially with the position of the insular cone as deduced from the Hato Puerco tuff and other beds (fig. 4). Judging from the general absence of coarse-grained volcanic debris, volcanic activity during the deposition of the Fajardo sediments was either on a reduced scale or was relatively remote. Certainly the vents which ejected the

Figuera volcanics were inactive in this area or else were emitting only fine ash. On the other hand, the tuff beds in the upper part of the formation reflect a renewal of explosive activities somewhere in the general neighborhood. Some of these pyroclastic deposits may even have accumulated subaerially and may thus be the landward continuation of the marine sediments of the formation.

Age.—No fossils have been found in the Fajardo formation. Because it overlies the Figuera volcanics it is judged to be late Paleocene or Eocene in age.

INTRUSIVE IGNEOUS ROCKS

ALBITIZED BIOTITE GRANODIORITE PORPHYRY

Cropping out in the southern part of the San Juan area is a body of porphyritic rock, of highly irregular shape, whose average composition is approximately that of a sodaclase granodiorite. However, it seems very probable that in these rocks, as in the volcanic rocks of the area, the albite is a replacement of a once calcic plagioclase. The rocks are therefore called albitized granodiorite porphyry in preference to A. Johannsen's (1939, p. 144, fig. 106) term "sodaclase-granodiorite," which, to the writer, does not denote clearly enough, except by implication, the secondary nature of the albite.

Megascopically, the granodiorite porphyry generally consists of white to pink feldspar phenocrysts, 3 to 5 mm in length, abundant to sparse quartz crystals ranging up to 5 mm in length; and small, commonly bleached biotite flakes in an aphanitic bluish- to greenish-gray groundmass that makes up from 45 to 65 percent of the rock mass. The microcrystalline texture of the groundmass points to a hypabyssal origin for these rocks. Facies that are finer grained and coarser grained than the typical rock occur.

Microscopically the feldspar phenocrysts are seen to be mostly albite, in an advanced state of alteration to coarsely crystalline carbonate, sericite, and lesser amounts of chlorite. Some thin sections show orthoclase as well, but this mineral is never as abundant as albite. Some albite contains small relict patches of a calcic plagioclase; unfortunately the composition of these relicts could not be determined by the normal optical methods employed. The size and relative abundance of quartz phenocrysts is highly variable. In the coarse-grained rock that crops out at the south margin and near the southwest corner of the mapped area, quartz phenocrysts make up about 20 percent of the rock, but in other places they form less than 1 percent. The quartz crystals are generally somewhat rounded and embayed, and they occur as single individuals and as groups of twins. Extinction is sharp. Some thin sections show a slight continuous growth of quartz from the phenocryst into the groundmass, and others show a thin aureole of minute epidote spherulites that form a halo at the edge of the quartz. The biotite, which makes up from 8 to 10 percent of the rocks, is always colorless in thin section; it is partly to entirely replaced by chlorite. In some thin sections the biotite crystals are bent and much shredded at the terminations. Noted in one thin section were sparse phenocrysts of chlorite, which, judging from their outline, were originally an amphibole or pyroxene. The groundmass of the granodiorite porphyry is a microgranular aggregate of quartz and orthoclase—in which the percentage of quartz ranges from an estimated maximum of 80 percent to less than 20 percent—and very small scales of colorless mica in a sparse felted arrangement. Accessory minerals include rather common apatite up to 0.2 mm in length, sphene, and rare tourmaline in slender prisms. The secondary minerals chlorite (penninite), sericite, carbonate, and epidote were common in all thin sections studied.

The granodiorite porphyry is generally deeply weathered, and relatively fresh rock can be found only in stream beds. It weathers to a light gray to nearly white residual soil, characteristically rich in small mica flakes. The very light color of the soil and the presence of mica are of distinct aid in tracing the outcrop of this rock in the field. The weathered rock is easily eroded and the outcrops of granodiorite porphyry are commonly marked by topographic lows.

The outcrop pattern of the granodiorite porphyry indicates that the rock belongs to a rather large subjacent body of which only the upper part has been exposed. The deeper valleys show that the intrusive mass is discordant and widens at depth. Moreover, the contacts are generally sharp and show negligible metamorphic effects. The variations in texture and composition of the granodiorite porphyry suggest that it was formed under rather varied conditions of cooling, like that which might occur in the cupolas and uppermost reaches of a large subjacent magma body. These factors point to the possibility that the San Juan and adjoining areas are underlain by a broad intrusive mass, which has been unroofed by erosion in only a few places and which has a varied though predominately granodiorite-porphyry composition in its upper parts. This igneous body may well be related to, if not connected with, the batholith that crops out in southeastern Puerto Rico, which has been described by Fettke (1924).

AUGITE ANDESITE PORPHYRY

Under this heading are included coarsely porphyritic dark rocks that occur as both tabular and irregular-shaped bodies, which, in places, give evidence of assimilation of their wall rocks. These rocks are considered to be hypabyssal intrusives, although, as will be explained later, there is a problem of distinguishing some of these rocks from the volcanic Tortugas andesite. The rocks generally have a dark gray (*N* 3) aphanitic groundmass with randomly oriented plagioclase phenocrysts up to 8 mm in length and sparse augite crystals of about the same size. In places the groundmass is a lighter gray with dark greenish-gray specks consisting of spherulites of celadonite and (or) chlorite.

The largest body of augite andesite porphyry is in the southern part of the mapped area. Here the outcrop is marked by boulder-littered slopes and an especially red soil. Only several dikes of this rock have been shown on the geologic map, but narrow tabular intrusions are undoubtedly more common than these few examples indicate. Augite andesite porphyry also occurs as sills at several stratigraphic levels. One of these is in what is probably the contact of the Guaynabo and Frailes formation, that is to say, the horizon of the Tortugas andesite. The large quarry at Trujillo Alto is thought to be in a local thickening of such a sill. Although the Tortugas andesite is not always present in the section, its stratigraphic position is in several places marked by coarsely porphyritic andesites that are thought to be of intrusive origin. The reasons for considering these rocks to be intrusive rather than the extrusive Tortugas andesite is primarily (1) the coarseness of grain size in comparison with the typical Tortugas andesite, (2) the localization of the largest phenocrysts in the upper part whereas flow rock would probably have a chilled upper contact, (3) evidences of wall-rock assimilation, and (4) textural and compositional peculiarities, which will be described below.

The typical augite andesite porphyry contains about 70 percent of dark-gray to dark blue-gray groundmass. The groundmass has a hyalopilitic texture consisting of a felt of minute oligoclase-andesine laths (in places, skeletal crystals with swallow-tail terminations) and narrow prisms of augite in rosette arrangement in a mesostasis of devitrified brown glass. The glass is rich in crystallites, spherulites, and curly fibers of a colorless mineral (low birefringence and an index of refraction slightly above Canada balsam) and some green chlorite. In addition, there are many amygdule-shaped bodies of a fibrous, light brownish-yellow, clay mineral (possibly chlorite or celadonite) in spherulitic or concretionary structure. Calcite and scattered grains of clinozoisite also occur in the groundmass. The entire cryptocrystalline mesostasis, and particularly the chlorite and celadonite, is densely sprinkled with minute grains of high birefringence and relief (epidote and rutile?).

The phenocrysts consist of calcic labradorite (generally An_{67}), making up about 20 percent of the rock; fresh augite, making up about 2 percent of the rock; and a pyroxene entirely replaced by chlorite. In a few thin sections the plagioclase has been albitized.

There are strong indications of a certain amount of wall-rock assimilation. In several places the contact of the sedimentary country rock and the andesite is gradational over a distance of 50 or more feet and is first marked by the appearance of scarce, small plagioclase phenocrysts in what seems to be the country rock. These phenocrysts become more abundant as the andesite is approached until the typical andesite porphyry is developed. Fragments and short veinlike masses of microcrystalline calcite resembling normal unmetamorphosed limestone were noted in the andesite porphyry at the quarry at the edge of Trujillo Alto and in the small oval area south of Río Piedras. It is possible that these are unassimilated relicts of limestone country rock, although, if so, their apparent lack of recrystallization is unusual under the circumstances.

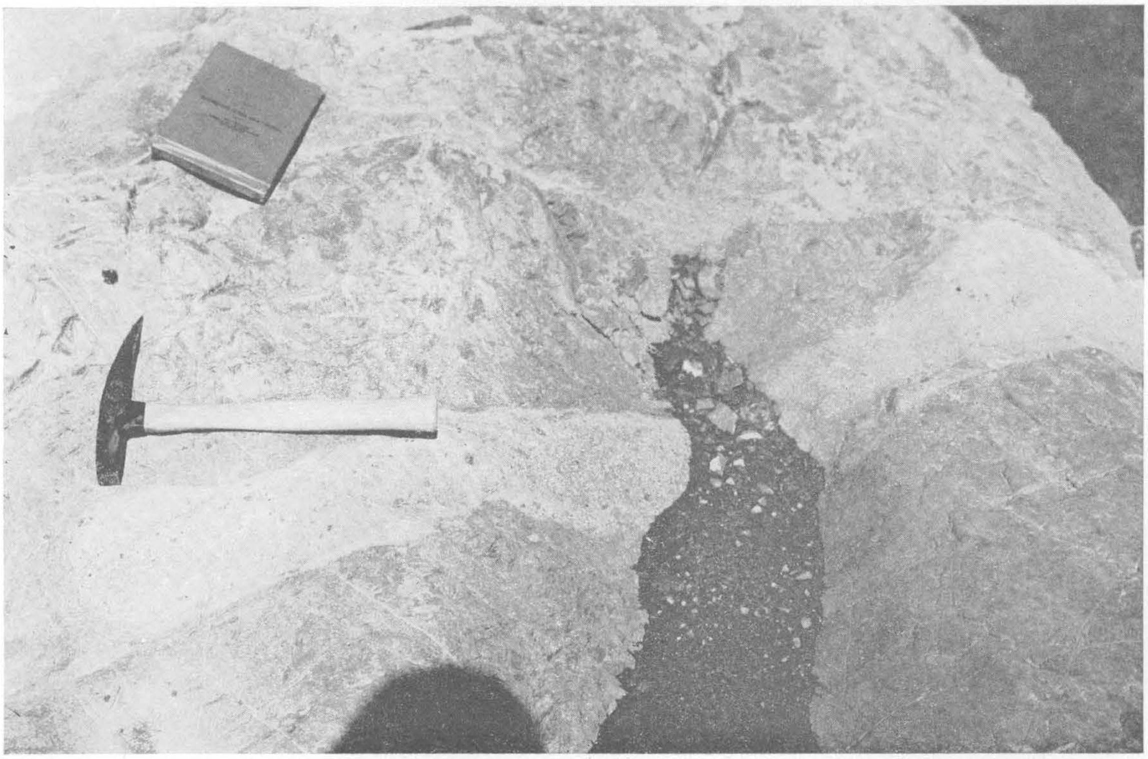
Where the sill of andesite porphyry crosses the new Río Piedras–Caguas highway, 2 miles south of Río Piedras, induration of the underlying sandstone and shale can be seen and large boulders of comb quartz, up to 12 inches across, are found on the lower slopes of the small hill just west of the highway at this point.

DIABASE

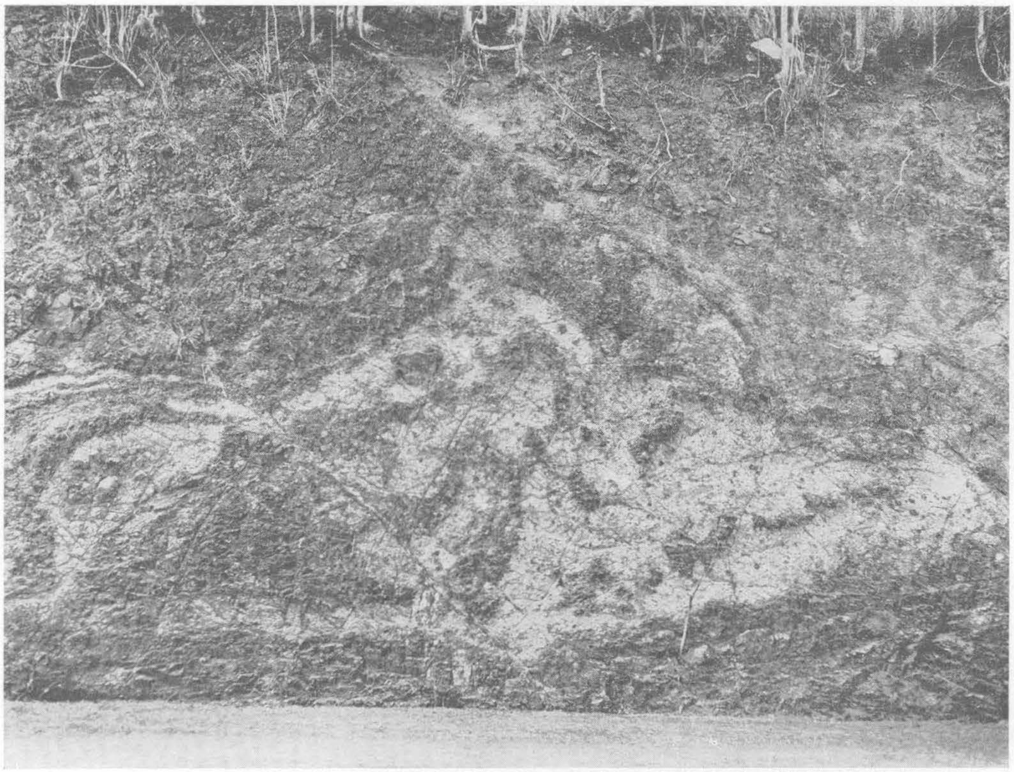
Diabase dikes, sills, and irregular pipelike bodies occur throughout the section of older complex rocks. Not uncommonly their outcrops are marked by low hills with large telltale residual boulders on the surface. The rocks range in texture from coarse-grained, containing plagioclase laths 5 mm or more in length, to fine-grained diabase, in which the plagioclase laths are about 0.7 mm in length. The presence of varied amounts of quartz is common, al-

A. DRUMSTICK DIKE IN THIN-BEDDED ASHY SILTSTONE

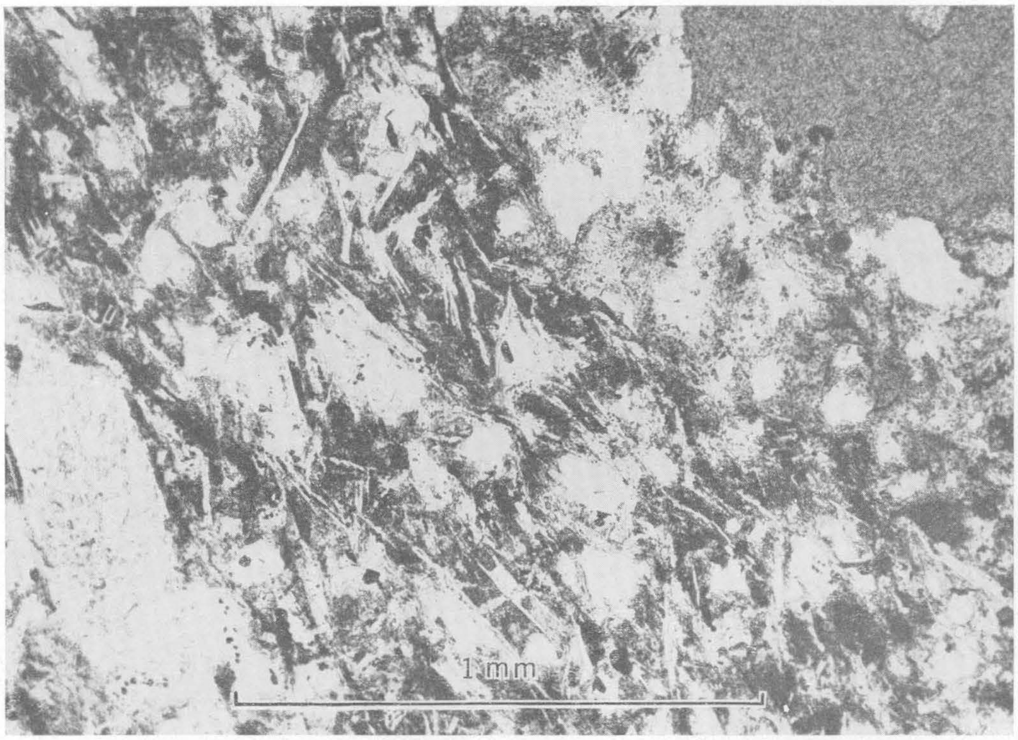
Note lack of bedding distortion that would have been expected if dike had been emplaced by dilation



B. DRUMSTICK DIKE (LIGHT) IN ACTINOLITIC METAANDESITE; BED OF THE RÍO GRANDE DE LOÍZA, AT DAMSITE



A. IRREGULAR-SHAPED REPLACEMENT OF THIN-BEDDED ASHY SILTSTONE BY ANDESITE PORPHYRY (LIGHT COLOR); COAMO QUADRANGLE, ON HIGHWAY 14



B. METAGRAYWACKE; FAJARDO QUADRANGLE, NORTH SIDE OF RÍO DEMAJAGUA VALLEY

Relict quartz (clear) with secondary swallow-tailed albite laths; albite porphyroblast in lower left and part of a chlorite-epidote "amygdule" in upper right. Magnification 69.9 ×, plane polarized light though some thin sections show none at all. Besides the usual augite there is some biotite and always considerable amounts of interstitial chlorite, which may be largely secondary after biotite. The feldspar is commonly albitized but in places still retains its labradorite composition. The diabases are generally extensively altered to chlorite, clinozoisite, zeolites, and carbonate.

AGE OF INTRUSIVE ROCKS

The oldest of the three intrusive rock types recognized in the San Juan area is probably the andesite porphyry. This rock has not been seen cutting other intrusive rocks. The last of the three rock types to be intruded is the diabase, for dikes and plugs of this rock are found cutting the granodiorite porphyry. An andesite porphyry dike cuts the Figuera volcanics a little less than a mile east of La Muda. Thin dikes of the same rock have been seen cutting the Fajardo ashy siltstone in the Montes de Hatillo. For this reason all three rock types are thought to postdate the entire sedimentary and volcanic section of the San Juan area, and their date of emplacement may therefore be late Paleocene or Eocene. This does not eliminate, however, the possibility that the andesite porphyry may have been intruded over a long time interval, starting perhaps in the Cretaceous. The intrusion of the granodiorite porphyry, from the outcrop pattern in the area east of La Muda, appears to have followed major faulting. The lack of strain shadows in the extinction of the quartz of the granodiorite porphyry and their presence in the quartz of the Figuera volcanics is another possible indication that major structural deformations preceded the emplacement of the former rock. This interpretation, however, requires further study.

METAMORPHISM AND ALBITIZATION

REGIONAL METAMORPHISM

Megascopically, none of the rocks of the San Juan area are metamorphic in aspect. All of them preserve intact the original structures and textures of igneous and sedimentary rocks. This is, moreover, true of most older complex rocks in Puerto Rico[4] and is in contrast with the adjoining island of Hispaniola, on which Koschmann and Gordon (1950) and others have studied well-developed, widespread metamorphism of a regional type. However, the Puerto Rican older complex rocks, and those in the San Juan area in particular, show persistent suites of secondary minerals, chiefly chlorite, epidote, and albite, and in places actinolitic hornblende (Hato Puerco tuff), which probably indicates metamorphic changes on a regional scale. If this is so, however, the large amount of original mineral constituents retained in the older complex rocks can be considered indicative of a very incomplete and lowgrade adjustment.

Chlorite (very commonly penninite) is almost ubiquitous; and epidote, clinozoisite, and calcite can be found in almost all thin sections regardless of rock type. Feldspars are commonly albitized. Secondary amphibole, generally in the form of fine actinolite, is largely confined in the San Juan area to the Hato Puerco tuff. All these minerals are typical of Eskola's (1939) green-schist facies, which is formed by the lowest grade of regional metamorphism. It is not certain, however, just how much these minerals owe their presence in the Puerto Rican rocks to metasomatism or to regionally elevated pressure and temperature.

There is some basis for thinking that the rocks have responded more to the introduction of new constituents and perhaps to heat than they have to pressure. There is a lack of preferred orientation to the platy secondary minerals, such as the chlorites. No study was made of quartz orientation, but some primary quartz has sharp extinction indicating a lack of strain. Both factors suggest that large stresses did not markedly effect the rocks, an impression that is substantiated by the general moderate deformation by folding that is exhibited by these rocks.

ALBITIZATION

One of the most persistent and characteristic of the mineralogic changes of older complex rocks is the alteration of soda-lime plagioclase to albite. Albite occurs in rocks of sedimentary, volcanic, and intrusive origin; and it is characteristically present in all rocks that show advanced alteration to secondary minerals. Thus albitized rocks are generally high in sericite, chlorite, calcite, and epidote.

Albite is commonly characterized in thin sections by incomplete extinction between crossed nicols. This effect probably arises either from a general disruption of the plagioclase space lattice by discordant or disarranged molecules, or from the general spatial disarray produced by the removal or regrouping of ionic components of the anorthite molecule during the process of albitization.

[4] The writer has seen fine- to coarse-grained schists at several localities in Puerto Rico. All of these, however, gave evidence of being localized in zones of contact metamorphism or major faulting.

The presence of relict soda-lime feldspar in some of the albite, as well as unaltered crystals of soda-lime plagioclase in rocks that are closely related to the albite-bearing rocks points to the secondary nature of most, if not all, of the albite and suggests the importance of local factors—such as relative permeability of the rocks to diffusibles—to the process of alteration. The importance of permeability seems especially indicated by the fact that dense, glassy rocks are somewhat less albitized than holocrystalline rocks. This suggests that the reagents responsible for albitization were more readily able to move along the wide channelways of crystal interfaces and along the cleavage partings in crystal space lattices than through the randomly distributed and probably discontinuous inter-ionic spaces of a glass.

The importance of metasomatism in the formation of a typical spilite-keratophyre association has been discussed by Turner and Verhoogen (1951, p. 201–212). These authors have emphasized the importance of marine connate waters within a thick sedimentary prism to the process of regional soda enrichment. Part of the sedimentary section of the San Juan area, however, is probably nonmarine in origin, and the Hato Puerco basement rocks constitute a volcanic cone, part of which probably accumulated subaerially. Moreover, albitization has affected the granodiorite porphyry which, it will be recalled, may form part of a larger subjacent igneous body. These facts suggest that soda from marine waters entrapped in the sediments was not entirely responsible for the albitization of the older complex rocks. At least some of the albitization may be due to magmatic emanations rich in soda, and some of it may be due to the selective removal of the anorthite molecule from the plagioclase space lattice and its replacement by calcite, sericite, and chlorite. The latter would appear possible on theoretical grounds and should be considered in a detailed study of an albitized province such as that of the older complex of Puerto Rico.

ASSIMILATION, METASOMATISM, AND CONTACT METAMORPHISM

The frequency with which one sees igneous textures blended into nonigneous rocks; the presence of fragments of country rock, particularly limestone, in the andesite porphyries; the structural relation of small intrusions and country rock; and the varied revelations of the microscope—all point to the probability that a large amount of sedimentary country rock has been transformed by one process or another into rocks that appear to be igneous. Whether this is a matter of assimilation or of metasomatism (andesitization?), as the terms are currently defined, remains to be investigated.

Basic dikes and odd-shaped intrusions, the mechanics of whose emplacement seems difficult to explain other than by assimilation or metasomatism, have been noted at several localities in Puerto Rico. One of the most frequently encountered forms of these intrusions is the drumstick dike, a term used here to designate a dike with an abrupt, rounded, and not uncommonly slightly bulbous termination (pl. 5*A*, 5*B*). Plate 5*A* is a typical example of one of these dikes and shows the lack of distortion of the thin-bedded ashy siltstones about the margins of the dike. Noble (1952, p. 35–36) has described drumstick dikes in the Homestake mine, South Dakota, and has shown that there the structure of the surrounding wall rock has been deformed to accommodate the intrusion. There is no structural evidence, however, that the spaces occupied by the several Puerto Rican dikes studied were due to dilation of the walls, either forcibly or otherwise. The only apparent means for the emplacement of this and similar dikes is by filling of a preexisting cavity or by the replacement of the wall rock, that is, by assimilation, metasomatism, or "granitization," depending on one's preference among these controversial terms.

In addition to drumstick dikes, several exposures of well-bedded rock were seen, in which andesite bodies of highly irregular shape graded into the normal wall rock or showed negligible wall-rock distortion, and where palimpsests of the bedding were apparent in the andesite. One of the best of these (pl. 6*A*) occurs outside the San Juan map area, on the Aibonito-Coamo road (Highway 14), about 4½ miles as the crow flies northeast of Coamo (167,070 m, 30,650 m). The country rock here is a thin-bedded, tuffaceous sandstone and ashy siltstone. The invading rock is a hornblende porphyry (probably andesitic) with an aphanitic groundmass. Several drumstick dikes occur and large irregular masses of porphyry grade into the country rock. The porphyry seems to replace the tuffaceous siltstone selectivity along bedding planes, and palimpsests of siltstone strata occur in position within the porphyry. No displacement of bedding is apparent around the margins of this body.

An interesting example of contact(?) metamorphic texture is a dark blue-gray hornfels with conspicuous amygdules that crops out on the north side of the valley of the Río Demajagua about 3 miles south of Fajardo, outside the San Juan map area. Prominent quartz and calcite amygdules litter the outcrop area. In the hand specimen, this rock resembles a dense aphanitic flow rock, and apparently it falls within the area mapped as the Figuera formation by Meyerhoff and Smith (1931). Microscopic examination, however, shows that it is probably an altered tuffaceous sandstone or graywacke.

In thin section (pl. 6*B*) the rock is seen to consist of scattered subrounded quartz grains, up to about 0.15 mm in size and showing, some continuous growth and strained extinction, and a groundmass that is made up of a combination of quartz and feldspar with much ore dust, minute patches of chlorite, and some very fine grained epidote. Slender, slightly bent albite laths, generally with swallow-tailed terminations, occur in a sparse felted arrangement between the quartz grains. There are a few scattered albite porphyroblasts about 0.5 mm in length. Sillimanite needles occur sparsely and seem to favor the quartz. Rods of ilmenite are rather common. The amygdules are of two types—those completely filled with strained quartz in fine to coarse grains, and those completely filled with fine-grained chlorite and some epidote.

The scattered quartz grains are the most obvious mineralogic relicts of the original graywacke. The alteration of some of the nonquartzose components of the original rock to albite laths in a felted arrangement seems particularly interesting. This texture suggests that similar contact metamorphism of a tuffaceous sandstone or graywacke with somewhat less quartz might conceivably produce a typical pilotaxitic or even diabasic texture that could be confused in thin section with an igneous rock. Whether or not this type of alteration produced any of the andesite porphyries and albitized diabases noted in the San Juan area is open to conjecture.

MIDDLE TERTIARY DEPOSITS

AGUADA FORMATION

According to Zapp and others (1948) the basal middle Tertiary in the San Juan area is the Aguada limestone of early Miocene age. Inasmuch as the formation consists predominantly of noncarbonate rocks in this area (see below), the designation in the San Juan area is hereby changed to Aguada formation to allow for the indicated lithologic variation. The contact of these beds with the older complex rocks has not been seen, but it is undoubtedly marked by an angular unconformity. Several water wells (McGuinness, 1946, wells Gb 17, Gb 22, and others) in the vicinity of Montes de Caneja, which reached the older complex beneath the middle Tertiary, show that the unconformity is an irregular surface here. The possibility exists that these irregularities are due to faulting, but there is no reason to think that a boundary fault separates the older complex and the middle Tertiary deposits in the San Juan area.

The beds assigned to the Aguada formation crop out as soil-covered rounded slopes and tepee-shaped hills east and west of Río Piedras. This topographic form is in contrast with that developed on the overlying dense Aymamón limestone, which generally forms karst hills with steep rocky slopes.

Several excellent exposures of the Aguada formation in the San Juan area—for example, at the base of the Montes de San Patricio (pl. 9*B*) and in a quarry just west of the Bayamón District Hospital west of the map area—as well as cuttings and samples from many water wells show that in this meridian the formation consists predominantly of marly clay, clay with small lime nodules, silty and sandy clay, sands that in places are highly quartzose, gravel, and some nodular calcareous sandstone. Limestone as such, and particularly dense limestone, occurs only sparsely and generally as thin lenses. The section exposed in the quarry on Highway 2, just west of the mapped area (183,900 m, 62,930 m), is considered typical of the formation in the area. All beds and units vary in thickness in the section that follows:

Section of Aguado formation exposed in quarry west of Bayamón District Hospital (183,900 m, 62,930 m)

Unit	*Lithologic description*	*Approximate thickness (feet)*
1.	Silt, light greenish gray, compact, sandy, with brown mottling. Upper part rich in hard white chalky lime nodules. Only lower part exposed in quarry face	15
2.	Sand, dark brownish gray, slightly cemented; contains rounded pitted masses of fossiliferous red calcareous sandstone up to 5 feet across. Overlying these nodules at one place is a concentration of black sand. The top of this unit is a possible paleosol(?), consisting of 6–8 inches of deep reddish brown, medium-coarse sand with slight clay binder and with thin clay partings rich in fossil leaves	14
3.	Sand, brown, silty, fine to coarse; occurring in a lens with angular hard calcareous sandstone nodules, coarse angular gravel, light-green and brown mottled silt	0–7.5
4.	Sand and gravel, medium to coarse angular to subangular. Sand consists mostly of quartz, chert, and miscellaneous rock fragments. Gravel up to 4 inches in size. Quartz and chert pebbles common. Some weathered andesite and tuff	16

Section of Aguado formation exposed in quarry west of Bayamón District Hospital (183,900 m, 62,930 m)—Continued

Unit	Lithologic description	Approximate thickness (feet)
5.	Clay, silty, slightly mottled, green, and fine sandy clayey silt. Clay is plastic and soapy to the touch. Unfossiliferous	6
6.	Sand, clayey, light green, with slight cohesion due to a plastic green clay binder. Sand predominantly quartz. Top 16 inches is iron-stained. Unfossiliferous. Variable in thickness	4
7.	Sand, medium-coarse, light brownish-gray, with some lime cementation. A few scattered pebbles up to 2 inches in size	6
8.	Clay, sandy, mottled light green and light brown. Sand is mostly angular clear quartz	⋝4
	Total Aguado formation exposed	62.5

Exposed about the base of the Montes de San Patricio are the green nodular clays of unit 1 (above), which apparently characterize the upper part of the Aguada formation in this area.

It is estimated that about 325 feet of predominantly clastic sediment make up the Aguada formation in the San Juan area. The 255-foot water well of the Caparra Dairy (McGuinness, 1946, well Gb 38) is entirely in this formation.

There is some question whether the formational name Aguada is correctly applied to all of these beds. According to Zapp and others (1948), the Aguada formation possesses the following characteristics: (1) It underlies the dense limestones of the Aymamón formation; (2) it possesses a fauna of Miocene aspect like the overlying Aymamón limestone; and (3) it consists essentially of interbedded pure limestone and softer chalky to marly limestone, although up to 32 feet of basal sand, gravel, and shale occur where the formation rests directly on the Cretaceous rocks.

It is clear that the predominant limestone lithology of the Aguada formation, as described by Zapp and his co-workers does not characterize the section in the San Juan area, where from a lithologic standpoint the beds more nearly resemble the noncarbonate clastic subdivisions of their Río Guatemala group of late Oligocene age, which according to these authors does not occur in the San Juan area. Inasmuch as no paleontologic study was made of the middle Tertiary section of the San Juan area in the preparation of this report, the formational assignment can not be examined in the light of the age criteria. The possibility should be recognized, therefore, that the Río Guatemala group is represented in part in the San Juan area, although it is also possible, as indicated by the authors mentioned, that the beds in the San Juan area are simply a thick, noncarbonate, clastic facies of the Aguada formation.

AYMAMÓN LIMESTONE

Overlying the clastic sediments of the Aguada formation are medium- to thick-bedded, dense, white to pink limestone and minor amounts of marl, sand, and clay that Zapp and others (1948) have termed the Aymamón limestone. This formation is the uppermost unit of the middle Tertiary section of the north-coastal plain as recognized by these authors, and is of early Miocene age.

The contact of the Aymamón limestone with the Aguado formation, where exposed northwest of Suchville and in the sides of the Montes de San Patricio, is sharp and generally conformable, although there is a slight irregularity and angularity of the bedding above and below the contact at the east end of the Montes de San Patricio.

Outcrops of the Aymamón limestone are marked by prominent hills with steep to vertical rocky slopes, a peculiar form well illustrated by the Montes de Caneja. This haystack type of outcrop is in marked contrast to the low rolling slopes of the underlying Aguada formation. The Aymamón limestone is cavernous and scored by deep solution pits. Vegetation is rooted in the soil-filled crevices and pits on otherwise almost soilless slopes.

The Aymamón limestone is prevailingly medium bedded. In natural exposures, however, it appears to be thick bedded to massive, owing to a coating of caliche (secondary $CaCO_3$) which tends to seal and obliterate much of the bedding and to mask the thin marly and sandy beds. In addition, caliche commonly cements together loose surface rubble into massive deposits of somewhat iron-stained, honeycombed rock.

The total thickness of the Aymamón limestone is not known, but from the width of its outcrop and by assuming an average north dip of 4°, it is computed that roughly 950 feet of Aymamón limestone underlies the island of San Juan. Yet, geophysical exploration by seismic method at Palo Seco, about 1 mile west of the San Juan area, suggests that close to 3,000 feet of middle Tertiary sedimentary rocks occurs there, indicating that the middle Tertiary section thickens strongly northward (Kaye, 1957). The Aymamón limestone may therefore aggregate a thickness of well over 2,000 feet at the latitude of the coast.

Age.—The Aguada formation and the Aymamón limestone are both placed in the early Miocene by Zapp and others (1948). As already pointed out, however, there are lithologic grounds for suspecting that part, at least, of the beds mapped as Aguada in this report may rightfully belong to what Zapp and others refer to as the Río Guatemala group. The age of those beds is late Oligocene (employing the twofold subdivision of the Caribbean Oligocene as suggested by Woodring and Thompson, 1949).

LATE TERTIARY(?) AND QUATERNARY DEPOSITS

OLDER ALLUVIUM

Widespread though discontinuous clayey and sandy deposits, whose origin and interrelationship are not entirely clear and which may include some residual soil, colluvium, and even estuarine sediments as well as alluvium (in the strict sense of the word) are lumped under the term "older alluvium" to differentiate them from the present-day flood plain sediments. The most characteristic features of these deposits are (1) the lack of relationship to present stream alluviation, inasmuch as the deposits occur in either high-stream terraces or on upper slopes and interfluves, and (2) the extensive conversion of nonquartz components to clay. The deposits now consist mostly of red, or mottled red and white, silty clays with variable amounts of quartz sand. In many places the original sand or gravel texture is still apparent to the eye in spite of the advanced state of alteration. Locally, as for example just north of the Penitenciaría, the older alluvium is predominantly thinly stratified clayey quartz sand.

In a few places fresh exposures showed high-angle faults, although surface expression of the faults was absent. In at least one place, however, this faulting might have been caused by collapse of the underlying middle Tertiary limestone, and one hesitates to conclude that any of it has a tectonic origin.

The reticulated mottling commonly found in these red clayey deposits is a striking feature, consisting generally of a somewhat crisscross pattern of veins, an inch or less in width, of white and buff clay. The central part of a typical vein consists of the white (light gray when moist) clay, and the buff clay composes an intermediate zone separating the white clay from the red. The white clay is more plastic than the red and, according to standard hydrometer tests, contains a greater percentage of material of colloidal dimensions. Both in plasticity and in grain size, the buff clay is intermediate between the red and the white clay. Roberts and others (1942, p. 458) report that the white-vein clay is higher in alumina and lower in iron and silica than the red clay. The white clay seems to be clearly the result of the alteration of the red, in which a leaching of the iron and the peptization of the clay particles, with a possible change in clay mineralogy, has taken place. The buff clay is the intermediate stage in the alteration of red clay to white. The alteration of the original red clay was probably localized along the paths of roots, as the pattern of reticulations not uncommonly suggests, and along shrinkage cracks. Alteration was brought about by percolating water charged with organic acids from the soil zone. This process is called "gleying" by pedologists (Robinson, 1949, p. 191–192).

Some of the best-developed veination seen by the writer was in the bottom of caisson excavations on the south side of San Juan Bay, where older alluvium was exposed at altitude 29 feet below mean sea level, beneath 30 feet of organic bay mud.

The contact between the older alluvium and the underlying bedrock is generally sharp. A thin pavement of pebbles and cobbles, among which fragments of vein quartz are particularly conspicuous, commonly marks the base of the older alluvium. The deposits are very variable in thickness and may exceed 100 feet in places.

The sandy clay of the older alluvium is particularly widespread betwen Trujillo Alto and Guaynabo, where it obscures the bedrock in the uplands, but is generally thin to absent on the valley sides. The full distribution of these deposits has not been shown on the geologic map (pl. 2) because of the difficulty in outlining them. Several areas where their presence is particularly obvious have been indicated, however, although even here the contact has been generalized.

The age of the older alluvium may be early Pleistocene or even late Pliocene. There is no direct evidence for dating the deposits. All that can be said is that considerable topographic and mineralogic decomposition has taken place since their deposition.

PLEISTOCENE LITTORAL DEPOSITS

Only a brief résumé of these and allied deposits will be given here; they are described in considerable detail in chapter B.

The friable, generally somewhat crossbedded sandstone that underlies the higher parts of Isla San Juan and Santurce as well as the offshore islets is mostly eolianite (cemented dune sand). At San Juan, four generations of dune accumulations can be recognized, each separated from the other by paleosols (ancient soils). In addition there is reef rock and associated littoral marine sandstone, which seem to provide the foundation for the series of superimposed dunes that were later cemented to eolianite. The best exposures of both eolianite and reef rock are in the cliffs on the north side of Isla San Juan.

Owing to limitations of the map scale, the four eolianites on Isla San Juan are not separated on the geological map. All of them have the same characteristics. They are typically thin-bedded, medium-grained sandstone, very friable where freshly exposed but with appreciable casehardening on long-exposed surfaces. They are generally lacking in megafossils. On the higher hills of Santurce, the eolianite is mostly blanketed with a red sandy soil; but it is occasionally exposed in building foundations.

The ages of the several eolianites and the elevated reef rock are discussed in chapter B. They are thought to fall entirely within the Quaternary.

SANTURCE SAND

The name Santurce sand is proposed for the widespread deposit of quartz sand (glass sand, see Thorp and Smith, 1933) and interbedded somewhat clayey quartz sand that form the surficial deposit of much of the coastal plain of the Puerto Rican north coast. The color of these deposits is characteristically white, though bright red occurs in places. The deposits are particularly thick under the low-lying areas on the western side of Santurce and are therefore named after this place. The white quartz sands and clayey sands also occur east of San Juan, where, however, they are covered by Recent littoral sands. Deposits of quartz sand occur widely as discontinuous surface deposits for a distance of 50 miles west of San Juan, both on the coastal plain and on the broader bottomlands between the haystack hills of the middle Tertiary limestone.

The outcrop of the Santurce sand is generally a loose, very well sorted, medium-grained sand without apparent stratification, pure white to light gray in color. In places the sand is slightly clayey and as a result has some cohesion. Surficially, this clay may be weathered deep red, thereby imparting a red color to the whole mass. The sand consists of more than 99 percent of angular to subangular clear quartz.

A foundation boring next to the Puerto Rico Water Resources building on Avenida Ponce de Léon, Santurce, (190,125 m, 68,700 m) penetrated 80 feet of quartz sand and slightly clayey quartz sand without reaching the bottom of the deposit. The elevation of the bottom of this boring was at approximately 70 feet below sea level. Borings in the U. S. Naval Reservation penetrated 100 feet of the deposit (Don U. Deere, oral communication). The maximum thickness of the deposit is not known.

Besides its nearly pure quartz composition, the folowing features of the Santurce sand are worthy of note: (1) The great uniformity of sorting of the sand component. All samples of sand studied from seven borings at a large office-building site (190,125 m, 68,700 m) showed a median grain size of 0.35 mm and a sorting coefficient ranging from 1.30 to 1.35. (2) The lack of any carbonate cementing material. (3) The cohesive nature of the clay binder, which generally constitutes less than 15 percent by dry weight of the total sample and yet imparts a great dry strength and gives the sand a somewhat rubbery consistency when moist. (4) The light-gray to white color of the clay component. (5) The erratic variations in the density of the sand with depth. The last factor was revealed by penetration tests in the course of the foundation borings just referred to. By measuring the number of hammer blows required to drive a split sampling spoon a foot under constant conditions, it was shown that the sand varies considerably and erratically in density of packing with depth. (6) The lack of fossils. (7) It widespread distribution on the lowlands of the north coastal area.

The problem of the origin of these sands has been examined by Thorp and Smith (1933). These authors concluded that the sands were derived from the leaching of limestone of middle Tertiary age, with some wind-blown addition from nearby beach sediments. The white color—or absence of iron staining—they attributed to gleying or podzolic leaching, in which the iron of poorly drained soils is leached by water rich in organic acids. If this is true, the Santurce sand represents the end product of the bleaching process that was advanced above as the explanation for the white veinations in the older alluvium. The sand gives some evidence, however, of possessing a depositional history somewhat different from that of the older alluvium; and very likely it is stratigraphically distinct from the older alluvium. The uniformity of grain size and paucity of clay point to a rather special sedimentary environment that in part, at least, is certainly eolian. The deposits may be simply the result of a reworking of the older alluvium, which, it will be recalled, is thoroughly decomposed except for quartz. In essence the process of concentration is the washing and winnowing out of clay. Older alluvium is being actively eroded today, and where slopes are gentle, as in the middle Tertiary belt, the quartzose older alluvium is base-levelled mostly by sheet erosion. This results in the removal of the clay and the formation of a thin lag residue of quartz sand, which in places has been concentrated by wind action into low dunes. Most of the quartz sand used for glass manufacture is dug from these eolian accumulations. In the broad valleys between the haystack hills the eolian deposits are generally thin—10 feet or less. On the lowland of the coastal plain to the north, and particularly in the lagoonal basins in back of the shore, wind deposited accumulations are thicker. Some concentration of quartz sand is of a deltaic nature. Small streams draining the older alluvium tend to deposit the quartz sand on their flood plains or as low alluvial fans on the coastal lowland. It seems very possible, then, that a combination of selective alluvial sorting and wind deposition has built up the 100 and more feet of Santurce sand and clayey sand around the western edge of Santurce. The white color of the clay binder seems most logically accounted for by Thorp and Smith's idea of the podzolic leaching of iron oxide by acidic water, particularly the poorly oxygenated waters of the bay and lagoons.

Because the winnowing out of quartz from the older alluvium is a continuing process, going on even today, the age of the Santurce sand probably includes material ranging in age from Pliocene(?) to Pleistocene, and possibly may include some Recent sand.

RECENT LITTORAL DEPOSITS

Recent littoral deposits consist of beach sand and deposits derived from beach sand, such as low foredunes, beach ridges and broad flat sand aprons that generally spread behind the beaches proper. Recent littoral sand apparently reaches a thickness of 40 or more feet (as at the site of the new International Airport, in the northeast quarter of the map area), and represents both normal beach accumulations and wind and storm-wave reworking of beach sands.

The littoral sands are generally medium to coarse; and in the San Juan area they consist of a mixture of mineral grains (predominantly clear quartz), comminuted shell, fragments of calcareous algae, and tests of Foraminifera. Although there is considerable variation in the relative proportion of organic and nonorganic components from place to place, nonorganic (mineral) grains make up the largest part of most samples of sand studied from the San Juan area.

BEACHROCK

In places along the coast, beach sand is cemented in the intertidal zone into a hard pavement. The cement is generally $CaCO_3$ but in one place in the quadrangle it is iron oxide. This cementation is apparently an active process that is going on in some places at the present time. In the San Juan area the beachrock exposed in the bight east of Punta El Medio is a particularly fine example of beachrock pavement. An unusual type of beachrock cementation occurs in front of the Medical School in San Juan. Here the cement is a black magnetic iron oxide. Besides the normal sand this rock also contains a large assortment of broken crockery, glass, bricks, wire, and other components of a former rubbish heap.

BAY MUD

Soft, black, highly organic clay (muck) and lesser amounts of rather clayey peat underlie and rim part of the bay and the several lagoons. These deposits, referred to locally as bay muds, form broad mangrove swamps where they are exposed and unreclaimed. Excavation through the bay mud, by means of caissons at the site of the steam-generating plant on the south shore of the bay, showed that it contained mollusk shells of existing lagoonal species whose original coloration had been destroyed, probably by the strong bleaching action of the hydrogen sulfide generated in these muds. The muds rest on rather compact mottled clays and sandy clays of the older alluvium. The thickness of the bay muds around Bahía de San Juan generally ranges from 25 to 35 feet but one boring on the north side of the bay, at the U. S. Naval Reservation, showed a thickness of 90 feet.

The muds are apparently derived from the fine clay that is carried into the bay by streams, to which has been added a large admixture of bay-derived organic material that is preserved by the reducing environment prevailing in this poorly circulated body of water.

RECENT ALLUVIUM

Gray to red alluvial clays occur on the broad, poorly drained meadows flanking the bay. The complex history of the alluvial fill in the San Juan area is indicated in a water well at the Rum Pilot Plant, less than a mile southwest of Río Piedras. This well penetrated a surface deposit of 18 feet of slightly plastic red silty clay, beneath which was 90 feet of alluvial material, varying in texture from gravel to highly organic clay. How much of the sediment can be referred to the older alluvium and how much to more recent deposition is problematical, although the part occurring below sea level (that is, below a depth of 55 feet) is possibly correlated with Pleistocene lower sea levels and therefore, by definition, would be excluded from the category of Recent alluvium.

Log of water well at the Rum Pilot Plant, Insular Agricultural Experiment Station.

Approximate altitude of top of hole, 55 feet.

Clay, red, silty	0–18
Silt, yellow; with trace of sand	18–25
Clay, plastic, yellow-brown; with trace of sand	25–33
Gravel, clayey; consists mostly of ashy siltstone of the Fajardo formation	33–38
Gravel, well-rounded; consists mostly of rocks characteristic of the Fajardo formation	38–43
Clay, sandy, grayish-brown; with some gravel	43–50
Sand, silty, micaceous, greenish-gray and reddish-consists of subangular quartz, feldspar, and tuffaceous rock fragments	50–55
Sand, silty, micaceous, greenish-gray and reddish brown	55–80
Clay, organically rich, dark gray and black; includes some sand and fine gravel	80–103
Gravel, medium- to fine-grained; consists of a wide variety of older complex rock types	103–108
Bedrock, green hornfels(?). Only a few small cuttings were available	108–200

STRUCTURE

The rocks of the older complex are greatly deformed; those of the middle Tertiary, much less so; and the younger deposits, not at all or, from a tectonic point of view, negligibly so (Kaye, 1957). More precisely, the older complex is folded and badly broken by faults (fig. 5), whereas the deformation of the middle Tertiary rocks consists of a gentle northerly tilt with superimposed minor undulations and possibly very shallow folds. Faulting of the middle Tertiary in the San Juan area is on a small scale (pl. 9*B*).

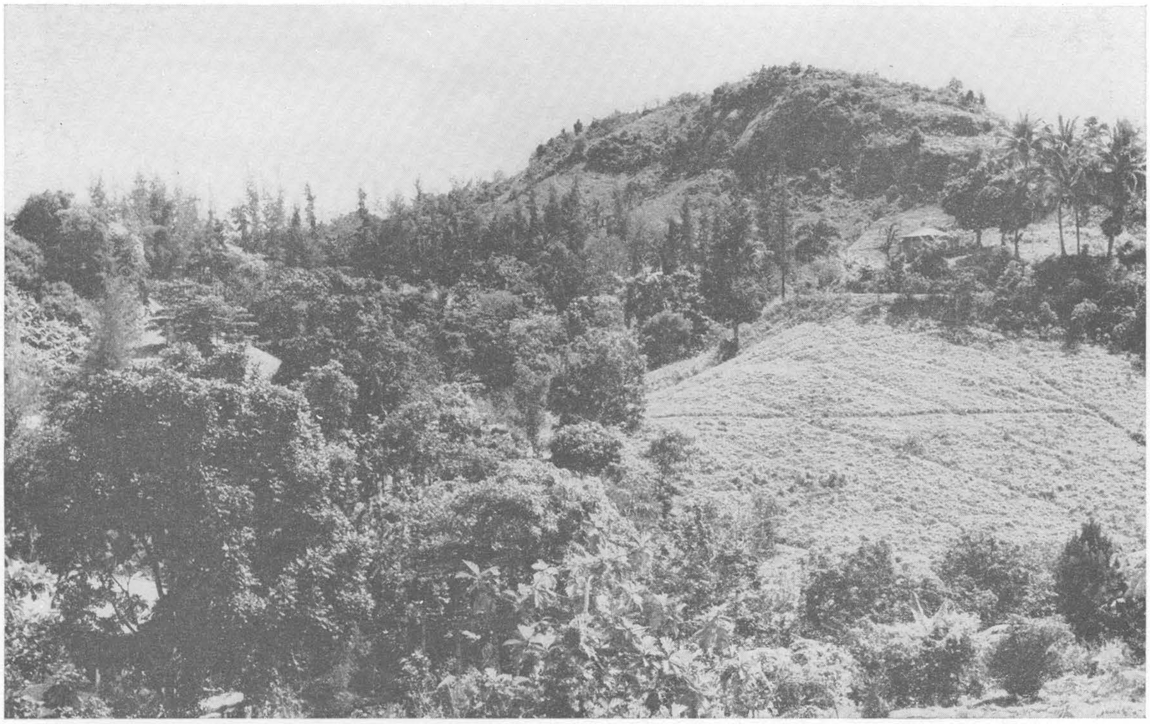
The older complex rocks in the San Juan area are folded into several relatively large, fairly symmetrical flexures (pls. 7B, 8). This, in the writer's experience, is typical of the folding of the older complex throughout the island; tight folds or much overturned folds are rare (Kaye, 1957). Except for the northeast and southwest corners of the island, which are characterized by prevailingly easterly strikes, and in the vicinity of the larger plutons, the general trend of folds throughout most of Puerto Rico is northwest. The San Juan area lies athwart the boundary between the east- and northwest-trending structural belts and contains folds that show the characteristics of both alinements.

The structural picture of the Puerto Rican older complex, in spite of the simplicity of the overall fold pattern, is nowhere easy to decipher. The difficulty in interpreting scattered structural observations is due in part to the wealth of unconformities, facies changes, and the uncertainty of the magnitude and direction of initial dips in these rocks. Perhaps more important than these factors are faults. Almost every sizable exposure of the older complex shows one or more faults (pl. 9*A*), and the impression is conveyed that the relatively simple structural fabric of the older complex is almost everywhere shattered to some degree by a dense network of small and large fractures.

The structural picture of the San Juan area is dominated by a large thrust fault (fig. 5) which from its inferred trace seems to vary from low angle (on the west) to high angle (on the east). The fault dips north and its trace crosses the mapped area in a prevailingly easterly direction. A small outlier or klippe of this thrust sheet possibly occurs northeast of El Laberinto, where it seems to be bounded by strongly oblique tear faults. Horizontal displacement along the thrust is estimated to have exceeded 3 miles, the upper plate moving south relative to the lower block. The fault trace is exposed at only a few places, and its position for the most part has been inferred from otherwise irreconcilable discordances in the attitudes of the rocks on both sides of the fault, and from the otherwise unexplainable juxtaposition of different stratigraphic units.

The structure of the overthrust sheet in the San Juan area is a broad, essentially east-west anticline that plunges to the west. The cuesta of the Montes de Hatillo forms the north flank of this fold, and the ridges west of Guaynabo mark the west closure. A fragment of the south flank is preserved in a downfaulted wedge of the thrust sheet, several miles south of Guaynabo. Dips in this fold are as high as 45° but in general are between 20° and 30°. Small drag folds and minor undulations are common features in the relatively incompetent ashy siltstones and bedded cherts of the Fajardo formation, which forms part of the overthrust plate.

The rocks beneath the thrust sheet are strongly faulted but preserve the essential features of an



A. GUAYNABO FAULT SCARP; ABOUT TWO MILES SOUTHEAST OF GUAYNABO
ELEVATED BLOCK IS HORNBLENDE ANDESITE BRECCIA OF THE FIGUERA VOLCANICS

B. SMALL PLUNGING ANTICLINE IN ASHY SILTSTONE OF THE FAJARDO FORMATION; NEAR GUAYNABO FILTRATION PLANT

GENTLE FOLDING IN ASHY SILTSTONE OF THE FAJARDO FORMATION. SCARP AT LEFT OF QUARRY FACE WAS FORMED BY A LARGE ROCK SLIDE

A. SMALL FAULT IN GRAYWACKE AND SHALE OF THE GUAYNABO FORMATION

Photograph also illustrates the occurrence of relatively unweathered rock in the streambeds of the deeper valleys

B. SMALL NORMAL FAULT IN VARIEGATED SANDS AND MARLS OF THE AGUADA FORMATION; AT THE EAST END OF THE MONTES DE SAN PATRICIO

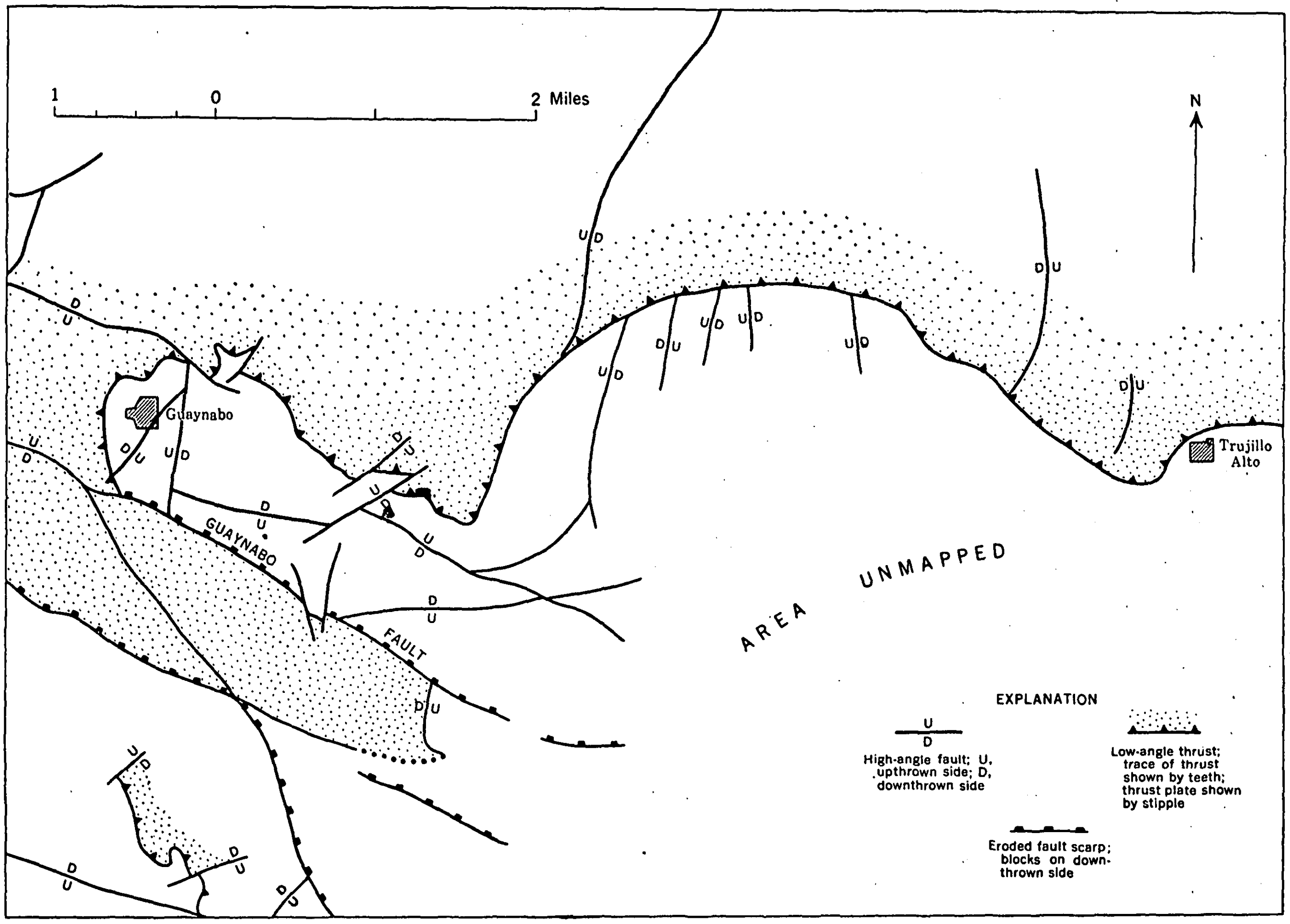


FIGURE 5.—Major known and inferred faults in the older complex in the San Juan area.

anticline whose axis in the southern part of the mapped area inscribes an arc that is concave to the north. This broad structure, which encompasses the entire mapped area south of the overthrust, shows by its flexed axis the influence of both the northwesterly and easterly structural trends already mentioned. The west end of the fold conforms to the northwesterly trend that prevails for many miles to its south and west. The east part of the fold shows evidence of having been dragged around to conform to the prevailingly easterly to slightly northeasterly trend that has been noted by the writer at several localities east of the San Juan area. Minor undulations and ill-defined folds occur on the flanks of this larger structure, like the east-trending chain of small synclinal sags at about the latitude of the village of Guaynabo. The plunging west end of one of these folds is discernible in the first road cuts just south of this village.

High-angle faulting both preceded and followed displacements along the large thrust fault already mentioned. As a result, some of these faults are mappable only to the trace of the overthrust, whereas others displace the trace of this major feature. Moreover, several of the faults in the La Muda area show a complex history, in which the earliest movement preceded the intrusion of the granodiorite porphyry, but with postintrusion movement along at least sections of these faults. In addition, reversal in the relative direction of fault movement is indicated in at least two large faults.

The strikes of the major high-angle faults form a conjugate pattern of two dominant trends, west-northwesterly and east-northeasterly (fig. 5). The west-northwesterly set is more strongly developed and probably has been active over a longer period of time.

Most of the northwest-trending faults are downthrown toward the north. An exception to this is the fault which bounds the Figuera andesite block on the north side, crossing the Guaynabo road about half a mile south of that village, and which is here called the Guaynabo fault. Stratigraphic evidence shows that the upthrown side of this fault is the north side, although today its prominent north-facing scarp (pl. 7*A*) probably records a relatively recent (late Tertiary? or Quaternary) reversal of movement. The Guaynabo fault and a small cross fault that slightly offsets the Guaynabo fault are both well exposed in the sides of the new highway north of La Muda. At this place the fault is vertical and is marked by a breccia zone only 2 feet wide. The thin cataclastic zone of this fault is typical of most faults seen in the San Juan area. An exception to this is a gouge zone, over 150 feet wide, of slickensided dark reddish-purple clay containing rolled and rounded breccia fragments of porphyritic andesite that is well exposed in the trail about half a mile east of the Escuela Segunda Unidad de Caimito.

A long, somewhat discontinuous fault, or fault zone, which also trends west-northwest, passes through La Muda. The south side of the fault in the western part of the mapped area is marked by a prominent though much-eroded scarp. Farther east the fault either fades out or is obscured. This fault gives evidence of a long and complex history. Its earliest movement may have been a scissors with a fulcrum close to La Muda. Renewed movement after the intrusion of the granodiorite porphyry seems to have elevated the block bounded by this fault and another steeply dipping fault that crosses it at La Muda. The picture conveyed by these faults and similar cross faults in the area is a plexus of fractures kept active over a long period of time, with changes in the directions of displacement.

Eroded fault scarps, similar to the two just described, occur at many places in Puerto Rico on the north side of the island divide (Kaye, 1957). Generally, though not invariably, they face north and tend to raise the general topographic level of the upland in successive steps. These escarpments are considered to be true fault scarps rather than fault-line scarps and are thought to be the result of extensive block faulting in the Pliocene and possibly Pleistocene. At least two faults in the San Juan area are therefore inferred to have been active in the late Tertiary. Most of the others have probably been inactive since the early Tertiary.

The middle Tertiary beds dip north at angles up to 6°. Undulations in the dip are not apparent to the eye in any one exposure but are detectable from surface study and from geophysical data. A seismic profile made at Palo Seco, on the west side of Bahía de San Juan and just west of the mapped area, indicates that steplike undulations and even very shallow folds developed in what are presumably the middle Tertiary rocks (Kaye, 1957). High-angle normal faults are not uncommon in the middle Tertiary strata, though those exposed in the San Juan area have small displacements (pl. 9*B*).

SUMMARY OF MAIN GEOLOGIC EVENTS

The geologic history of the San Juan area can be reconstructed, although with considerable uncertainty, as far back as the origin of the oldest rocks present, the Hato Puerco tuff. Much of this formation was probably deposited subaerially, as an insular cone that is comparable, we might suppose, to one of the volcanic islands of the present Lesser Antilles. The probable center of the cone was south and perhaps east of the area under study. Moreover, the depositional environment of the entire older complex section in the San Juan area appears to have been circuminsular, such that subaerial and submarine deposition took place around one or more volcanic vents in an area of great crustal instability. The settling of the volcanic pile and its sedimentary debris—a settling that probably was erratic in nature—permitted the extensive overlap of thick accumulations of marine sediments onto deposits of subaerial origin; it is possible that the rate of subsidence exceeded the rate of volcanic accretion, so that at times the island may well have foundered completely beneath the level of the sea. The overlap of subaerial deposits onto marine deposits also probably took place with the building out of the cone by fresh ejecta or by the growth of alluvial fans and the deltaic progradation of the shoreline.

A foredeep origin has been hypothesized by Ewing and Worzel (1954) for at least the oldest Antillean deposits. The evidence, however, for marine deposition of the older complex of the San Juan area in moderate to shallow depths includes (1) the shallow-water faunas of the Trujillo Alto limestone, (2) the prevailingly coarse texture of much of the sedimentary rock, and (3) the absence of red shale derived from abyssal red clays and other types of deep-sea oozes. A subaerial depositional environment for some of the flow rocks and sediments is suggested by the absence of pillow structure and the presence of thick sections of tuffaceous sandstone and gravel devoid of marine fossils but containing abundant plant fragments (for example, the Guaynabo formation). Admittedly, the evidence for nonmarine deposition is not conclusive, and the writer's general impression that several formational units of the older complex are probably nonmarine is certainly open to further study. The nonmarine depositional environment proposed herein is therefore a "best estimate"—one that most rationally accounts for the field facts as they concern the Hato Puerco tuff.

In reconstructing the deposition of the Hato Puerco tuff, we can imagine a composite volcanic island, roughly comparable to the island of Guadaloupe, which was centered somewhat to the south and east of the San Juan area. This geographical position is only relative, for evidence is lacking as to the amount of lateral movement there has been since Late(?) Cretaceous time. The geographic coordinates of the cone of origin were therefore not necessarily those of eastern Puerto Rico today.

The volcanic centers of the ancestral Hato Puerco island might have been dormant or extinct for a considerable time prior to the deposition of the younger deposits. This may have been initiated by a renewal of volcanic activity and the onset of tectonic movement. The sequence of deposition, both volcanic and sedimentary, was very probably broken at any one point by periods of little deposition and considerable erosion, though there are scant data positively reflecting this.

The Tertiary was possibly ushered in by marine inundation, when limestone was deposited and a new cycle of volcanic eruption commenced. In places the volcanism tore up pieces of limestone from the ocean floor and incorporated them with volcanic ejecta. In the San Juan area 3,000 feet or more of hornblende andesite ejecta (Figuera volcanics) piled up a large cinder cone, the top of which may have emerged above sea level. The pattern of volcanic activity then changed, for in the San Juan area 3,000 or more feet of fine ash (the Fajardo formation) accumulated on the ocean floor. This ash, possibly ejected from centers somewhat removed from the San Juan area, was probably largely airborne, raining into the sea directly from the atmosphere and coming to rest on a steadily subsiding ocean bottom. The interfingering of this marine-deposited fine ash with coarser sediments (such as those cropping out a mile and a half west of Guaynabo) point to a source of land-derived sediments probably lying to the south or southwest. We can imagine, then, that in early Tertiary time islands continued to dot the line of the island arc, just as they did in Late Cretaceous time and just as they do in the Lesser Antilles today.

The Fajardo formation is the youngest stratigraphic unit of the older complex in the San Juan area. Between the time it was deposited, probably in the Paleocene or Eocene, and the onset of the deposition of the next youngest rocks in the early Miocene, a profound crustal revolution took place during which occurred most of the folding, faulting, and intrusion of igneous material that characterizes the older complex. This Antillean revolution probably dates from the Eocene, or even possibly the late Paleocene. The older complex was deformed by the orogeny into long, open folds that in most of Puerto Rico were alined northwest-southeast (Kaye, 1957). Strong overturning of folds, or directionally consistent overturning, has not been recognized by the writer in Puerto Rico. A direction of dominant compressive stresses is therefore not evident, and the general picture that is conveyed is one in which faulting has been more important than folding in producing the complex deformation of the structural fabric of the island.

There has been no attempt here to speculate on the forces and the mechanics responsible for the Antillean geosyncline and the incipient island arc just alluded to, so only a few general remarks will be devoted to the mechanics of the Antillean revolution as it applied to Puerto Rico (for recent speculation on the tectonics of island arcs see Ewing and Worzel, 1954; Griggs, 1939; Hess, 1938; Vening Meinesz, 1954). It seems to the writer that the most plausible orogenic mechanism is the deep foundering of a long, narrow northwest-oriented crustal zone that probably coincided with the geosyncline. (An analogous structural trough today may be the Puerto Rican deep.) Into this narrow crustal downwarp, the older complex rocks of the surrounding sills moved by sliding. Descent into the restricted, narrow zone of the downwarp was accompanied by a certain amount of plastic deformation. Such deformation would be marked by the absence of a consistent direction of overturning to the folds and by an increase in intensity of folding with depth within the downwarp. The older complex in Puerto Rico, by its moderate folding, may therefore represent only the upper part of such a downwarped geosynclinal wedge, and with depth the Puerto Rican rocks may be intensely folded and very much metamorphosed, like many of the rocks that crop out in the nearby Dominican Republic and Cuba. Deformation in the uppermost part of such a downwarp, and particularly along the outer margins, would probably be characterized by large-scale thrust faulting (Griggs, 1939; Vening Meinesz, 1954). A possible example of this is the thrust fault in the San Juan area.

Batholithic intrusion may have occurred as the base of the sinking wedge fused and was converted to magma. Part of the energy for this fusion may have been the high frictional temperatures that were generated in the downwarp. Further sinking of the trough possibly resulted in the squeezing of the magma upwards into the overlying solid part of the sinking wedge. The high hydraulic pressures developed by this mechanism might account for the essentially concordant nature of the small batholiths located in southeastern and central Puerto Rico (Kaye, 1957). In the San Juan area the granodiorite porphyry is possibly an apophysis of this batholith.

Following the downwarp that marked the culmination of the early Tertiary orogeny, the deeply infolded older complex rocks were then uplifted. This was possibly an isostatic adjustment to the wedge of relatively light crustal material that had been dragged deep into the dense subcrust by the downwarp. By a relaxation of the stresses that may have been responsible for the downwarp, the structural trough rebounded and the disturbed belt arched up isostatically.

From the Eocene to early Oligocene Puerto Rico probably underwent some positive crustal movements, which may have been progressive or interrupted and which may even have included intervals of subsidence. Any sedimentary deposits formed at that time have since been removed by erosion or else are overlapped by the more recent middle Tertiary rocks. By the beginning of late Oligocene time Puerto Rico still presented a rugged aspect. The upper Oligocene coarse basal conglomerates that occur on the north and south flanks of Puerto Rico and the uneven surface of the unconformity that separates the older complex from the middle Tertiary in the western part of the island are evidences of the ruggedness of the terrain.

In late Oligocene time a new structural alinement—destined to characterize all the island's later tectonic vicissitudes—was impressed on Puerto Rico. This was an east-west axis, which marks the shape of the island as well as all of its post–middle Oligocene deformations. The cause of this change from a northwest structural alinement in early Tertiary time to an east-west geanticlinal structure in the middle Tertiary is also speculative. It may somehow be genetically connected with the onset of the sinking of the Puerto Rican trough, an east-west oceanic foredeep lying some 70 miles to the north of the island, although such an interrelationship has yet to be established. One such interrelating mechanism could be the formation of a thermal convection cell in the earth's mantle—different from any that may have contributed to the early Tertiary downwarp—that had a negative side under the foredeep and a positive side under the Puerto Rican axis. But such a facile explanation—assuming that this mechanism were physically possible (see Scheidegger, 1953, for a compelling objection to the convection-current hypothesis)—leaves many questions unanswered.

In any event, by late Oligocene time the north and south flanks of the newly constructed Puerto Rican geanticline were overlapped by marine sediments. Very probably, however, a narrow strip of the axis of the geanticline remained emergent even during maximum flooding in the early Miocene. This deposition continued at least into the late part of early Miocene, and possibly even later. Deposition was terminated with the uplift of the island's axis.

In the San Juan area the first middle Tertiary flooding presumably came not in the late Oligocene but rather in the early Miocene with the deposition of the Aguada sands, silts, and marls. The overlying Aymamón limestone indicates a change to clearer waters or else a growing remoteness of the shore or a diminution of sediment being carried to the ocean by the rivers.

The island that emerged in the middle Miocene seems to have been eroded to an old-age surface by late Miocene or early Pliocene time. This peneplaned surface was then re-arched, but this time mostly by the differential elevation of discrete blocks separated from each other by essentially easterly faults. These fault blocks were mostly confined to the central part of the island. The steplike arrangement that was thereby given to the topography of the island's interior is still crudely preserved. As already mentioned, two such scarps occur in the San Juan area—namely, that which is formed by the Guaynabo fault and that which rises less than a mile to the south (pl. 3*A*, 7*A*). Some rejuvenation of these scarps by renewal of fault movement throughout Pliocene and early Quaternary time seems likely.

The depositional history of the north coastal area in late Cenozoic time was complex. It is discussed in some detail in Chapter B of this study. In response to alternate rising and falling of sea level during the Pleistocene, a chain of barrier reefs and dunes formed approximately along the present shoreline and are still preserved as low ridges. In many places, such as in the San Juan area, bays and sounds behind these ridges remained; but in others the lagoons have filled with organic muds and alluvium, forming broad swanmps or low-lying coastal plains.

ENGINEERING GEOLOGY

In an urban area like San Juan, the engineering properties of earth materials are of great economic importance. The choice of a construction site, however, is generally controlled by economic rather than purely engineering factors. Grade design and geography determine road alinements. Factories are built where they can operate economically and where land at the right price is available, rather than where the foundation problem would be at a minimum. The geologist, who can be of great service in providing the proper kind of guidance and advice during the design and construction phase, finds that for purposes of engineering planning his geologic map becomes relatively unimportant because of the massive economic considerations involved and the technical competence of modern engineering to cope with the most difficult of earth problems—that is, providing the engineer is forewarned by the geologist.

From the standpoint of engineering geology, the older complex cannot be discussed formation by formation. All mapping units (with the exception of the La Muda limestone member of the Frailes formation and the Trujillo Alto limestone) are characterized by rock that is hard, tough, dense, and durable where fresh. Fresh rock, however, generally does not occur at the surface; and unless cuts are deep, surface excavation will involve decomposed rock and silty clay regolith, whose physical properties do not materially differ from one formation to another. Exceptions to this statement are: (1) the clays that occur on the several pure limestones (the La Muda limestone member and Trujillo Alto limestone), which tend to have a higher plasticity than the leaner and more silty clays found on the other rocks; (2) the graywacke of the Guaynabo formation, which tends to yield a somewhat more sandy regolith. Hydrologic factors such as seepage, always an important element in the behavior of earth materials, also do not lend themselves to generalization on a formational basis. The presence or absence of such features as faults, shear zones, or densely jointed zones are important elements here, and these, of course, can be appraised only after site examination. In lieu, therefore, of an attempt to synthesize the engineering properties of the various mapping units, a small sample of geologic questions and their impact on engineering structure in the area will be discussed. Actually there are as many problems of an engineering geologic nature as there are engineering structures, and the numerical data given below are not meant to be generalized for entire geological formations but should be interpreted simply as samples of what has been found in specific site explorations.

FOUNDATION

Most modern heavy structures in the San Juan area are built on the Santurce sand, the bay mud, or the older alluvium. The Santurce sand, having a varied density, has therefore a varied strength as foundation for heavy structures. On the basis of empirical formulae (Terzaghi and Peck, 1948 p. 423–424), standard penetration tests (Terzaghi and Peck, 1948, p. 265) in the quartz sand at a site in Santurce indicated bearing values for spread footings ranging from 1 to 3 tons per square foot. It was quite clear from this study that the erratic densities of the sand required individual design for each footing or, what is probably the preferred engineering practice, design of all footings on the basis of the lowest bearing value. This situation probably can be anticipated elswhere in the quartz sands.

The bay muds, which form an extensive fringe around San Juan Bay, are the weakest foundation soils in the area. The highly organic clay (mud or muck) is extremely compressible and has a very low strength. Most structures are built on end-bearing piles that penetrate the mud and rest on the underlying compact clays. Roads built on the mud settle badly unless the mud has been artificially compressed (consolidated, in the soil mechanics sense of the word). This has been done in the construction of Highway 2 by the use of sand piles (Carpenter, 1948), which are simply vertical holes of large diameter that are backfilled with highly permeable coarse sand. These serve as vertical drains for the pore water in the surrounding mud. As the pore water drains into the sand under the weight of the enbankment fill, the mud compacts. The pavement is laid only after most of the settlement has taken place.

Very compact red clays and sandy clays underlie the bay mud at depths ranging from 25 to 35 feet. These clays are probably the equivalent of the older alluvium. Extensive tests of the clays were made in foundation studies for the steam generating plant of the Puerto Rico Water Resources Authority on the south side of the Bahía de Puerto Nuevo. The clay was exposed in caissons, where it was seen to be mottled and veined with white and ochre-colored clay that is characteristic of the older alluvium on the surface. The spread footings for the generating plant rest on the surface of the clay beneath about 30 feet of mud and are designed to carry 3 tons per square foot.

BORROW AND QUARRYING

The need for fill in the San Juan area is tremendous, and the reclamation of the extensive marshes requires a cheap source of strong run-of-bank material. Several formational units are currently providing the bulk of this. In addition, the universal use of reinforced-concrete construction, coupled with an expanded program of highway construction, demands a cheap and abundant supply of strong rock aggregate and road metal. This too is provided locally. Moreover, portland cement for the concrete is made from locally derived limestone and clay; and clay for constructional tile and brick is quarried and dug within the area.

Economically, the ashy siltstone of the Fajardo formation is one of the most important rock units in the area. Because it is easily excavated and breaks up readily into manageable slabs and blocks along joints and bedding planes, it is widely used for general-purpose fill. A large quarry on the Trujillo Alto road (pl. 8) provides much of this material for the San Juan area. The clayey overburden and the clay intercalations between beds are generally mixed with the rock slabs and provide a certain amount of binder.

Thin flagstone of the less weathered and somewhat siliceous ashy siltstone of the Fajardo formation is very fashionable in ashlar masonry for decorative building facades; it has been used in many buildings erected since 1950.

The ashy siltstone and intercalated thin white kaolinitic clay is quarried at Saint Just (Highway 848, just east of the mapped area) for use in the manufacture of brick and constructional tile. The rock is crushed in a pug mill and mixed with a certain amount of alluvial clay that is dug adjacent to the plant (located several miles north of the quarry).

Aymamón limestone is quarried at the west end of the Montes de Caneja for the nearby cement mill. In addition, rubble from this formation is a source of common fill. A certain amount of residual clay generally adheres to the rock and acts as a slight binder.

Rock for crushing, which is used mostly as road metal, is quarried chiefly in the vicinity of Trujillo Alto road (pl. 8) provides much of this material Trujillo Alto vicinity the rocks quarried are: massive amphibolitic tuff (or flows?) of the Hato Puerco tuff; the gray tuffaceous limestone of the Leprocomio member of the Frailes formation; the Trujillo Alto limestone; and, at the east edge of the town of Trujillo Alto itself, augite andesite porphyry. East of La Muda several quarries exploit the Tortugas andesite, and one, the La Muda limestone member of the Frailes formation.

Gravel is dug from the bed of the Río Grande de Loíza, both upstream and downstream from Trujillo Alto. This is the principal source of natural gravel in the San Juan area.

Beach sand was formerly dug from beaches in the San Juan area for concrete aggregate. Fear of inducing accelerated beach erosion, however, led to discontinuance of the practice in the San Juan area, and beach-sand digging is limited to selected stretches of the coast both east and west of the mapped area.

DAMSITE

The concrete gravity dam across the Río Grande de Loíza, 2 miles south of Trujillo Alto, built by the Puerto Rico Sewer and Aqueduct Authority as a water-supply project for the San Juan metropolitan area, was completed in 1952. The dam is 50 feet high, 700 feet long, and has eight 30- by 39-foot tainter gates. Clearing for the abutments and foundation of this dam exposed a particularly good picture of the local geology. The foundation rock is a dense massive andesite or tuff that is altered to a fine-grained amphibolite and probably belongs to the Hato Puerco tuff. It is intruded by a light-colored hornblende diorite and aplite (pl. 5 *B*). Several tightly sealed small shear zones were noted in the foundation but otherwise no faults were observed. The rock exposed in both river bed and abutment excavations was remarkably fresh and required a minimum of stripping, grouting, or other foundation treatment. A thin deposit of sand and gravel in the river bed rarely exceeded 5 feet in thickness. The geologic generalization that can probably be drawn from this is that river downcutting has exceeded the weathering rate of the rocks. In consequence, in the uplands relatively unaltered and fresh rock may be rather common beneath the alluvial beds of major streams, particularly where the valleys are narrow and steep sided.

ROCK SLIDES

An interesting rock slide occurred in a large quarry on the Trujillo Alto road (pl. 8), which demonstrated the potential instability of steep excavated slopes in the well-jointed ashy siltstone of the Fajardo formation, particularly if subject to jarring or to strong vibrations.

At the site of the slide the ashy siltstone strata were separated from one another by thin layers of white plastic clay, and the entire section was broken by two sets of joints at approximately right angles. The siltstone, which was exposed in a nearly vertical quarry face approximately 35 feet high, dipped at about 15 degrees toward the quarry floor. It is the writer's opinion that the jarring of the small explosions in the quarry was sufficient to destroy the tenuous cohesion of the siltstone slabs and to set the myriad of newly isolated flags slowly shifting and slipping down along the intervening clay intercalations. The initial state was not unlike that of an unstable pile of greasy dinner plates reposing on a tilted drainboard. In six months much of the hillside behind what had been the quarry face had slowly moved a distance of about 200 feet out into the quarry and the surrounding fields.

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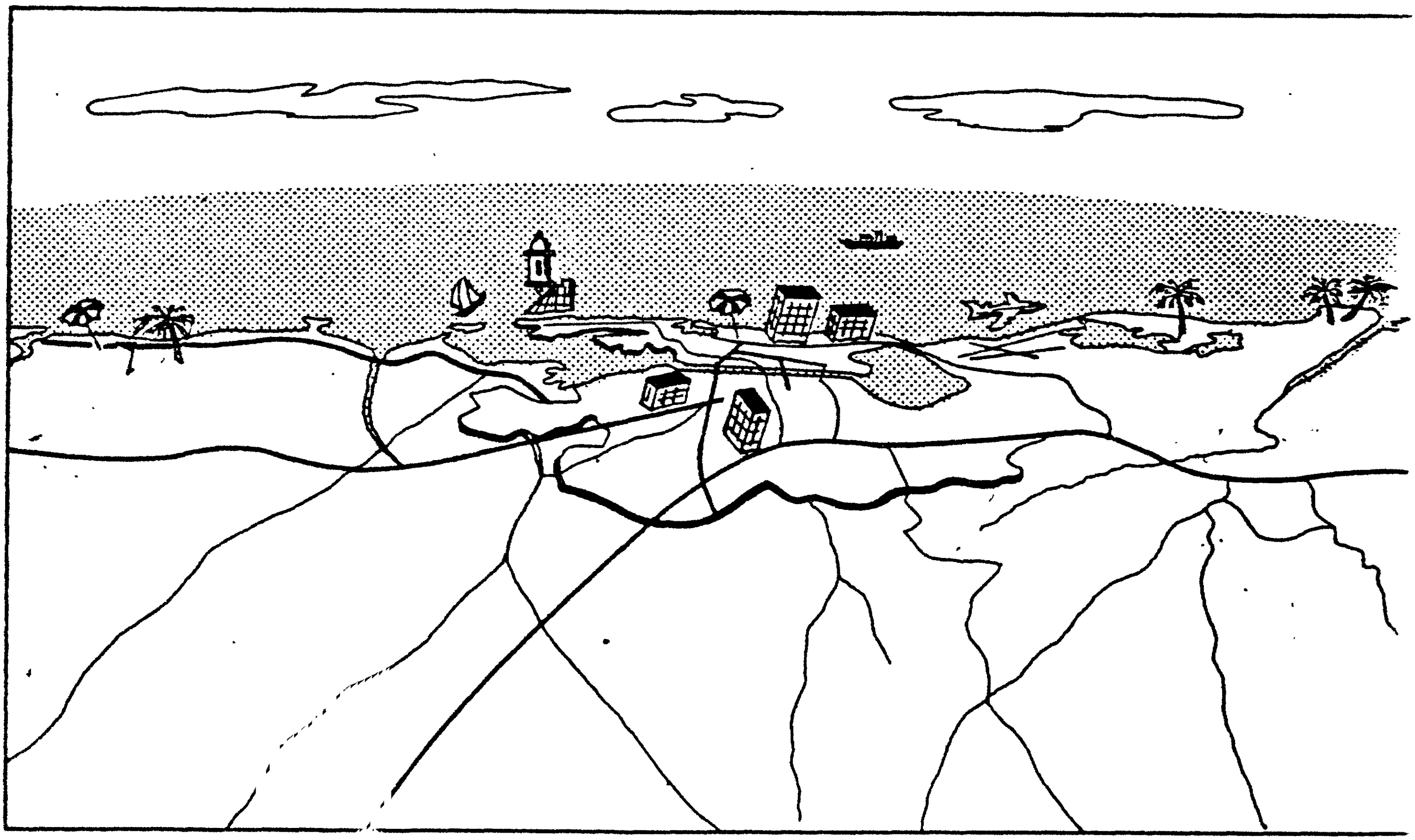

Prepared in cooperation with
Commonwealth of Puerto Rico

U S DEPARTMENT OF THE INTERIOR
March 3 1849

GROUND WATER IN THE SAN JUAN METROPOLITAN AREA, PUERTO RICO

By Henry R. Anderson

U.S. GEOLOGICAL SURVEY

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July 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

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Factors for converting English units to International System (SI) units

Multiply English units	By	To obtain SI units
Length		
inches (in)	25.4	millimetres (mm)
inches (in)	.0254	metres (m)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
Area		
square miles (mi^2)	2.590	square kilometres (km^2)
Volume		
cubic feet (ft^3)	28.32	litres (l)
cubic feet (ft^3)	.02832	cubic metres (m^3)
cubic feet per second-day [(ft^3/s)-d]	2447	cubic metres (m^3)
gallons (gal)	3.785	litres (l)
gallons (gal)	3.785×10^{-3}	cubic metres (m^3)
million gallons (10^6 gal)	3785	cubic metres (m^3)
million gallons (10^6 gal)	3.785×10^{-3}	cubic hectometres (hm^3)
Flow		
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
gallons per minute (gal/min)	6.309×10^{-5}	cubic metres per second (m^3/s)
million gallons per day (10^6 gal/day)	43.81	litres per second (l/s)
million gallons per day (10^6 gal/day)	.04381	cubic metres per second (m^3/s)
Other		
hydraulic conductivities (ft/day)	.3048	metres per day (m/day)
million gallones per day per square mile [(10^6 gal/day)/mi^2]	16.92	litres per second per square kilometres [(l/s)/km^2]
specific capacities [(gal/min)/ft]	.207	litres per second per metre [(l/s)/m]
specific capacities [(gal/min)/ft]	$.207 \times 10^{-3}$	cubic metres per second per metre [(m^3/s)/m]
transmissivities (ft^2/day)	.0929	metres squared per day (m^2/day)

NOTE: To convert degrees Celsius (°C) to degrees Fahrenheit (°F) use the following equation:

$$°F = 9/5\ (°C) + 32.$$

GROUND WATER IN THE SAN JUAN METROPOLITAN AREA, PUERTO RICO

by Henry R. Anderson

ABSTRACT

San Juan is on the north coast of Puerto Rico, a coastal lowland of seaward dipping Tertiary formations which lap up on Cretaceous volcanic mountain core.

Ground water in San Juan has played a declining role in water supply since the completion of the Loíza reservoir project in the early 1950's. Ground-water yield is limited because the aquifers are small and susceptible to seawater intrusion.

Wells tapping the more permeable weathered zone in the volcanics may obtain as much as 300 gal/min (19 l/s) but specific capacities of wells are low, 1.4 (gal/min)/ft of drawdown [0.29 (l/s)/m]. The volcanic rocks contain the least mineralized ground water in San Juan, averaging about 250 mg/l dissolved solids.

The basal Tertiary formation, the San Sebastián Formation, together with the lower part of the Cibao Formation, is a confined aquifer made up mostly of sand and marly limestone less than 330 ft (100 m) thick. Average yields are 240 gal/min (15 l/s), with specific capacities of wells of 3.1 (gal/min)/ft of drawdown [0.64 (l/s)/m] and transmissivities of 1,000 ft^2/day (93 m^2/day). Recharge is estimated to be 0.7 (10^6 gal/day)/mi^2 [12 (l/s)/km^2].

The Cibao Formation in general, and clay beds in particular, make up the semi-impermeable zone between the confined sand and the limestone that forms the unconfined aquifer.

Yields in Aguada Limestone of the unconfined aquifer are as much as 2,500 gal/min

(160 l/s) and average 540 gal/min (34 l/s). Average specific capacity of wells is 41 (gal/min)/ft [8.5 (l/s)/m]. The freshwater lens along the coast is less than a mile wide in San Juan. Consequently seawater intrusion is a threat. The Aymamón Limestone, which overlies the Aguada Limestone, is highly permeable but for the most part contains salt water. In Sabana Seca, a freshwater-bearing zone has transmissivity of 200,000 ft^2/day (1.86×10^4 m^2/day).

Ground-water recharge to the limestone unconfined aquifer is on the order of 1 (10^6 gal/day)/mi^2 [17 (l/s)/km^2]. Coastal discharge to the sea is about 4.5 (10^6 gal/day)/ linear mi [0.20 (m^3/s)/linear km] of coast.

Ground water becomes less mineralized inland from the ocean. Median concentrations of dissoved solids, hardness, and bicarbonate are 525, 295, and 300 mg/l for the Aguada and Aymamón Limestones, which are nearest the sea; and 363, 195, and 226 mg/l for the San Sebastián and Cibao Formations, which lie farther inland.

A summary of the water budget for the Río de Bayamón shows that for a typical average rainfall of 64 in (1,625 mm) about 28 in (710 mm) is runoff, and 36 in (915 mm) evapotranspiration, assuming storage in a basin is constant. Ground-water flow from weathered volcanic rocks to streams and the sedimentary rock aquifers is about 15 in (380 mm) annually, about half the total runoff.

Ground water continues to play a small role for water supply in the San Juan area. The limited quantity available, perhaps 30×10^6 gal/day (1.3 m^3/s), is currently about half used. Nevertheless, ground water is important for use in special situations such as backup supply for droughts and special industrial uses.

Studies could be carried out to evaluate the practicability of artificial recharge, urbanization effects on ground water, and disposal wells in the saline aquifers. Construction and use of analog, digital, or hybrid models would facilitate these studies and additional water-related stresses on the system.

INTRODUCTION

Ground water once supplied much of the water requirements of the San Juan area. With the completion of the Lago Loíza reservoir in 1953, surface water gradually replaced ground water as a source of supply. It was not until the severe droughts of the mid-1960's when inflow to the Lago Loíza declined to near zero that the vulnerability of surface-water sources was realized. An emergency drilling program developed sufficient ground-water supplies to supplement surface-water supplies and meet the needs of the metropolitan area.

A post-drought analysis of the sources of water supply for the metropolitan area indicated a need for better knowledge of the ground-water resources. A study was implemented through the cooperative water-resources investigation program between Commonwealth agencies of Puerto Rico and the U.S. Geological Survey.

The metropolitan area (fig. 1) includes the capital city of San Juan and all or part of the municipalities of Carolina, Bayamón, Cataño, Guaynabo, Dorado, Río Piedras, and Toa Alta. The study area extends from the Río Grande de Loíza on the east to the Río de la Plata on the west, and from lat 18° 22' N, which approximately parallels the volcanic-sedimentary rock contact, north to the Oceano Atlantico. For purpose of reference, the metropolitan area has been arbitrarily divided into three units--Bayamón, San Juan, and Carolina (as shown in fig. 1).

GEOGRAPHY

Physical Setting

The metropolitan San Juan area lies in the Northern Coastal Lowland and Northern Foothills physiographic regions (Picó, 1950). The Northern Coastal Lowland is a plain about 5 mi (8 km) in width, that slopes gently from the sea to the foothills. The plain has been built up by surficial deposits consisting of sand, silt, clay, and muck overlying a dissected older surface, the remnants of which stand above the plain as isolated mogotes or hills. Many of the mogotes rise more than 300 ft (90 m) above sea level and 200 ft (60 m) or more above the coastal plain.

A nearly continuous line of marshes, mangrove swamps, and lagoons lie just inland of the shoreline. The lagoons, including Bahía de San Juan, are joined by channels. Direct access of the lagoons to the sea is poor and circulation of water is sluggish.

The Northern Foothills characteristically are rounded hills, many attaining an altitude of 1,000 ft (300 m) and some as much as 2,000 ft (600 m). The hills are composed chiefly of sandstone and siltstone, associated volcanic and intrusive rocks, and some limestone. Streams rising in the interior uplands pass through the foothills in narrow valleys whose flood plains are flanked by alluvial terraces.

Major rivers bounding or passing through the study area are, from east to west; the Río Grande de Loíza, Río Piedras, Río de Bayamón, and Río de la Plata. The Río Piedras empties into Bahía de San Juan; whereas, the other rivers discharge directly to the sea.

Population and Economic Situation

Puerto Rico in general, and San Juan in particular, have experienced probably one of the

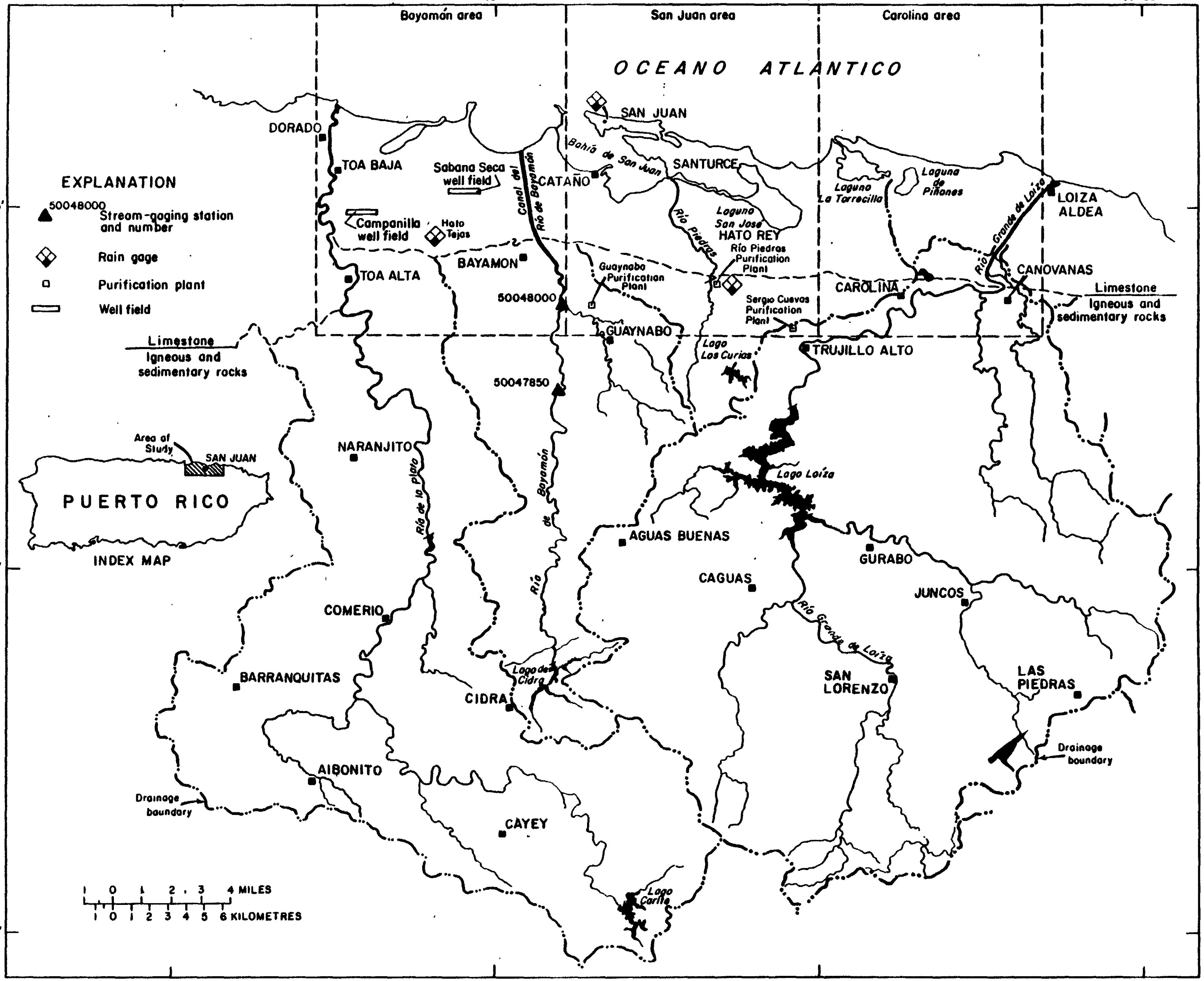

Figure 1.--The San Juan project area: contributing drainage basins and principal features.

fastest economic growth rates in the world in the past 25 years. The Commonwealth has grown at a rate comparable to Israel and Japan and about twice that of the continental United States--more than 10 percent per annum.

The population of the San Juan metropolitan area has grown 26 percent from 1950 to 1960 to 647,979 inhabitants; and 31 percent from 1960 to 1970 to 851,247 inhabitants. Almost one third of all the inhabitants on the island live in the San Juan metropolitan area. The trend in population is outward to the suburban areas as transportation, housing, and living standards improve, and as the urban center becomes more commercialized.

The industries in and around San Juan are similar to those of other large cities. The leading types of commercial establishments are food products, tobaccos, textiles and clothing, furniture and wood products, printing, chemicals, cement, metal fabrication, machinery and electrical equipment, glass, petroleum refineries, rum distilleries and breweries. Although the island's rate of unemployment is high, more than 12 percent (1970), the rate in San Juan is comparable to the continental United States average of 6 percent.

Climate

The climate in San Juan is tropical marine. Air temperature at the National Weather Service station, in Old San Juan, ranges from an average of 27.2° C in August to 23.9° C in January.

Throughout Puerto Rico rainfall increases inland toward the mountains. In the San Juan metropolitan area, the average annual rainfall ranges from 60 in (1,520 mm) on the coast to 80 in (2,030 mm) 5 mi (8 km) inland. Rainfall is seasonal with a rainy period from July through October (the hurricane season) and a secondary wet period in May. The dry season occurs between January and April. In an average year, there are 209 days of measurable precipitation in Old San Juan.

Figure 2 shows the long-term annual rainfall at Río Piedras and Old San Juan. Wet and dry periods are evident from the 5-year moving average. Of particular prominence are the severe droughts of the 1920's, 1930's and 1960's.

Pan evaporation measured at the Old San Juan weather station exceeds rainfall by about 20 in (508 mm) a year. The average annual evaporation measured over 4 decades is 82 in (2,080 mm) with an average monthly high of 8.04 in (204 mm) in March and a low of 4.48 in (114 mm) in December. A short distance inland at Río Piedras, however, the rainfall, 74.2 in (1,880 mm), exceeds the pan evaporation, 72.4 in (1,840 mm).

In Puerto Rico the prevailing trade wind is from the east or the north-northeast; however, from September to November there is an alternating of wind currents from the south and the southeast. In addition, there are breezes caused by the differential heating of the land and the sea--during the day the breeze is from the sea to land, but at night it is reversed.

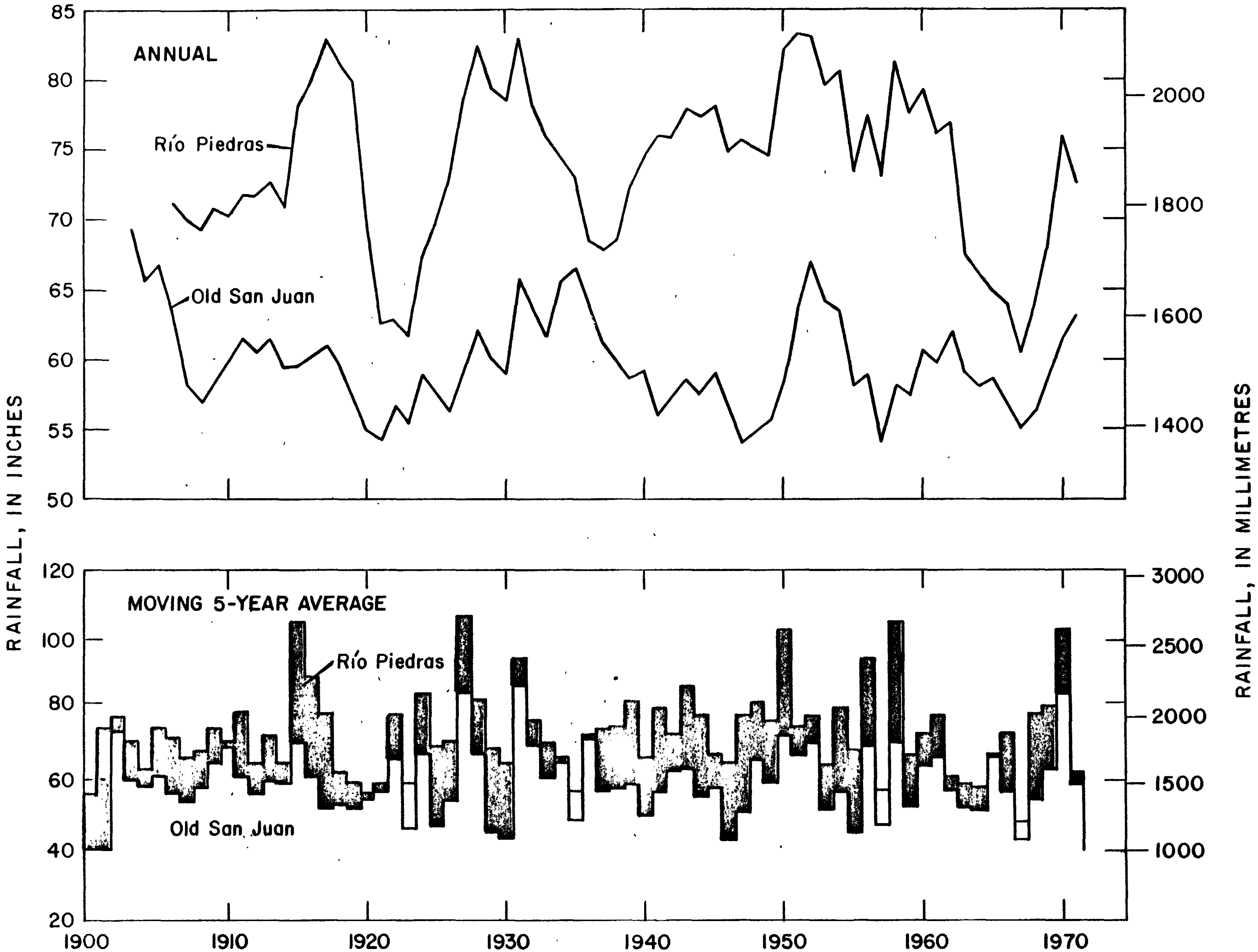

Figure 2.--Annual and moving 5-year average rainfall of Río Piedras and Old San Juan rain gages, 1900-71 (data from U.S. National Oceanic and Atmospheric Administration).

Hurricanes commonly originate in the Caribbean but only six storms of hurricane intensity have affected San Juan in the past 60 years.

Water Use and Municipal Supply

Before 1953, San Juan obtained its water supply from a combination of surface water from the Río Piedras and the Río de Bayamón, and ground water from several high-yield wells. Apart from the municipal supply, many installations in San Juan, such as the Ft. Buchanan military complex, maintained their own wells. With the completion of the Lago Loíza reservoir in 1953, many of the well systems were abandoned and water was obtained from the municipal supply system. Ground-water pumpage declined from 5×10^6 gal/day (0.22 m^3/s) in 1945 to 3×10^6 gal/day (0.13 m^3/s) in 1960.

In fiscal year 1971 (July 1970-June 1971), the output of municipal water supply in metropolitan San Juan averaged about 108×10^6 gal/day (4.7 m^3/s), double the 54×10^6 gal/day (2.4 m^3/s) in fiscal year 1959. The water consumed or paid for in fiscal year 1971 was about 80×10^6 gal/day (3.5 m^3/s) indicating a water loss, apparently through leaky mains, of about 25 percent.

GEOLOGY

The rocks of the San Juan area are classified for the purpose of convenience as volcanic rocks, sedimentary rocks, and surficial deposits. Needless to say, there are large variations in rock type in each group. The areal extent of these rocks in the San Juan area is shown in the hydrogeologic map (fig. 3).

Volcanic Rocks

Volcanic tuff, breccia and lava; associated sandstone, siltstone and limestone; and some intrusive rocks of Cretaceous and Tertiary age are found in the Northern Foothill region south of San Juan. Folding, faulting and metamorphism have destroyed many of the original physical characteristics of these rocks, such as solution limestone, porous tops in lava flows, and open-pore space in sandstones. Common to these rocks is a general lack of permeability, except in a weathered and fractured surficial zone as much as several hundred feet thick that follows the general topography.

Sedimentary Rocks

Sedimentary rocks of Tertiary age underlie the Northern Coastal Lowland region. The formations are composed of consolidated gravel, sand, and clay and calcareous rocks ranging from marl to indurated limestones. They have a roughly east-west strike and dip 4 to 6 degrees seaward. Some high-angle normal faulting is evident; however, displacement is small and does not seem to be significant.

Production, distribution, capacity, plant, system, and source of water supply in fiscal year 1971

Plant 1/	Capacity million gal per day (cubic metres per second)	Production million gal per day (cubic metres per second)	Source	Distribution	System
Sergio Cuevas	60 (2.6)	67.5 (3.0)	Lago Loíza 2/	Carolina-San Juan area and 10×10^6 gal (38,000 m^3) underground storage tank	Loíza
Guaynabo	26 (1.1)	29.7 (1.3)	Lago de Cidra 3/ Río de Bayamón Río Guaynabo	Guaynabo-Bayamón area and 2 storage tanks 10×10^6 gal (38,000 m^3)	Bayamón
Univ. of P.R. Experiment Station, Río Piedras	2.5 (0.11)	2.2 (0.10)	Lago Las Curias 4/	Río Piedras-San Juan area	Río Piedras
San Juan	10.7 (0.47)	0.2 (0.01)	18 wells	San Juan area	Hato Rey
Campanilla-Sabana Seca	15.6 (0.68)	8.88 (0.39)	16 wells	Levittown area	Levittown

1/ See figure 1 for location.

2/ 6.5 billion gal (24.6 hm^3) storage reservoir.

3/ 1.7 billion gal (6.43 hm^3) storage reservoir.

4/ 367 million gal (1.39 hm^3) storage reservoir.

These formations are best exposed in the west and inland parts of the study area. They are overlain by surficial deposits near the sea and in the eastern part of the study area.

The rocks can be separated into four recognizable formations. In order from oldest to youngest, they are: San Sebastián Formation, Cibao Formation, Aguada Limestone, and Aymamón Limestone.

San Sebastián Formation

The San Sebastián Formation of Oligocene age is composed of crossbedded to massive beds of sand, sand and gravel, and sandy clay; with some thin beds of sandstone and sandy limestone. The formation can be considered to be consolidated but is essentially uncemented. The outcrop area and the configuration of the top of the San Sebastián are shown in figure 4. The formation attains its maximum thickness of about 500 ft (150 m) in the western part of the study area, but Pease (1968) attributes 150 ft (45 m) of this thickness to the Mucarabones Sand, a formation overlying the San Sebastián and grading into the Cibao. In this report the Mucarabones Sand, as mapped by Pease (1968), is included in the San Sebastián. However, recent work in the Bayamón quadrangle by Monroe (1973) indicates that the Mucarabones Sand intertongues eastward with the entire lower part of the overlying Cibao Formation; so that the age of the Mucarabones Sand is Oligocene and Miocene. The San Sebastián Formation commonly is 165 to 330 ft (50 to 100 m) thick, becoming progressively thinner to the east.

In the vicinity of Carolina, the San Sebastián either pinches out or the remnants become indistinguishable from the overlying Cibao Formation.

Cibao Formation

The Cibao Formation (fig. 3) is of Oligocene and Miocene age and conformably overlies the San Sebastián Formation. The Cibao is composed of interbedded marl, limestone, clay, sand and gravel. It attains its maximum thickness of 380 ft (115 m) in the westernmost part of the study area, thinning eastward to about 130 ft (40 m) thick in the vicinity of Carolina.

In the westernmost part of the study area, the Cibao has been divided into five members (Monroe and Pease, 1962):

1. Upper member--chalk, sandy limestone and sandy marl; 100 to 160 ft (30 to 50 m) thick.

2. Miranda Sand Member--sand and gravel, filling channels cut into the underlying limestone; 0 to 60 ft (0 to 20 m) thick.

3. Quebrada Arenas Limestone Member--consists of alternating beds less than 3 ft (1 m) thick, of dense crystalline limestone and soft marly limestone; 0 to 70 ft (0 to 20 m) thick.

4. <u>Río Indio Limestone Member</u>--a yellowish-orange earthly limestone that grades into a sandy marl toward the east; reported to be 230 ft (70 m) maximum thickness.

5. <u>Lowermost member</u> (unnamed)--consists of sandy limestone and marl facies transitional with the San Sebastián; 100 to 230 ft (30 to 70 m) thick.

The three middle members apparently crop out only in the Río Bucarabones Valley (section A-A', fig. 3). The upper and lowermost members are identifiable in the vicinity of the Río de Bayamón (section B-B', fig. 3).

In the San Juan and Carolina areas, the Cibao has not been officially divided into members; consequently, the formation is described as one geologic unit (section C-C' and D-D', fig. 3).

In the Carolina area, the Cibao overlaps the San Sebastián and is believed to rest directly on the bedrock formations of tuff and volcanic rocks. Here the formation is about 130 ft (40 m) thick.

In places the Cibao forms topographic ridges but more commonly makes up the lower slopes of hills and mogotes capped by the more resistant Aguada and Aymamón Limestones. In the San Juan area exposures of the Cibao are evident at the base of Montes San Patricio, Montes de Canejas, and the smaller hills south of the San José Lagoon. Figure 5 is an outcrop map of the Cibao Formation showing structure contours on the top of the formation.

Aguada Limestone

The Aguada Limestone of Miocene age is a transitional formation between the Cibao marl and the relatively pure crystalline limestone of the overlying Aymamón Limestone (fig. 3). Briggs and Akers (1965) described the Aguada on the north coast as "hard, thick-bedded to massive calcarenite and dense limestone interbedded with chalky limestone and marl; commonly containing some quartz grains and locally thin-bedded near top." It ranges in thickness from 100 to 250 ft (30 to 75 m) in outcrop in the study area. South of the Bahía de San Juan, the hard crystalline beds occur in the upper part while the softer and marly beds predominate in the lower part (Gelabert, 1964).

The Aguada is a ridge former and together with the Aymamón Limestone makes up most of the mogotes in the San Juan area. Except for these last remaining vestiges of the great karst region to the west, the limestones in San Juan have been largely eroded away and covered with alluvial clay, sand, and beach deposits.

Aymamón Limestone

The uppermost limestone, the Aymamón of Miocene age, is exposed as case-hardened caps on a few hilltops in Montes de Canejas and in the small hills around the juncture of

Caño Martín Peña and the Laguna San José (fig. 3). Elsewhere it lies beneath a mantle of alluvium and other surficial deposits. The following description of the formation is given by Zapp, Bergquist, and Thomas (1948), "It consists almost entirely of very dense conchoidally fracturing limestone of white, light gray, buff and rose colors; unit is quite uniform over its entire outcrop and throughout its entire thickness." The map by Monroe and Pease (1962) of the Bayamón quadrangle shows the limestone outcrops, both of the Aguada and Aymamón to be quite extensive, forming the tops of many of the haystack hills. In the Bayamón area the Aymamón is either pink or white, well indurated, usually dense limestone, 215 ft (65 m) thick were exposed. Kaye (1959) estimates the thickness of the Aymamón to be as much as 2,000 ft (600 m) at the coastline. Geophysical studies at Palo Seco indicate an aggregate thickness of middle Tertiary limestones (Aguada and Aymamón) to be about 3,000 ft (900 m).

Surficial Deposits

A variety of alluvial, terrace, blanket sand, beach, and dune deposits ranging in age from Miocene to Holocene mantles the bedrock over much of the study area. Terrace and blanket sand deposits are sometimes referred to as old alluvium, and form a veneer of red to white silty clay, sand and clay, and sand over the older formations. The thickness of these deposits may be more than 100 ft (30 m) in San Juan (fig. 6).

A blanket of loosely cemented dune sand of Pleistocene age overlie the Santurce and Old San Juan areas. The dune sand is composed of quartz and calcite grains, cemented in a calcite matrix. The Holocene deposits include beach sand, swamp and lagoon mud, and recent alluvium or flood-plain deposits of the existing river systems.

HYDROLOGY

Rainfall on the inland mountain slopes drains into four main catchment areas--Río Grande de Loíza, Río Piedras, Río de Bayamón, and Río de la Plata (fig. 1). For the most part, these basins lie on relatively impervious volcanic rock; runoff is rapid, commonly resulting in flash flooding in the lower urbanized reaches of the streams.

Water infiltrating the volcanic rock flows largely through the weathered zone and then into stream valleys. Some ground-water flow through the volcanic rock may ultimately recharge the Tertiary sand and limestone aquifers.

The sand and limestone aquifers of the coastal plain are the principal water-bearing formations in the San Juan area. Recharge to these formations is principally on their outcrops by rainfall and infiltration of streamflow, and discharge is principally into swamps and lagoons along the coastline. Discharge from the confined zones of these aquifers probably is by vertical leakage to the overlying formations.

A possible secondary source of recharge to the aquifer in urbanized areas is leaky water and sewer lines.

In the following section of the report, the terms specific capacity, transmissivity, and hydraulic conductivity will be used in reference to the hydraulic properties of the aquifers. Specific capacity, expressed in gallons per minute per foot of drawdown or cubic metres per second per metre of drawdown is, as the units indicate, the yield of a well divided by the difference between the nonpumping and pumping water level (drawdown) in a well for a time period. The duration of discharge in this report is for a period of 8 hours. Hydraulic conductivity (formerly referred to as coefficient of permeability) is the volume of water that will pass through 1 ft^2 (1 m^2) of an aquifer in 1 day; whereas, transmissivity is the volume of water that will pass through a 1-ft (1-m) wide vertical section, the full thickness of an aquifer in 1 day. Hydraulic conductivity is expressed in $(ft^3/day)/ft^2$ [cubic feet per day per square foot] or ft/day [feet per day]. Transmissivity is expressed as $(ft^3/day)/ft$ [cubic feet per day per foot] or ft^2/day [feet squared per day]. In metric terms, hydraulic conductivity is expressed as $(m^3/day)/m^2$ [cubic metres per day per square metre] or m/day [metres per day], and transmissivity is $(m^3/day)/m$ [cubic metres per day per metre] or m^2/day [square metres per day].

Wells in the metropolitan area are often perforated the entire length of their casings. Consequently, wells starting in the unconfined aquifers may be completed in the confined aquifers and tap both zones. Composite yields and water levels commonly result. Often the yield of a well is controlled to a large degree by the most permeable aquifer tapped, and the water level in a well may be higher or lower than that in the unconfined aquifer owing to the head effects of the lower confined aquifer. Consequently, direct use of well data to describe well performance and aquifer characteristics can be misleading. Variations in transmissivity of the coastal aquifers shown in figure 3 are primarily a composite of the transmissivity of the various water-bearing units.

Ground-Water Levels

Altitudes of the water surface in the volcanic and sedimentary rock unconfined aquifers and of the potentiometric surface of the confined zones of the sedimentary rock aquifers are shown in figure 7. The water surface in the volcanic rocks reflects the control exerted by surface drainage features with ground-water discharge being primarily to streams. But it also shows that in interbasin areas there is some ground-water discharge from the volcanic rocks directly to the sedimentary rocks as indicated in the Montes de Hatillo area, south of Hato Rey. Ground-water levels in the unconfined aquifers of the sedimentary rock also show control exerted by surface-drainage features along the major rivers. The potentiometric surface of the confined zones of the aquifer, in contrast, reflects the head created by the ground-water levels in the recharge area and friction losses in the aquifer.

Observations of the ground-water levels (fig. 8) show that recharge generally occurs during the rainy season from August through November, with a secondary recharge period in April or May. Recharge, however, can occur at any time of the year as the result of major rainstorms.

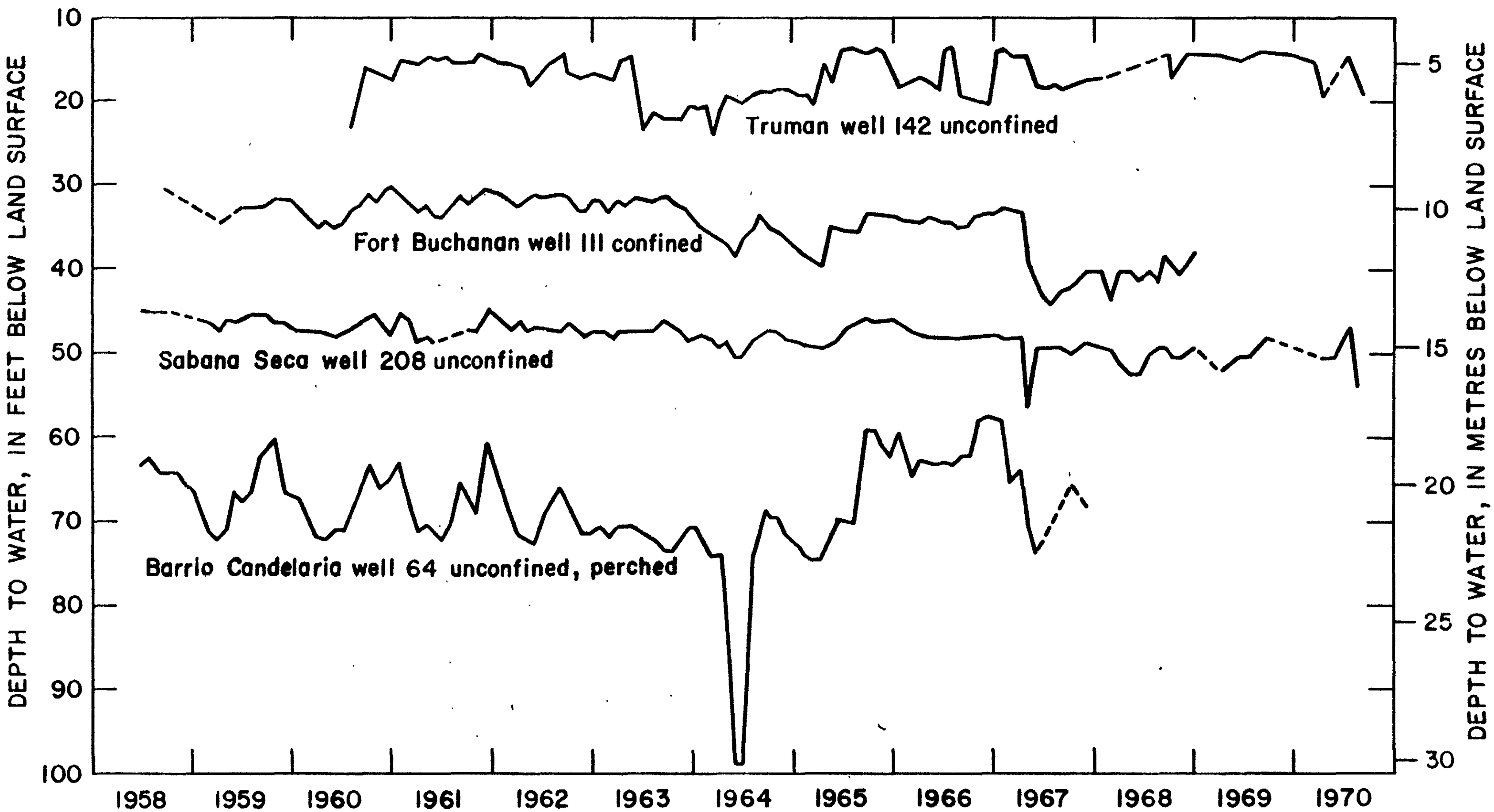

Figure 8.--Hydrographs of selected wells in the San Juan area.

Water-level fluctuations reflect the hydraulic characteristics of the aquifers. The Candelaria well 64 (fig. 8) is situated on the high plateau west of Bayamón, the recharge area for Tertiary formations in the Bayamón area. The wide fluctuation of the water levels in the well indicates the generally low permeability and porosity of the Cibao Formation. A water-level high of 58 ft (18 m) below land surface was reached in late 1966, following several successive wet years. The low water level of record was 99 ft (30 m) below land surface in mid-1964, in response to the dry years of 1963-64. Ordinarily there is about a 10-ft (3-m) variation between the high-water levels in the rainy season and the low levels in the dry season in this well.

The Truman well 142 (fig. 8), along with a number of other Puerto Rico Aqueduct and Sewer Authority wells in San Juan, is used to supplement municipal supply during dry periods when surface-water storage is low. Measurements were taken in the Truman well, both under nonpumping and pumping conditions. The well shows only very modest changes in water level from a high of 13 ft (4.0 m) to a low of 24 ft (7.3 m) below land surface. The low level was primarily a reaction to the drought of 1963-64, when the well was being pumped continuously. Because of the high permeability and storage of the limestone, a more constant water level is sustained during adverse conditions than in the less permeable Cibao and San Sebastián Formations.

Recharge

The average annual recharge to an aquifer or aquifer system determines the long-term yield that can be obtained without depletion or other damage to the aquifer. Recharge usually occurs on the outcrop surface of the aquifer either from the infiltration of rainfall or from surface water from streams that flow across the outcrop. Occasionally recharge will be from underlying or overlying water-bearing formations.

Rainfall is usually the principal source of recharge. Even then a combination of certain conditions must occur before recharge will result. Rainfall must be sufficient to overcome soil moisture demands and yet be of low intensity for maximum infiltration to occur. As these conditions are usually reached only during the rainy season, recharge is cyclic.

The condition of the outcrop area that receives recharge is also critical--the surface must be permeable. Throughout metropolitan San Juan, the recharge areas of the aquifers are being urbanized. High-density housing, streets, and other impervious surfaces are or will greatly impair the receptivity of the recharge areas of the aquifers.

The principal recharge areas in the Bayamón area are the high plateau or ridge of Aguada and Aymamón Limestones lying on top of the Cibao Formation and the outcrop area of the Cibao and San Sebastián Formations to the south (figs. 3, 4, and 5). Important to the recharge on the plateau and the area to the south are the large areas of blanket sand forming an absorbent surface through which rainfall can percolate to the underlying limestone and sandstone. Water infiltrating the ridge flows either northward through the Aguada Limestone or downward through the Cibao Formation and south to the San Sebastián Formation (see fig. 3, section A-A').

In the San Juan-Carolina area, recharge to the San Sebastián Formation is derived from rainfall on the outcrop area, in places mantled by alluvium, from flow losses from the Río Piedras in the intake area, and from underflow through the weathered zone in the volcanic rocks of Montes de Hatillo. Recharge to the Cibao Formation, to the Aguada Limestone, and to Aymamón Limestone is primarily from rainfall on the outcrop area of the Cibao, by percolation through the alluvium mantling these formations, and to a lesser extent through isolated limestone mogotes.

Within the Carolina area, a mogote ridge, Cerro San José (fig. 3, section D-D') is a source of recharge to the limestone and possibly to the underlying sand aquifer of the Cibao Formation. The water-table map (fig. 7) indicates a low swell in this area that may indicate the contribution of local recharge.

Recharge to the aquifers of the metropolitan area is undoubtedly being reduced by extensive urbanization of the intake areas. It is possible that much of the natural recharge that has been lost because of roads, housing, and other impervious structures is being made up by leakage from water and sewage mains. The 28 x 10^6 gal/day (1.2 m^3/s) unaccounted loss from the metropolitan distribution system lends credence to this possibility.

Volcanic Rocks

The bedrock aquifer consists of consolidated rocks principally of marine volcanic origin. These include siltstone, tuff, breccia, andesite, and limestone of Cretaceous and early Tertiary age. Usually these rocks are fine grained and tightly compacted and do not yield water freely to wells. Water that is available flows through cracks, fractures, and bedding planes in the weathered zone of the bedrock. In general, the water-bearing zone is a surficial mantle as much as 300 ft (90 m) thick.

Wells producing from the bedrock aquifer are chiefly in the eastern half of the metropolitan area tapping Tertiary-Cretaceous siltstone underlying the Montes de Hatillo and the Carolina area. The average yield of 25 wells is 52 gal/min (3.3 l/s) with a maximum yield of 300 gal/min (19 l/s). Specific capacities of wells averaged 1.4 (gal/min)/ft [2.9 (l/s)/m] of drawdown. No wells are known to tap the Cretaceous limestone in the Carolina area; however, modest yields possibly could be derived from this formation if metamorphism has not destroyed the original porosity or if secondary solution openings have developed.

Sedimentary Rocks and Surficial Deposits

The Tertiary sedimentary rocks comprise the principal aquifers of the coastal lowlands. Water-bearing units in these rocks range in composition from sand and gravel to nearly pure limestone.

Quaternary sediments predominately of alluvial origin, mantle the Tertiary rocks throughout much of the area. Clay and silt are the principal constituents of these deposits in the coastal areas, but inland in association with the mogotes of Tertiary rocks are high-level terrace deposits commonly referred to as blanket sands. Water-bearing sand and gravel lenses are often found in the valley alluvium deposited by present-day rivers.

The water-bearing units of all the formations are hydraulically interconnected to some degree. The San Sebastián Formation and the lower part of the Cibao Formation are water-table aquifers in their recharge areas but become artesian seaward. The upper part of the Cibao Formation, the Aguada and Aymamón Limestones, and the Quaternary sediments are water-table aquifers.

San Sebastián Formation

In the past years, the San Sebastián Formation was not recognized as a major aquifer in the metropolitan area. Reexamination of well records, however, shows that many wells formerly assigned to the alluvial aquifer actually tap the San Sebastián Formation. In the metropolitan area, the San Sebastián is comprised predominantly of sand and some gravel with local limestone lenses--a sharp contrast to the typical gravelly clay that comprises the formation farther to the west.

In the outcrop area, ground water in the San Sebastián and basal Cibao is unconfined. Downdip (seaward), however, clay zones in the middle part of the Cibao form a confining layer creating confined conditions in the underlying rocks. From the vicinity of the Río de Bayamón east, it is possible that the clayey alluvium overlying the San Sebastián and Cibao Formations also acts as a confining layer. That this is the case becomes more plausible when it is considered that the Cibao Formation is predominantly a sand in the San Juan-Carolina area and the confining clay zone in the middle of the Cibao is generally missing.

Yield of wells tapping the San Sebastián Formation-Mucarabones Sand is low to moderate. Well yields range from 13 to 800 gal/min (0.8 to 50 l/s), with an average of 244 gal/min (15.4 l/s). Many wells have been abandoned because of low yield, particularly those located near the featheredge of the formation's southernmost outcrop. The specific capacities of wells are modest and average 3.1 (gal/min)/ft [0.64 (l/s)/m] of drawdown.

Cibao Formation

Of the formations containing fresh water in the western part of the metropolitan area, the Cibao is the thickest; yet it has the least favorable water-bearing properties largely because of the clayey nature of the formation. There are, however, horizons of limestone and sand that contribute appreciable quantities of water to wells. The limestone horizons in the upper part of the Cibao Formation merge with the unconfined aquifer of the San Sebastián Formation. Between these water-bearing units is an ill-defined section of clay or clay lenses that acts as a confining layer.

The Cibao Formation thins in the eastern part of the metropolitan area and the clay confining layer between the upper and lower members of the formation essentially disappears.

The Cibao Formation can be considered to be a transition formation between the sandy San Sebastián Formation and the relatively pure Aguada and Aymamón Limestones. As such it is part of both water-bearing units.

Throughout much of the metropolitan area, it is often difficult to determine from which unit a well in the Cibao is obtaining its water.

In the Bayamón area, wells in the Cibao Formation are located along Highway 2 on the plateau-like ridge which is also a major recharge area for this formation. Practically all the wells have low yields, low specific capacities, and a diversity of water levels. Wells along the ridge often tap the shallow water-bearing zones perched in limestone overlying the clay horizon and a deeper water-bearing zone in the lower marl of the Cibao. For example, in well 118 (fig. 3) water cascaded from the perched zone to lower levels of the ground-water surface 280 ft (85 m) below. To make the well useful, it was backfilled to within 80 ft (24 m) of the surface to tap the perched water.

Other examples of the water levels in wells becoming lower with depth are evident on the Bayamón ridge. Well 87 (fig. 3), a shallow well, has a water level of 5 ft (1.5 m) below land surface, and a deep well nearby (well 91) has a water level of nearly 100 ft (30 m) below land surface. In the same general area an 80-ft (24-m) well (well 66) has a water level of 56 ft (17 m) and a 130-ft (40-m) well (well 75) has a water level of 126 ft (38 m). The differences can be explained in section A-A' (fig. 3) by imagining that the deeper wells intersect surfaces of lower head that emerge on the sides of the water-table mound. Shallow wells, on the other hand, intersect potential lines of higher head found near the top of the mound.

Wells in the report area tapping the Cibao Formation give a wide range in yield: 0 to 510 gal/min (0 to 32 l/s), but average only 120 gal/min (8 l/s). Specific capacities of wells are low, averaging 3.1 (gal/min)/ft [0.64 (l/s)/m] of drawdown for 24 wells. A water-level recovery test run on a well in San Juan gave a transmissivity of 160 ft^2/day (15 m^2/day) indicating properties of a confining bed rather than an aquifer.

Aguada Limestone

The Aguada Limestone attains its permeability and porosity from solution openings in the rock. In the course of geologic time, percolating ground water has dissolved the soluble material leaving openings from the size of capillaries to huge caverns, often crosscut by solution pipes or fracture crevices. Generally the average texture of these solution openings in the Aguada is from finger to fist size, not large enough for subterranean rivers but capable of supporting large yields to wells. Many large caverns and vertical pipes, carved during and before the Pleistocene age, are now filled with clay and sand plugs which actually tend to reduce porosity. Most of these plugs appear to be above the water table and may not affect the water-bearing capacity of the saturated zone. The average yield from 50 wells is 540 gal/min (34 l/s).

Aymamón Limestone

The Aymamón Limestone is similar to the Aguada Limestone but contains salt water throughout most of the metropolitan area. The lower part of the Aymamón is slightly less permeable than the Aguada, but scattered well data indicate the upper part of the Aymamón is more permeable. The average yield of the Aymamón to 21 wells is 455 gal/min (29 l/s). The upper part of the Aymamón along the coast yields as much as 2,000 gal/min (130 l/s) of salt water.

Artesian Aquifer

The San Sebastián Formation and the basal part of the Cibao Formation comprise a single water-bearing unit that in much of the metropolitan area is a confined aquifer. These formations are distinctive in the Bayamón area but tend to grade into each other to the east.

Aquifer Hydraulics

The transmissivity of the aquifer, largely computed from specific-capacity data, varies from less than 150 to 2,000 ft^2/day (14 to 185 m^2/day). The transmissivity and storage coefficient from well 89 at the foot of Montes de San Patricio are typical of the aquifer. An aquifer test (Unklesbay, 1945) yielded a transmissivity of 1,000 ft^2/day (93 m^2/day) and a storage coefficient of 1.3×10^{-4} indicative of confined conditions. The well was pumped for 26 hours at an average rate of 400 gal/min (25 l/s).

An estimate of ground-water flow through the aquifer can be made using the formula

$$Q = TIL$$

where: Q = quantity in cubic feet per day (cubic metres per second)

T = transmissivity in square feet per day (square metres per day)

I = gradient of potentiometric surface in feet per foot (metres per metre)

L = width of aquifer under consideration in feet (metres).

Using the data from the above aquifer test as representative of the transmissivity of the confined aquifer and the potentiometric gradient in the vicinity of Montes de San Patricio, then

$$Q = 1{,}000\ ft^2/day \times \frac{43\ ft}{5{,}280\ ft} \times 5{,}280\ ft$$

$Q = 43{,}000\ ft^3/day$ [322,000 gal/day] flow per mile width of aquifer parallel to the coast, or in metric terms 760 (m^3/day)/km.

The intake area of the artesian aquifer covers approximately 15 mi^2 (39 km^2). Average daily recharge derived principally from rainfall is estimated at 0.75 (10^6 gal/day)/mi^2 [1,100 (m^3/day)/km^2] of outcrop area--a total of about 11×10^6 gal/day (42,000 m^3/day) or 20 percent of the average rainfall, 52×10^6 gal/day (197,000 m^3/day). If recharge is evenly distributed over the 38 mi^2 (98 km^2) of the coastal plain believed to be underlain by the aquifer, an estimated yield of 0.30 (10^6 gal/day)/mi^2 [440 (m^3/day)/km^2] is available.

The potentiometric surface of the confined zone is above land surface in much of the low-lying coastal plain (fig. 7). Wells in those areas that tap this unit often flow. Known flowing wells occur in the lower valleys of the Río de Bayamón and the Río Piedras and the coastal plain south of San José Lagoon. The largest of these has a flow of 275 gal/min (17 l/s). The head in the aquifer at the well is 15 ft (5 m) above land surface. It is likely that many other wells in the low-lying areas that tap the confined zone would also flow were their castings not perforated in the overlying limestones, thus permitting water from the artesian zone to flow into the limestone.

Water-Table Aquifer

The upper part of the Cibao Formation and the Aguada and Aymamón Limestones forms a prolific unconfined aquifer. The freshwater part of the aquifer ranges from about 2 mi (3 km) in width in the Bayamón area to less than 1/2 mi (1 km) in width in the Carolina area.

Yields of 71 wells in the unconfined aquifer range from 30 to 2,500 gal/min (2 to 160 l/s) and average 510 gal/min (32 l/s). Specific capacities of wells are high, averaging 41 (gal/min)/ft [8.5 (l/s)/m] for 42 wells. In an earlier study, Bogart and others (1964) indicated an average yield of 400 gal/min (25 l/s) from 29 wells, and an average specific capacity of 53 (gal/min)/ft [1.1 (l/s)/m] from 20 wells, for the limestone aquifer. In the present study, transmissivities computed from specific-capacity data showed a range of from 7,000 to 135,000 ft^2/day (650 to 12,500 m^2/day) indicating the high conductivity of the aquifer. The average transmissivity computed from specific-capacity data is 13,000 ft^2/day (1,200 m^2/day).

The greatest production potential of the unconfined aquifer is in the Bayamón area (fig. 9) where the freshwater zone of the aquifer not only has its greatest extent but the recharge area is extensive in comparision with the areas to the east.

Two major well fields operated by the Puerto Rico Aqueduct and Sewer Authority are located in the Bayamón area (fig. 1). The Campanilla field tapping the Aguada Limestone has wells yielding as much as 1,000 gal/min (63 l/s). Average specific capacity of five wells is 63 (gal/min)/ft [13 (l/s)/m].

The Sabana Seca field taps the Aymamón Limestone and the upper part of the Aguada Limestone. Yields range from 500 to 1,000 gal/min (32 to 63 l/s) in the 10 wells in the field. During summer and fall of 1968, production from the field was 4.3 x 10^6 gal/day (0.19 m^3/s). Water quality, however, was affected by salt-water encroachment from the Río de Bayamón estuary. The wells, in an east-west line on the west bank of the estuary, showed a declining chloride concentration away from the estuary. The well nearest to the estuary had a chloride concentration of 360 mg/l (milligrams per litre). The chloride concentration of the next six wells in line progressively decreased with distance from the estuary, but all exceeded 100 mg/l.

During an aquifer test in the Sabana Seca well field, the production well (well 220, fig. 3) was pumped for 4 days at a rate of 615 gal/min (39 l/s), with a drawdown of 12.5 ft (3.8 m) and a specific capacity of 49 (gal/min)/ft [10 (l/s)/m]. Measurements made during the test showed drawdowns of less than 0.5 ft (0.15 m) in observation wells 1,000 ft (300 m) from the pumped well.

Computed transmissivity was 160,000 to 240,000 ft^2/day (14,900 to 22,300 m^2/day) and coefficient of storage was 0.001 (Leggette, Brashears and Graham, 1969).

Transmissivities computed from specific-capacity data on individual wells in the field are much less, 4,500 to 27,000 ft^2/day (420 to 2,500 m^2/day) than those computed utilizing the aquifer test. The discrepancies are attributed to well entrance losses which tend to reduce the specific-capacity values and the corresponding transmissivities. Use of properly designed wire-wound or shutter-type screens, in places of perforated casing could reduce entrance losses and thereby improve specific capacities to several hundred gallons per minute per foot of drawdown.

Static water levels in the Sabana Seca well field are from 2.9 to 5.6 ft (0.9 to 1.7 m) above sea level. Accordingly, at these levels the fresh water-salt water interface should lie at depths of 120 to 225 ft (37 to 69 m) below sea level (the depth to salt water below sea level increases approximately 40 ft [12 m] for each 1-ft [0.3-m] increase in water-table altitude above sea level). Consequently any stress put on the well field in a sustained long-term pumping effort could readily lead to a salt-water intrusion problem.

The ground-water flow through the aquifer can be estimated from the aquifer-test data computed at Sabana Seca. Using the formula: $Q = TIL$, it is found that about 600,000 ft^3/day (4.5×10^6 gal/day) of ground water is moving through a 1-mi (1.6-km) wide strip of aquifer to a seaward discharge area or about 25×10^6 gal/day (1.1 m^3/s) in the area between the Río de la Plata and the Río de Bayamón. Large variations in this discharge can occur when the ground-water gradient, normally about 3 ft/mi (0.6 m/km), is changed owing to tidal effects, seasonal changes in rainfall, droughts, and pumpage.

The limestone area between the Río de Bayamón and the Río de la Plata and to the divide south of Highway 2 includes about 28 mi^2 (73 km^2). The principal drainage from the limestone is ground-water flow toward the sea and, to a lesser extent, to the main stream systems of the Río de Bayamón or the Río de la Plata. An estimated 20 mi^2 (52 km^2) of limestone terrane containing fresh water drains toward the coast. Water-budget studies made in the Tortuguero area to the west (Bennett and Giusti, 1972) show the approximate recharge to the karst limestone, which is on the order of 1 (10^6 gal/day)/mi^2 [0.02 (m^3/s)/km^2]. Applying this magnitude of recharge to the coastal drainage between the Río de la Plata and the Río de Bayamón, an estimated 20×10^6 gal/day (0.9 m^3/s) is recharge to the aquifer as compared with approximately 25×10^6 gal/day (1.1 m^3/s) discharge computed above. At the present time, about 10 x 10^6 gal/day (0.44 m^3/s) is pumped by wells from the aquifer, mainly in Campanilla and Sabana Seca. The current artificial draft on the aquifer is roughly half the estimated recharge rate.

In the San Juan-Carolina area, fresh water in the unconfined aquifer is found only in the upper part of the Cibao Formation and the Aguada Limestone. Well yields of more than 2,000 gal/min (130 l/s) can be obtained from the fresh-water part of the aquifer in the San Juan area; although, the yields usually are restricted to less than 200 gal/min (13 l/s) depending upon the proximity of the salt-water front. Data are too few to give a valid evaluation of the unconfined aquifer in the Carolina area. Akers (written commun., 1965) reported a well yielding 2,500 gal/min (158 l/s) of marginal-quality water (350 mg/l chloride) in the limestone, east of the Río Grande de Loíza.

Estimates of transmissivity and ground-water gradients in San Juan indicate that seaward ground-water discharge through the aquifer is on the order of 1 (10^6 gal/day)/linear mi [27 (l/s)/linear km], approximately, along the fresh-water contact. The apparent recharge area for the unconfined aquifer, however, does not appear to be extensive enough to supply the required volume of water. Recharge to the unconfined aquifer could be augmented by lateral flow from the unconfined part of vertical flow from the confined part of the San Sebastian Formation and lower part of the Cibao Formation and leaky water or sewer mains.

The Aymamón Limestone is part of the unconfined aquifer and in the San Juan-Carolina area it contains mostly salt water. Wells tapping the Aymamón near the sea yield as much as 2,000 gal/min (130 l/s) of salty water.

Surficial Deposits

The surficial deposits are not an important source of water in the San Juan area, though they do serve as a conduit for recharge to underlying aquifers. The Pleistocene eolianite deposits along the coast yield water high in chloride concentration, mainly to shallow wells. Locally, in Carolina, a few wells tap abundant supplies from Holocene alluvial deposits. Sources of fresh water, formerly described as recent alluvial deposits, are often sand and gravel deposits of the San Sebastián Formation. Examination of more than 100 driller's logs from wells in the San Juan area show the alluvial deposits to be highly clayey and relatively unfavorable for the development of wells; except possibly in some stream valleys.

Yields from several industrial wells tapping the alluvium of the Río Grande de Loíza on the eastern edge of the study area are as much as 700 gal/min (44 l/s), but they are not typical of well yields from the alluvium in the metropolitan area. Records available for 17 wells in surficial deposits show a median yield of 60 gal/min (3.8 l/s).

Surface Water-Ground Water Relationship, Río de Bayamón Basin

The base flow of streams is ground-water discharge from the adjacent aquifers. Base flow, therefore, can be an indication of the long-term yield of an aquifer and also of the long-term average recharge to the aquifer.

An analysis of the total and base flow of the Río de Bayamón was made for different time periods, to verify, where possible, estimates of recharge and ground-water discharge determined by analyses of hydraulic data obtained from the performance of wells tapping the aquifers in the San Juan area.

The Río de Bayamón basin encompasses an area of about 95 mi^2 (246 km^2). The river rises in the mountains about 20 mi (32 km) inland and flows northward to the sea. The upper two-thirds of its course is incised in a complex of Cretaceous age volcanic rocks, whereas the lower third flows over Tertiary age sediments and younger, predominantly Holocene age surficial deposits. The gradient of the channel changes abruptly from 95 ft/mi (18 m/km) on the volcanics to 11 ft/mi (2 m/km) on the sedimentary rocks and surficial deposits of the coastal plain.

The Río de Bayamón, as mentioned earlier, is a highly regulated stream. In August 1970, diversions from the Bayamón system were 5.56×10^6 gal/day (0.24 m^3/s) from the Lago de Cidra, 15.32×10^6 gal/day (0.67 m^3/s) from Old San Juan Dam, and 7.42×10^6 gal/day (0.33 m^3/s) from Santa Rosa--a total of about 28×10^6 gal/day or 43 ft^3/s (1.2 m^3/s).

Streamflow is augmented by industrial and municipal sewage effluent discharge to the Río de Bayamón and its tributaries. In August 1970, the Guaynabo sewage treatment plant discharged an average of 2.5×10^6 gal/day (0.11 m^3/s) of secondary-treated sewage to the Río Guaynabo. An industrial plant on the Río Minillas and two plants on the Río Hondo had a combined disposal capacity of 1.14×10^6 gal/day (0.05 m^3/s). A fourth industrial plant, north of Bayamón, contributed 1.04×10^6 gal/day (0.046 m^3/s) of sewage to the Río de Bayamón. The total recorded contribution of sewage effluent to the Río de Bayamón in August 1970 was about 6×10^6 gal/day or 9 ft^3/s (0.26 m^3/s).

Figure 10 shows the relationship of rainfall at Hato Tejas to discharge at the Río de Bayamón at Bayamón (station 50 0480 00) corrected for diversions. Runoff is approximately 35 percent of precipitation for the 4 years of record. Giusti and López (1967) calculated runoff as 33 percent of precipitation for 8 years of record on the adjacent Río de la Plata basin. Figure 10 also shows that evapotranspiration for a 70-in (1,780-mm) annual rainfall would be about 52 in (1,320 mm), or about double the runoff.

Figure 11 shows a series of curves corresponding to a given chance, or probability, that a certain daily discharge will be equaled or exceeded in a given month. Mean daily discharges are plotted on the vertical axis and months are represented along the horizontal axis. The curves show, in a qualitative way, the behaviour of the stream regimen in the basin and the role of ground water to streamflow.

The 90-percent curve corresponds in general to base flow and has the same variation as the seasonal fluctuation of the ground-water surface. The 1-percent curve, on the other

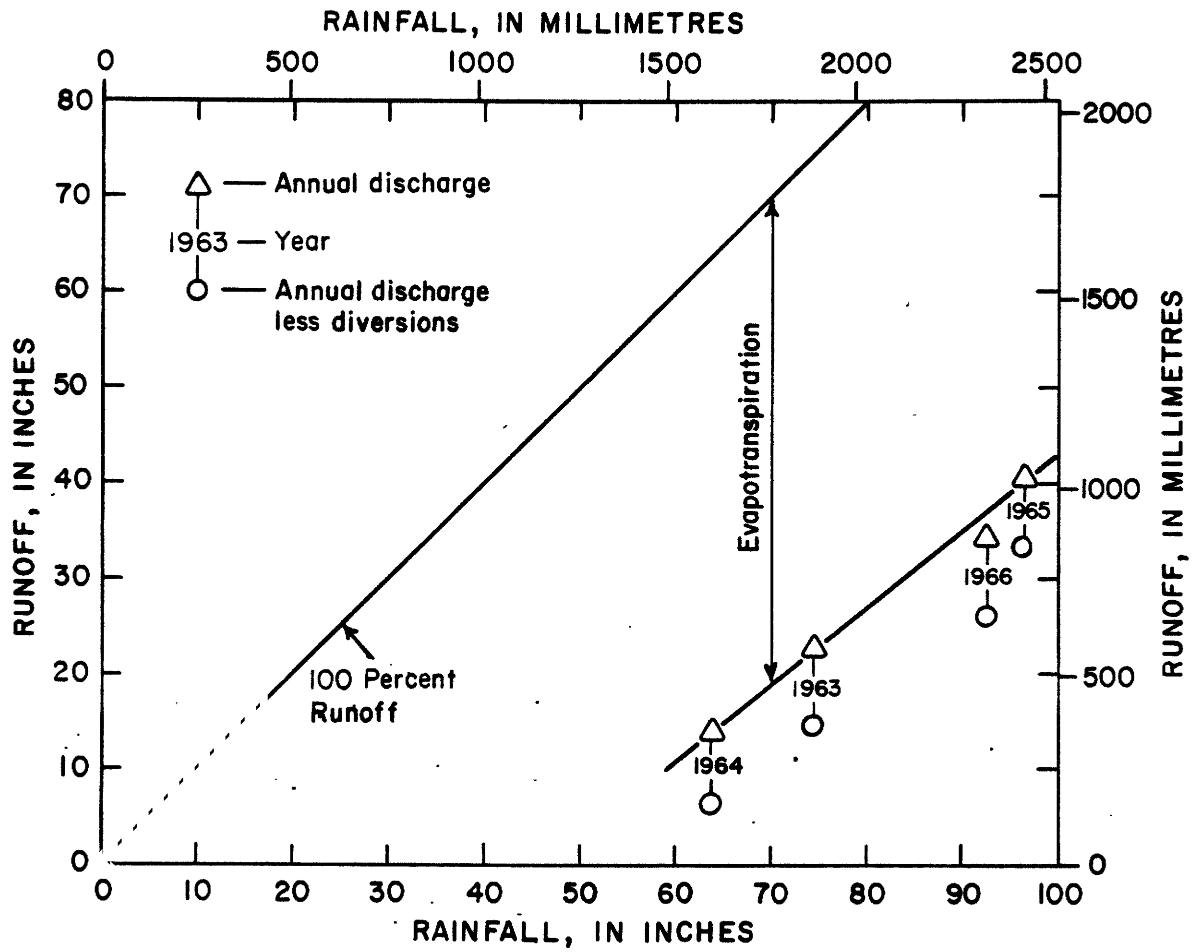

Figure 10.--Relationship of rainfall at Hato Tejas to discharge of Río de Bayamón at Bayamón (station 50 0480 00).

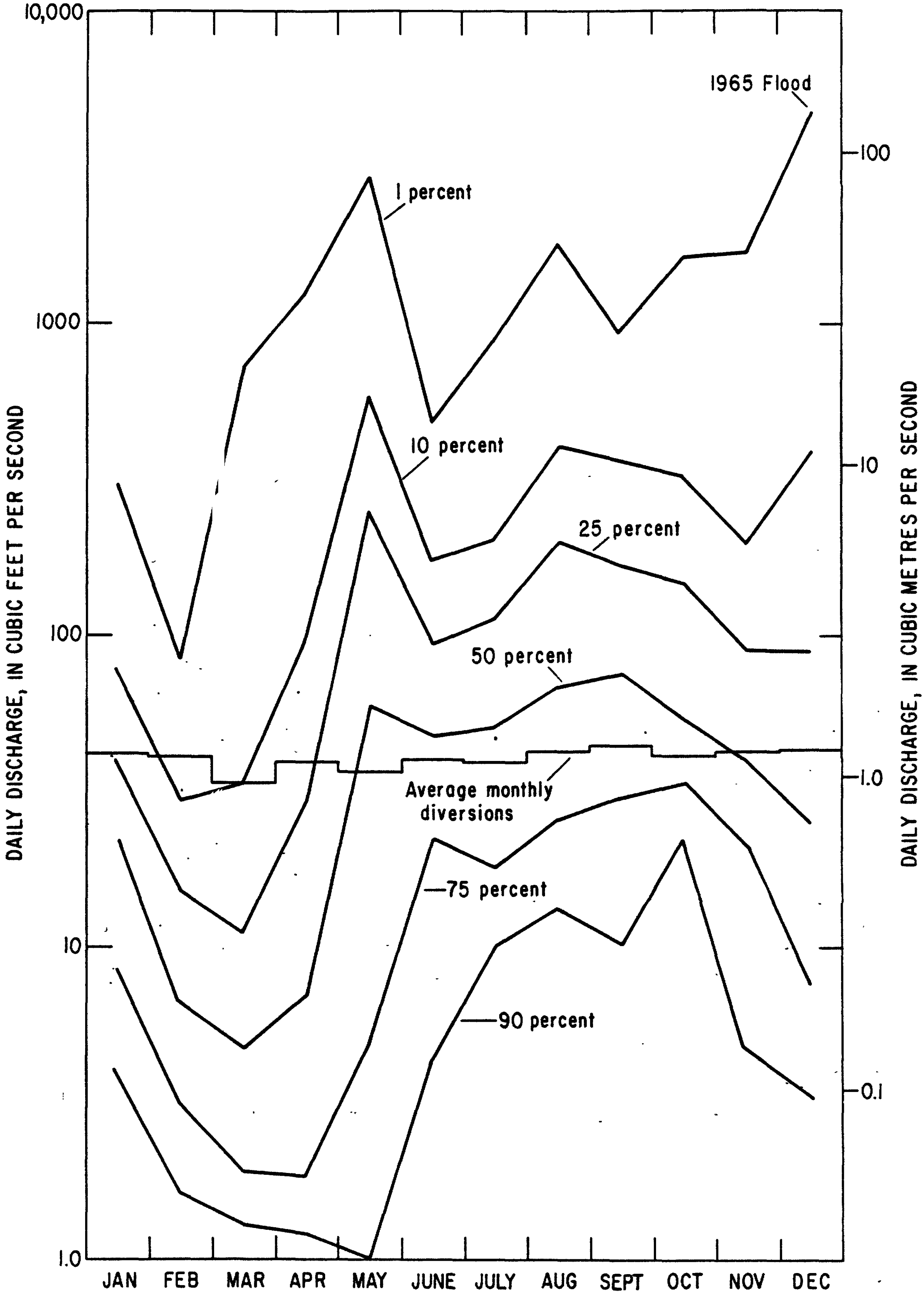

Figure 11.--Percentage of time that a certain mean-daily discharge was equaled or exceeded in any 1 month, January 1963 to December 1966, Río de Bayamón at Bayamón (station 50 0480 00).

hand, follows a pattern similar to the monthly rainfall in the basin, as high, infrequent flows or floods are in direct response to intense rains.

The minimum flow in the 10-percent curve is in February, when storm runoff is least; whereas, the minimum in the 90-percent curve is in May, when the ground-water surface and base flow are lowest. The 10-percent curve shows highs in May and August, when rainfall and runoff are greatest; while, the 90-percent curve shows a high in October, when the ground-water surface is high and base flow is greatest.

Figure 12 shows the discharge, diversions, and sewage inflow of Río de Bayamón near Bayamón (station 50 0478 50) and Río de Bayamón at Bayamón (station 50 0480 00) for the first 4 months of 1966. The basin above both stations overlie volcanic rocks. The sites differ geologically only in the valley floor; for about 2 mi (3 km) above Río de Bayamón at Bayamón, the valley is filled with alluvium.

Base flow at the two stations, shown by the depletion curves, was high in early January; as the result of extremely heavy rainfall in the latter part of 1965. The first 3 months of 1966, however, were very dry with little rainfall, and the base flow reflects the depletion of ground water in storage in the volcanic rocks due to the lack of recharge. The steeper slope of the depletion curve of Río de Bayamón at Bayamón is attributed to losses of base flow to the alluvium in the riverbed.

Table 1 gives the average daily base flow per unit area for January, February and March 1966, at each station and also for that part of the basin between the stations. In January base flow was essentially the same at both stations. It can be concluded that the alluvium above the lower station was saturated and that ground-water discharge from the volcanic rock was at or near maximum. The following months show a steady decline in base flow at the upper station from a maximum of 1.28 to 0.73 $(ft^3/s)/mi^2$ [14.0 to 8.0 $(l/s)/km^2$]. Short-term data for drought periods indicated the ground-water contribution to streamflow from the volcanic rocks may be as small as 0.5 $(ft^3/s)/mi^2$ [5 $(l/s)/km^2$].

In February and March, the area between the two gaging stations showed a major decline in flow per unit area that is attributed to infiltration of streamflow into the alluvium. In both months, the apparent daily loss was about 0.3 $(ft^3/s)/mi^2$ [3 $(l/s)/km^2$] or about 6×10^6 gal/day (0.26 m^3/s) in 2 mi (3 km) of stream channel.

Downstream from the gaging station Río de Bayamón at Bayamón (station 50 0480 00) the river flows on alluvium across the outcrop of the San Sebastián Formation. Measurements, corrected for sewage inflow, made upstream and downstream of the outcrop of the San Sebastián Formation (area 1.3 mi^2 or 3.4 km^2) on February 19, 1962, when base flow was high, showed a ground-water contribution of about 0.3 $(ft^3/s)/mi^2$ [3 $(l/s)/km^2$] to the stream. On March 4, 1963, at a low base flow a net loss of about 0.6 $(ft^3/s)/mi^2$ [7 $(l/s)/km^2$] was computed.

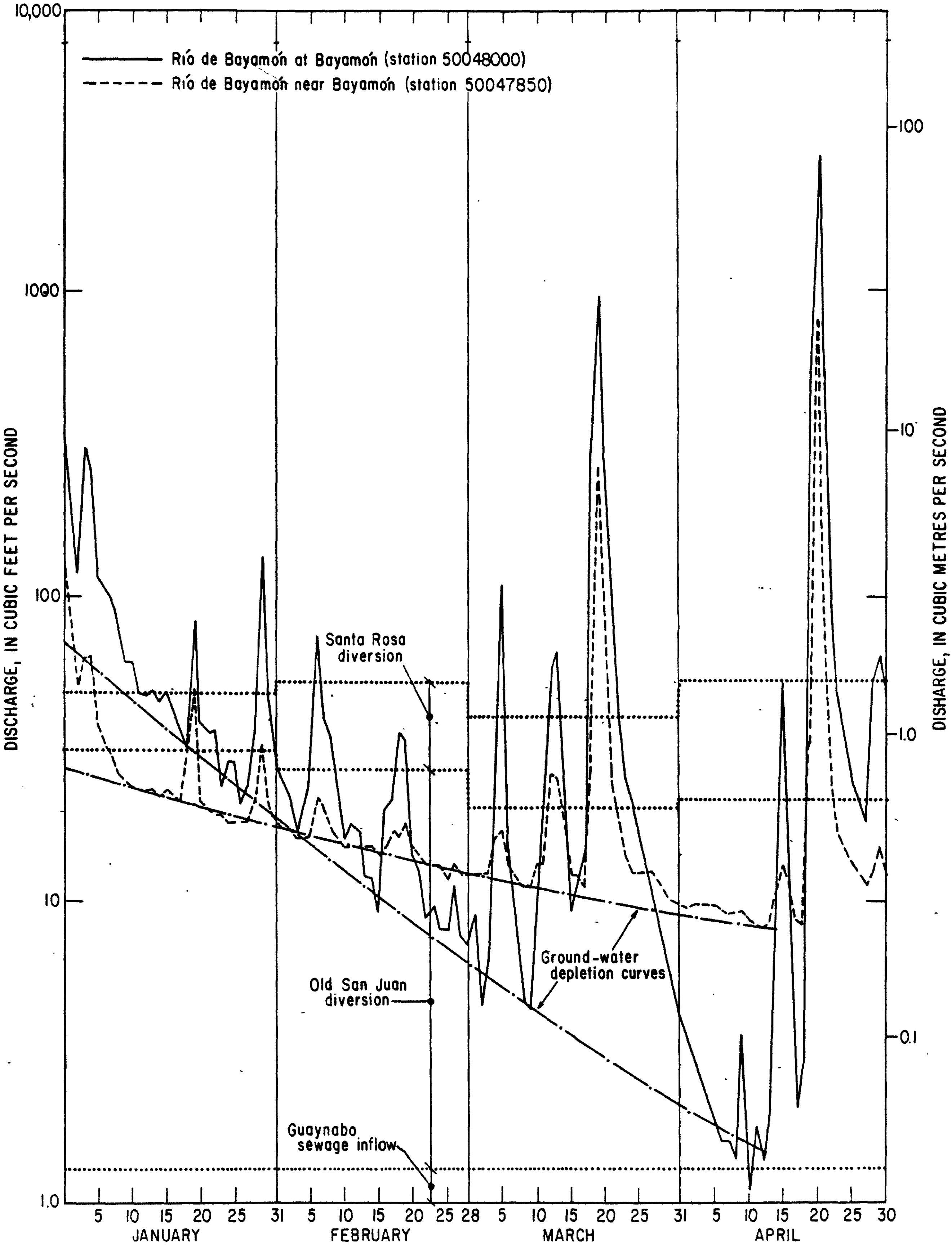

Figure 12.--Diversions of and sewage inflow to Río de Bayamón and discharge at Río de Bayamón near Bayamón (station 50 0478 50) and Río de Bayamón at Bayamón (station 50 0480 00), 1966.

Table 1.--Base flow of the Río de Bayamón, January–March 1966 (Discharge is in cubic feet per second)

Station	Drainage, square mile (km^2)	Date	Base flow, daily average	Diversions, daily average	Sewage, daily average	Total base flow: Daily average	Total base flow: $(ft^3/s)/mi^2$
50 0478 50 (volcanic rock only)	41.8 (108)	Jan.	22	31.5	0	53.5	1.28
		Feb.	15.5	27.0	0	42.5	1.01
		Mar.	10.4	20.0	0	30.4	.73
50 0480 00 (alluvium over volcanic rock)	71.9 (186)	Jan.	44	48	1	91	1.27
		Feb.	12	52	1	63	.88
		Mar.	4	40	1	43	.60
50 0480 00 minus 50 0478 50	30.1 (78.0)	Jan.				37.5	1.25
		Feb.				20.5	.68
		Mar.				12.6	.42

Gain or loss in flow of the Río de Bayamón, as it traverses the Aguada and Aymamón Limestones, is not known. In the basins west of the San Juan area, ground water from the limestone contributes from 21 to 50 percent of the runoff for seven major streams (Giusti and Bennett, in preparation). Because of the small areal extent of the limestones in the Bayamón area, the ground-water contribution probably is considerably less, and it may be that there is a net loss from the Río de Bayamón to the limestone.

The average precipitation (computed by the Thiessen method) for the Río de Bayamón basin in 1963-66 was 64 in (1,625 mm). Streamflow at Río de Bayamón at Bayamón station averages 28 in (710 mm) annually, including 8 in (205 mm) of diversions. Ground-water flow to the Río de Bayamón, but not accounting for losses to the alluvium upstream of the station, is largely from Cretaceous volcanic rocks and is estimated to be 15 in (380 mm) per year. The daily ground-water contribution to the river of 1.1 $(ft^3/s)/mi^2$ [12 $(l/s)/km^2$] was more than 50 percent of the total streamflow.

When ground-water levels are low, generally in the months of January through April, the alluvium and likely the Tertiary rock aquifers receive recharge from the river. In the upper 2 mi (3 km) of the alluviated valley, maximum stream loss is about 3 $(10^6$ gal/day)/linear mi [0.08 (m^3/s)/linear km] of channel. Downstream loss may be as great as 6 $(10^6$ gal/day)/linear mi [0.16 (m^3/s)/linear km] where the river crosses the outcrop of the limestones. On the coastal plain proper, the alluvium in and adjacent to the river channel is very fine to clayey and the infiltration rate is probably much less than upstream. Hydrographs of wells and water quality of the Sabana Seca well field indicate some hydraulic connection between the limestone aquifer and the river.

If streamflow is available, an estimated 20×10^6 gal/day ($0.9\ m^3/s$) probably is recharged to the aquifers during the dry months. During the rest of the year, the aquifers either are in balance with the stream system or contribute water to the stream.

CHEMICAL QUALITY OF WATER

Ground Water

The chemical differences of ground water in the aquifers in the San Juan area are very slight. The predominant ground water is a calcium bicarbonate type. Some ground water is a sodium sulfate type; however, water of this type does not conform to any recognizable pattern of distribution.

Ground water generally becomes more mineralized from the mountain region toward the coast (fig. 13) where the occurrence of the more soluble limestone formations and seawater contribute to the mineralization of ground water.

A summary of analyses of water samples from the unconfined aquifer, principally the Aguada Limestone, shows the water to be alkaline (pH 7.7 to 8.3), moderately high in dissolved-solids concentration (293 to 4,550 mg/l) and very hard (110 to 1,100 mg/l) but otherwise of good quality (table 2). The aquifer is susceptible to salt-water intrusion and the uppermost formation, the Aymamón Limestone, contains brackish or seawater along much of the coastline.

Ground water from the Cibao and San Sebastián Formations in both the unconfined and confined parts of the aquifer is considerably less mineralized than the water from the limestone aquifer. A summary of analyses of water from these formations is given in table 3.

For comparison, the median concentrations of dissolved solids, hardness and bicarbonate for the Cibao and San Sebastián Formations are 363, 195, and 226 mg/l, respectively; whereas, the median concentrations for the limestone formations are 525, 295, and 300 mg/l, respectively.

Figures 14 and 15 show the generalized distribution of chloride concentration and hardness in the unconfined aquifers in the metropolitan area.

Table 2.--Summary of chemical analyses of water from wells in limestone of the unconfined aquifer (15 samples)

Parameter	Concentration mg/l Minimum	Maximum	Average	Median
Silica	9.5	52	29	30
Calcium	23	190	93	77
Magnesium	5.4	160	28	18
Sodium	20	1,570	205	83
Potassium	.6	17	3.7	2.2
Bicarbonate	160	396	285	300
Sulfate	3.8	330	56	24
Chloride	22	2,400	330	120
Fluoride	.0	.9	.2	.15
Nitrate	.0	12	2.6	.9
Dissolved solids	293	4,550	867	525
Hardness	110	1,100	344	295
Conductance (umhos)	517	7,680	1,500	920
pH	7.7	8.3	--	7.8
Temperature °C	25	27.8	26.1	26

Table 3.--Summary of chemical analyses of water from wells in sand of the confined aquifer (17 samples)

Parameter	Concentration, mg/l Minimum	Maximum	Average	Median
Silica	9.6	56	38	43
Calcium	14	92	57	58
Magnesium	2.3	20	12.9	11
Sodium	10	120	57.5	46
Potassium	1.2	46	5.8	3
Bicarbonate	120	364	230	226
Sulfate	6	170	47	23
Chloride	17	190	57	34
Fluoride	.0	.4	.14	.1
Nitrate	.0	85	7.5	.6
Dissolved solids	253	619	400	363
Hardness	45	290	195	195
Conductance (umhos)	361	1,070	645	625
pH	7.3	8.5	--	8.0
Temperature °C	24.5	27.5	25.7	25.5

POSSIBILITIES FOR FURTHER INVESTIGATION

Deep Test Well

In metropolitan San Juan, a deep test well could be drilled to explore the geologic and hydrologic environment below 300 ft (90 m). In the present state of knowledge, the geologic composition and structure beneath San Juan is largely unknown. The specific objectives of a deep-well program would be threefold: 1) to test the sand and marl aquifer for artesian water at depth; 2) to determine the aquifer's hydraulic characteristics and extent of salt-water intrusion; and 3) to determine the feasibility of recharging aquifers through wells or subsurface storage of liquid wastes through wells.

Artificial Recharge

Further investigation could reveal if artificial recharge may have practical application in San Juan. Surplus runoff from upland streams might be used to recharge aquifers through wells or pits. The additional head might tend to move the salt-water front seaward, thereby safeguarding existing aquifers or possibly reclaiming a contaminated aquifer. The sand and marl aquifer possibly could be recharged through injection wells to create a reservoir to be tapped during drought.

Specific sites that might be suitable for recharge include: 1) the foothills of Montes de Hatillo on the San Sebastián Formation intake area; 2) the Sabana Seca Naval Station between the mogotes of the Aguada-Aymamón Limestone and in conjunction with this, the level of Caño El Hato could be raised, thereby creating a hydraulic barrier to seawater encroachment; and 3) a recharge pit in the intermogote valley, bottomed by the Cibao Formation and surrounded by Aguada Limestone hills, at Ft. Buchanan. The pit could recharge and freshen aquifers presently used in Las Palmas industrial area to the north. In addition, recharge wells installed north of the industrial area could act as a hydraulic barrier to seawater intrusion.

A collapsible dam or a tidal gate on the Río de Bayamón floodway, to prevent salt water from moving up the channel from the sea, has been considered by planners. Consideration might be given to an investigation of the effect on the aquifer with and without a control.

Effect of Urbanization on Recharge Areas

If runoff due to urbanization increases, there should be concomitant decreases in ground-water recharge to the aquifers. Investigation could determine the effects of urbanization on the ground-water reservoir and the extent of seawater intrusion. Some recharge areas have been cemented over or otherwise destroyed by construction.

North Coast Artesian Aquifer

Evidence is accumulating that an extensive artesian aquifer exists throughout the north coast. The confined sand aquifer represents this zone in the San Juan area. Artesian water has been found at Manatí, 1,200 ft (370 m) below sea level; near Barceloneta, 900 ft (270 m) below sea level; and at Arecibo, 2,300 ft (700 m) below sea level, from an electric log of an oil-test well. Yields are as much as 2,000 gal/min (130 l/s). Though the aquifer varies from relatively pure limestone to sand and marl, a fairly uniform confining layer is provided by the Cibao clay. Further investigation is needed to determine the potential of this aquifer throughout the north coast, particularly where the upper aquifers are salty or where large quantities of water are desired.

Modeling

Hydrologic conditions in the San Juan area could be simulated by an analog or digital model. Such a model probably would facilitate additional studies of the area and would be a valuable tool in evaluating the effects of existing or proposed water-related developments on the system.

RESUME OF PRINCIPAL FINDINGS

1. The principal aquifers in the San Juan metropolitan area are the unconfined limestone aquifer--composed of the upper part of the Cibao Formation, the Aguada and the Aymamón Limestones, and the artesian sand aquifer--composed of the lower part of the Cibao and San Sebastián Formations. Clay layers in the Cibao Formation and probably clayey alluvium act as confining beds of the artesian aquifer.

2. The yield of the unconfined limestone aquifer is much greater than that of the artesian sand aquifer. For example, average yields respectively are 510 gal/min (32 l/s) versus 240 gal/min (15 l/s) and specific capacity 41 (gal/min)/ft [8.5 (l/s)/m] versus 3 (gal/min)/ft [0.6 (l/s)/m]. The transmissivity of the unconfined limestone aquifer is as much as 135,000 ft^2/day (12,500 m^2/day), and that of the artesian sand aquifer is usually less than 2,500 ft^2/day (230 m^2/day).

The unconfined aquifer is susceptible to seawater intrusion; whereas, the artesian aquifer has not encountered this problem.

3. A hydrologic analysis of the Río de Bayamón basin indicates that for 1963-66 the

average annual precipitation was about 64 in (1,630 mm), at Hato Tejas. Of this amount, basin runoff amounted to 28 in (710 mm). Approximately 15 in (380 mm) represents ground-water flow from Cretaceous volcanic rocks to the Río de Bayamón. This is essentially the base flow of the stream. In the dry season, practically all this base flow is diverted for supply. The annual evapotranspiration from the basin is about 36 in (915 mm).

4. Areas blocked out as being unfavorable for ground-water development include the unconfined limestone aquifer north of lat 18°26' N, which yields brackish water, and unconfined volcanic rocks in the uplands south of San Juan, which are low yield.

5. Ground-water pumpage in past decades has changed from 5×10^6 gal/day (220 l/s) in 1945 to 3×10^6 gal/day (0.13 l/s) in 1970.

6. Locations for drilling high-yield wells in the unconfined limestone aquifer are most promising between Campanilla and Sabana Seca and, in San Juan bordering the southern shores of San José Lagoon. Though yields in the limestone improve to the north, so does the chance for salt-water intrusion. Moderate yields can be developed from the confined sand aquifer beneath areas where the limestone aquifer is brackish.

7. The chemical characteristics of ground water in the aquifers are similar. Except for some isolated occurrences, water is predominantly of the calcium bicarbonate type. The dissolved-solids concentration, in the ground water, shows a progressive increase from the Cretaceous volcanic rocks to the Tertiary sandstones and limestones. Water in the limestone is the most highly mineralized.

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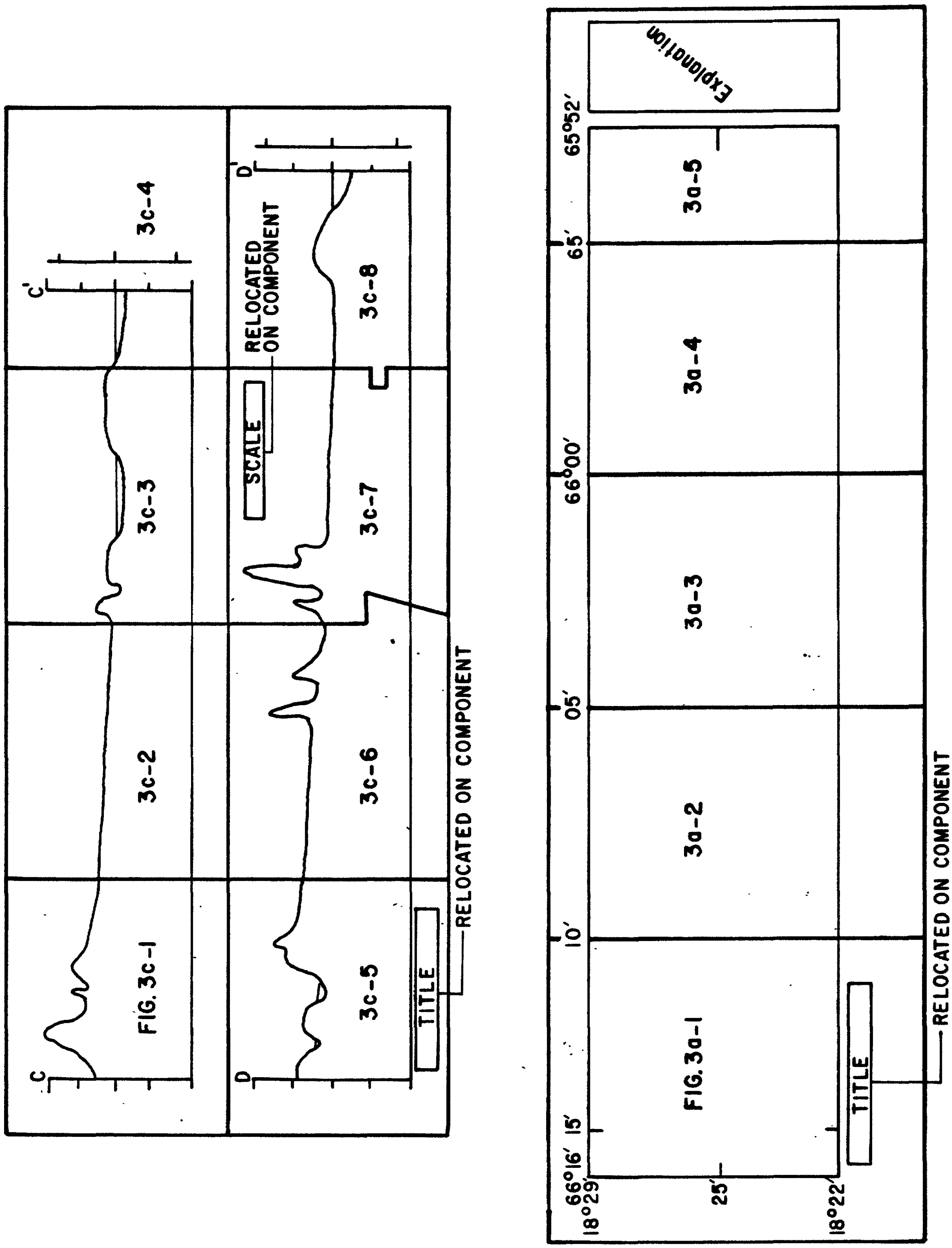
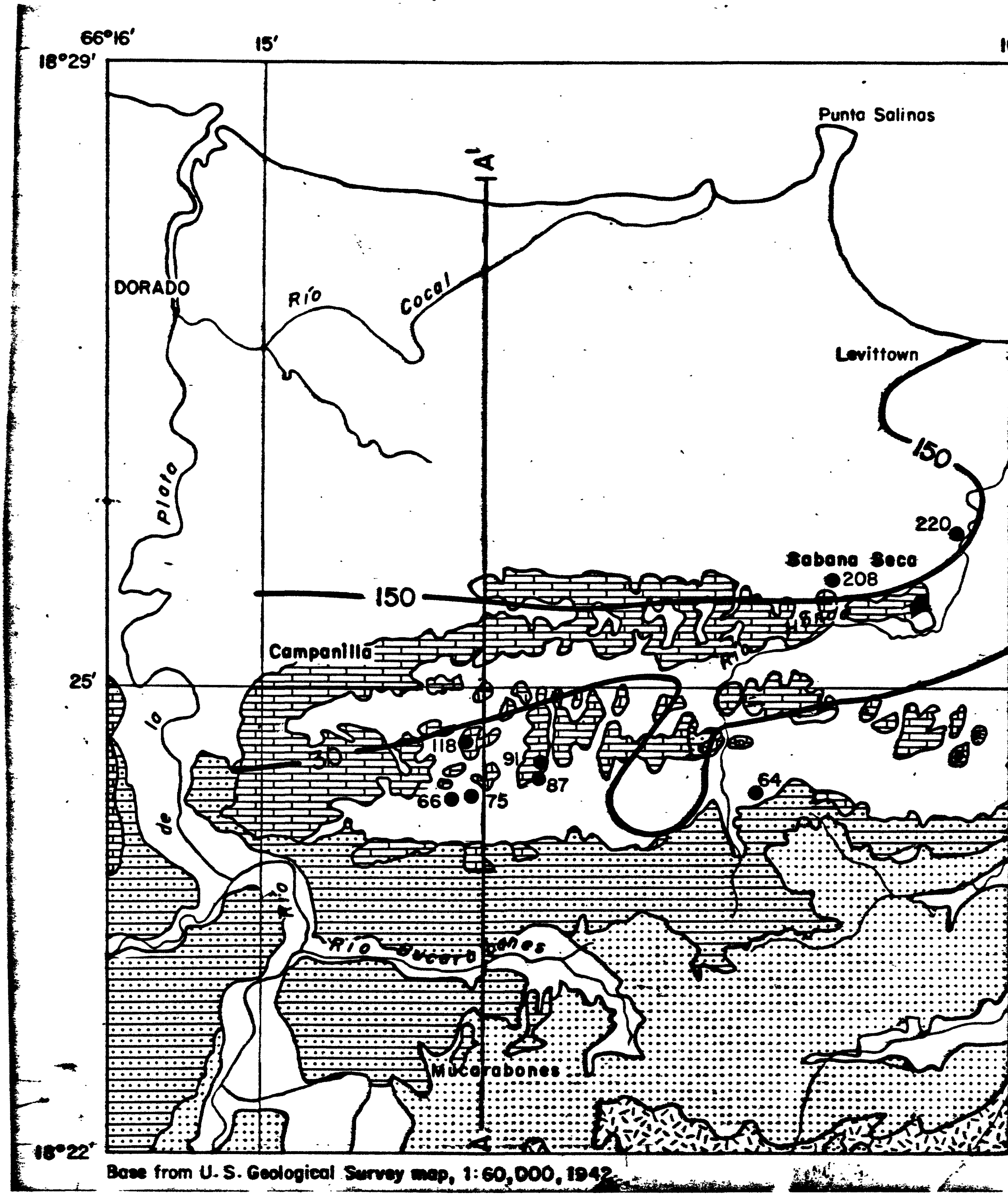


(FIGURES 3c AND 3a COMPOSE THIS 18"x 24" PLATE)

3a - 0

3c - 0

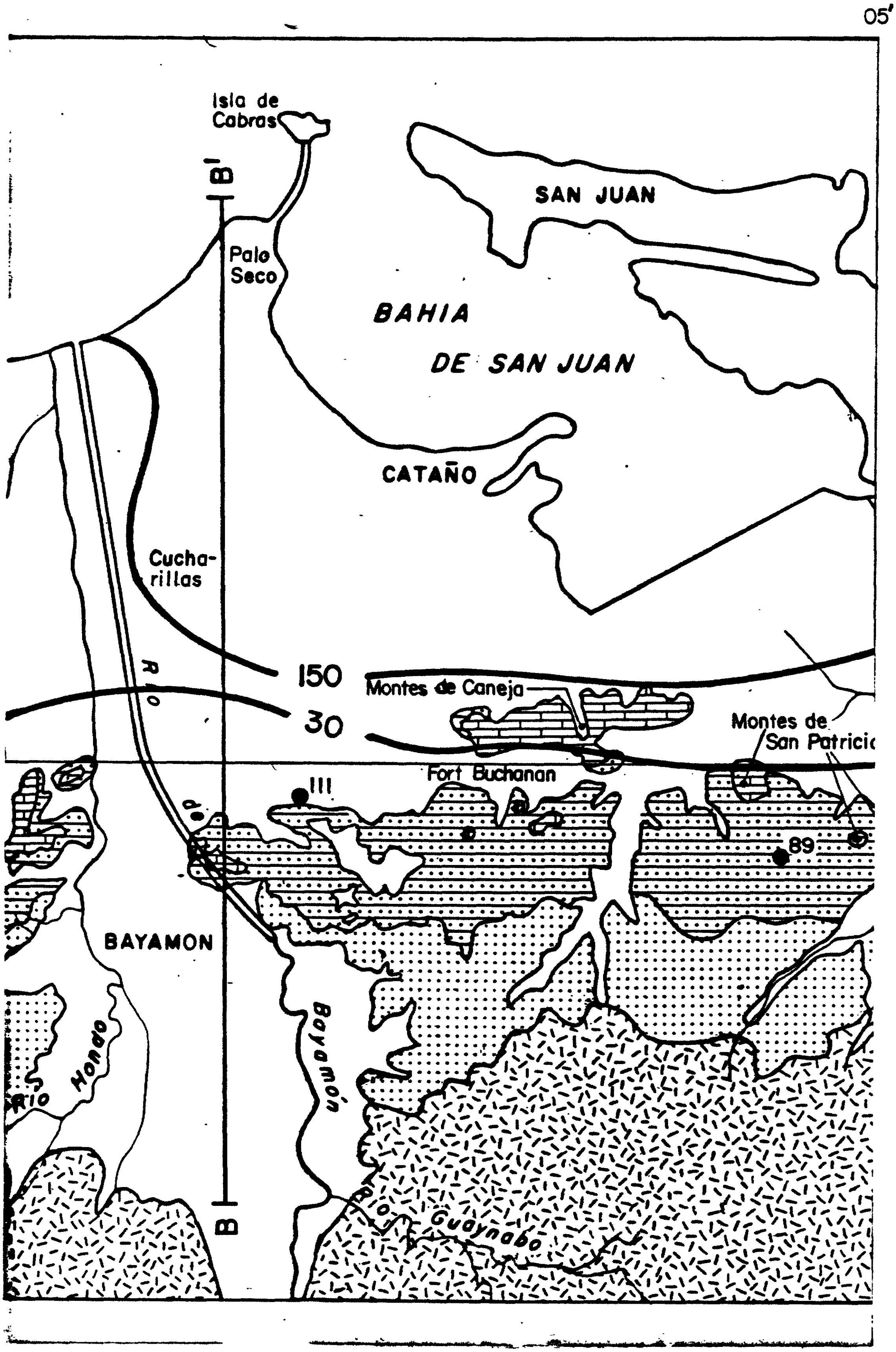
35



3a-1

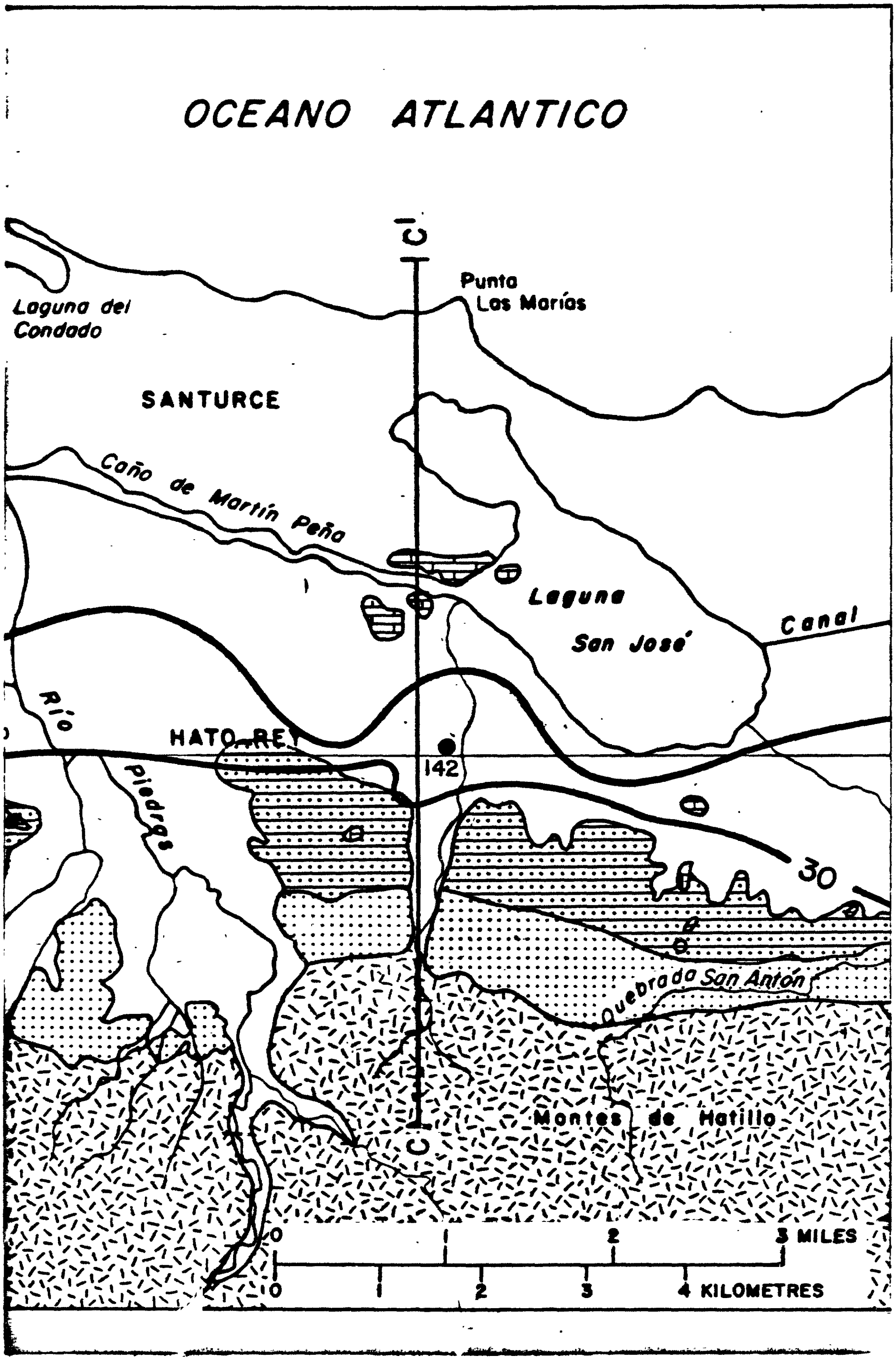
FIGURE 3a -- HYDROGEOLOGIC MAP SHOWING GENERAL TRANSMISSIVITY OF AQUIFERS.

36


05'
Isla de Cabras
B'
Palo Seco
SAN JUAN
BAHIA
DE SAN JUAN
CATAÑO
Cucha-rillas
Rio
150
30
Montes de Caneja
Montes de San Patricio
Fort Buchanan
111
89
de
BAYAMON
Bayamón
Rio Hondo
Guaynabo
B

3a-2

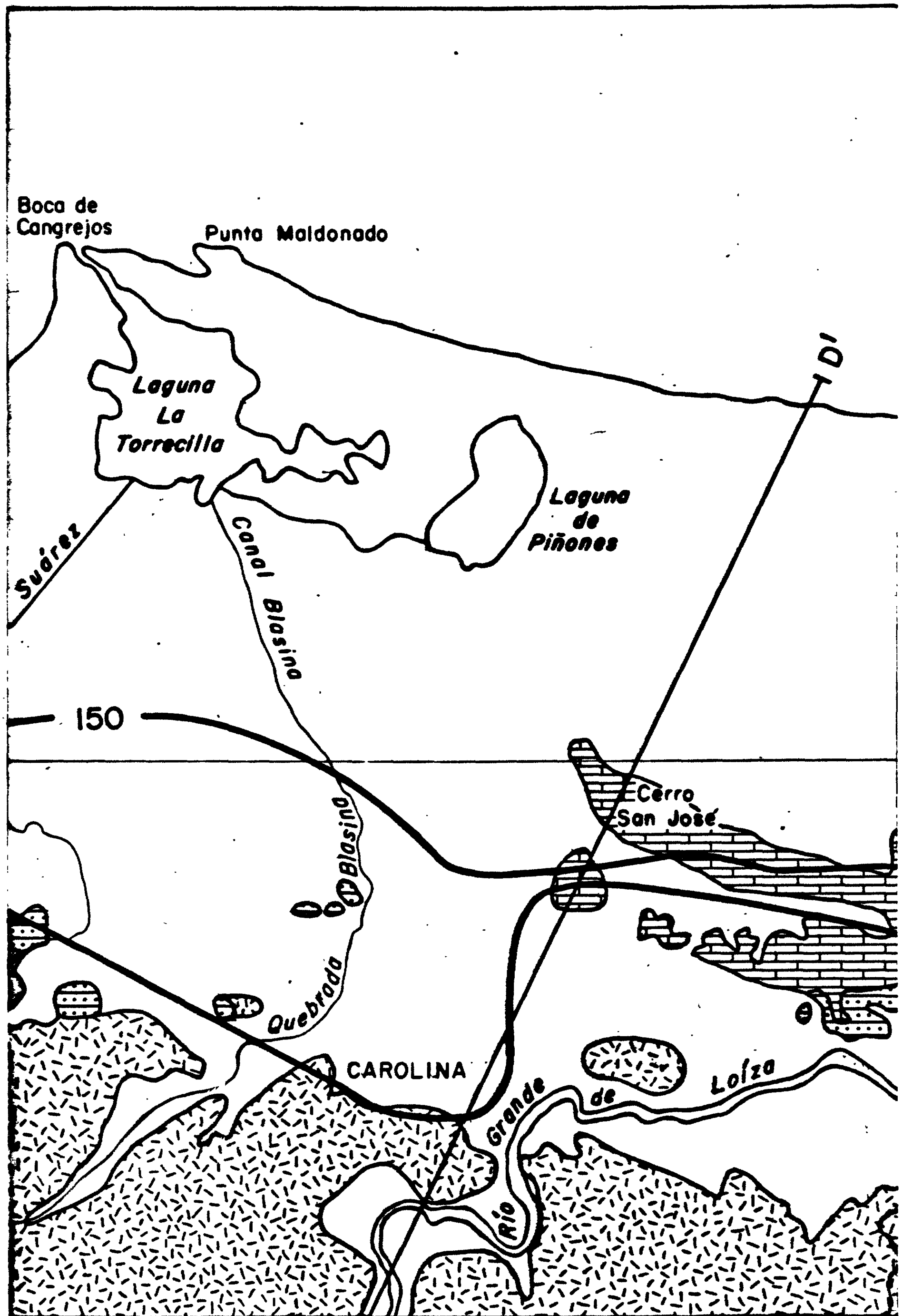
66°00′



OCEANO ATLANTICO
C′
Punta Las Marías
Laguna del Condado
SANTURCE
Caño de Martín Peña
Laguna San José
Canal
Río Piedras
HATO REY
142
30
Quebrada San Antón
Montes de Hatillo
C
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

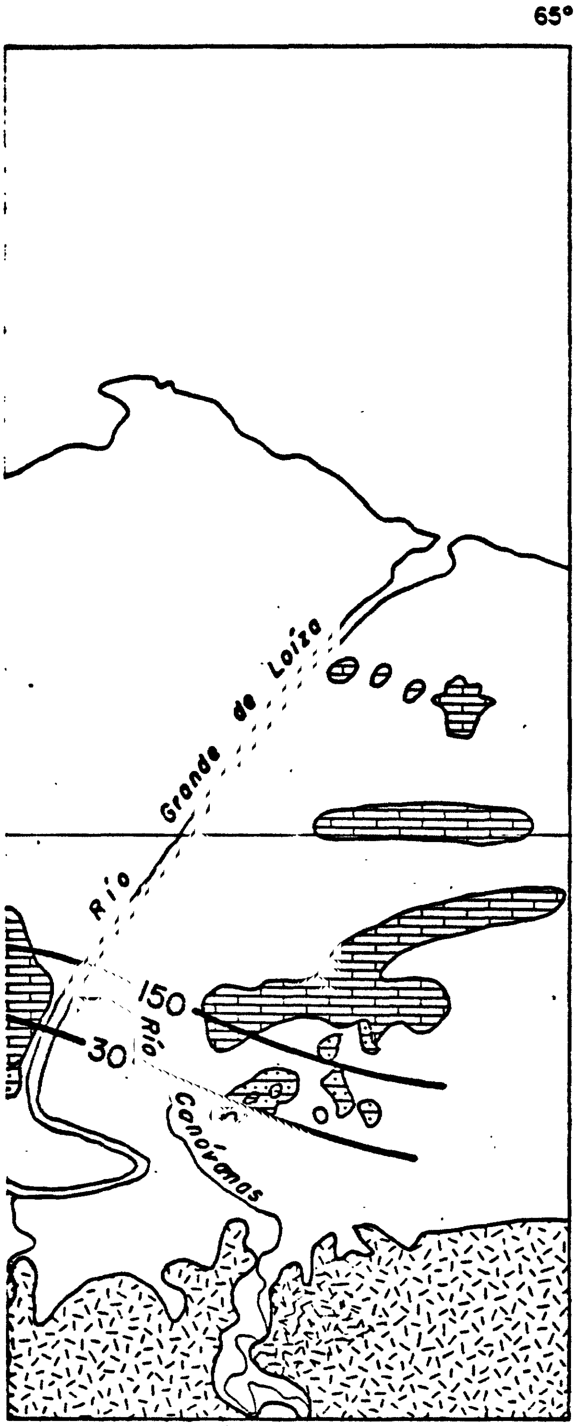
38

55′



Geology after Kaye (1959).

39



Monroe and Pease (1962).

EXPLANATION

TERTIARY TO QUARTERNARY

Miocene to Holocene

Surficial deposits
Clay, silt, sand, gravel, and peat in river terraces, blanket sand deposits, beaches, dunes, and marshes. Not important as an aquifer.

TERTIARY

Miocene

Aymamon and Aguada Limestones
Aymamon is dense crystalline limestone. Yields as much as 2000 gal/min (126 l/s) to wells but contains mostly salt water.

Aguada is thick-bedded calcarenite and dense limestone. Average yield to wells, 540 gal/min (34 l/s). Susceptible to sea-water intrusion.

Oligocene and Miocene

Cibao Formation
Interbedded clay, marl, sand, and lime-stone. Grades into San Sebastián Formation. Clay is confining layer.

Oligocene

San Sebastian Formation
Clay, sand, and gravel beds. Within lower part of the Cibao Formation is an artesian aquifer yielding as much as 500 gal/min (32 l/s) to wells. Includes overlying Mucarabones Sand in western part of the area.

CRETACEOUS AND TERTIARY

Volcanic rocks
Volcanic siltstone, sandstone, and lava. Includes some limestone and intrusives. Average yield to wells, 50 gal/min (3 l/s). Water-bearing zone in fractured and wea-thered rock.

Contact

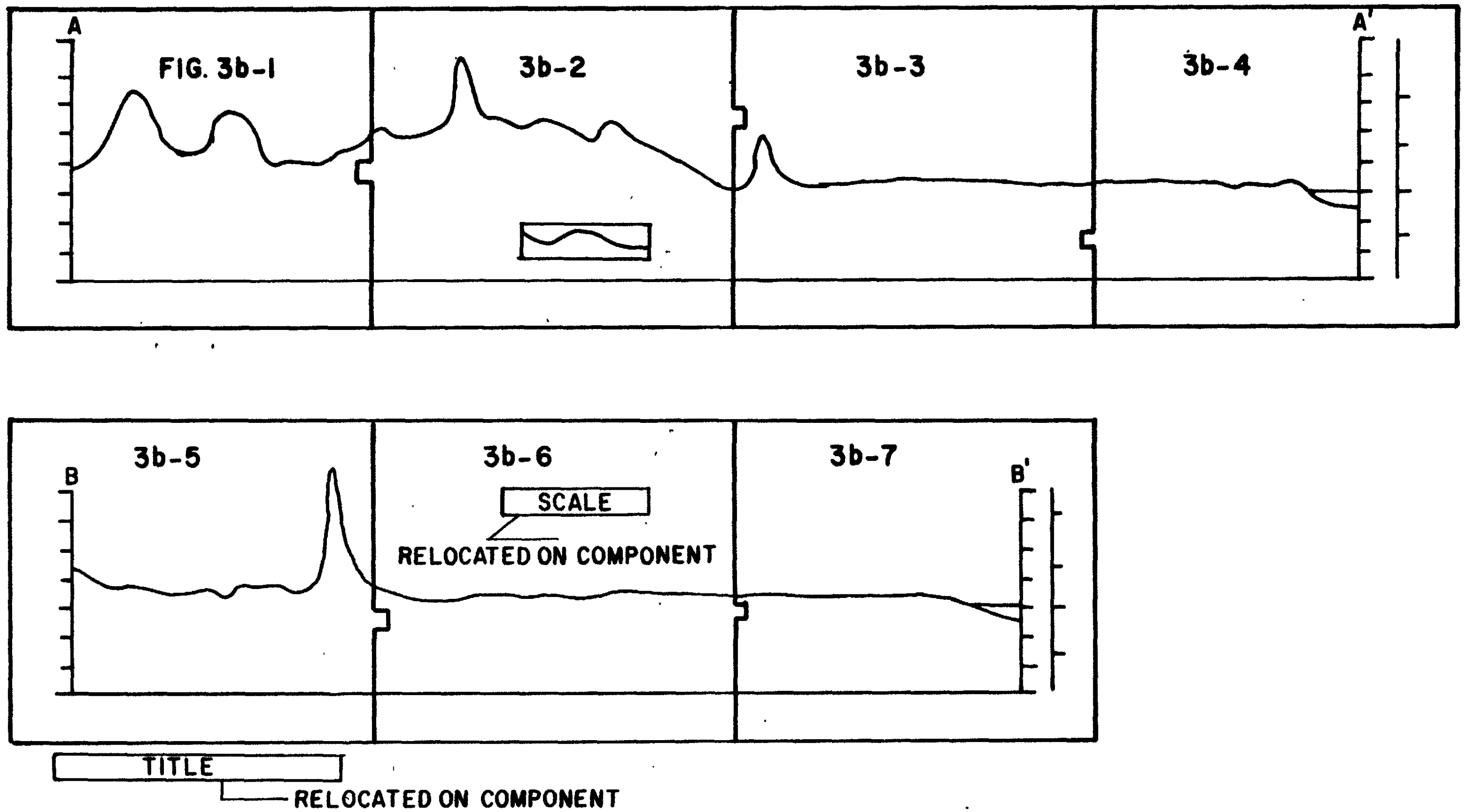
30

Line of equal transmissivity. Interval 120 feet squared per day (11 metres squared per day)

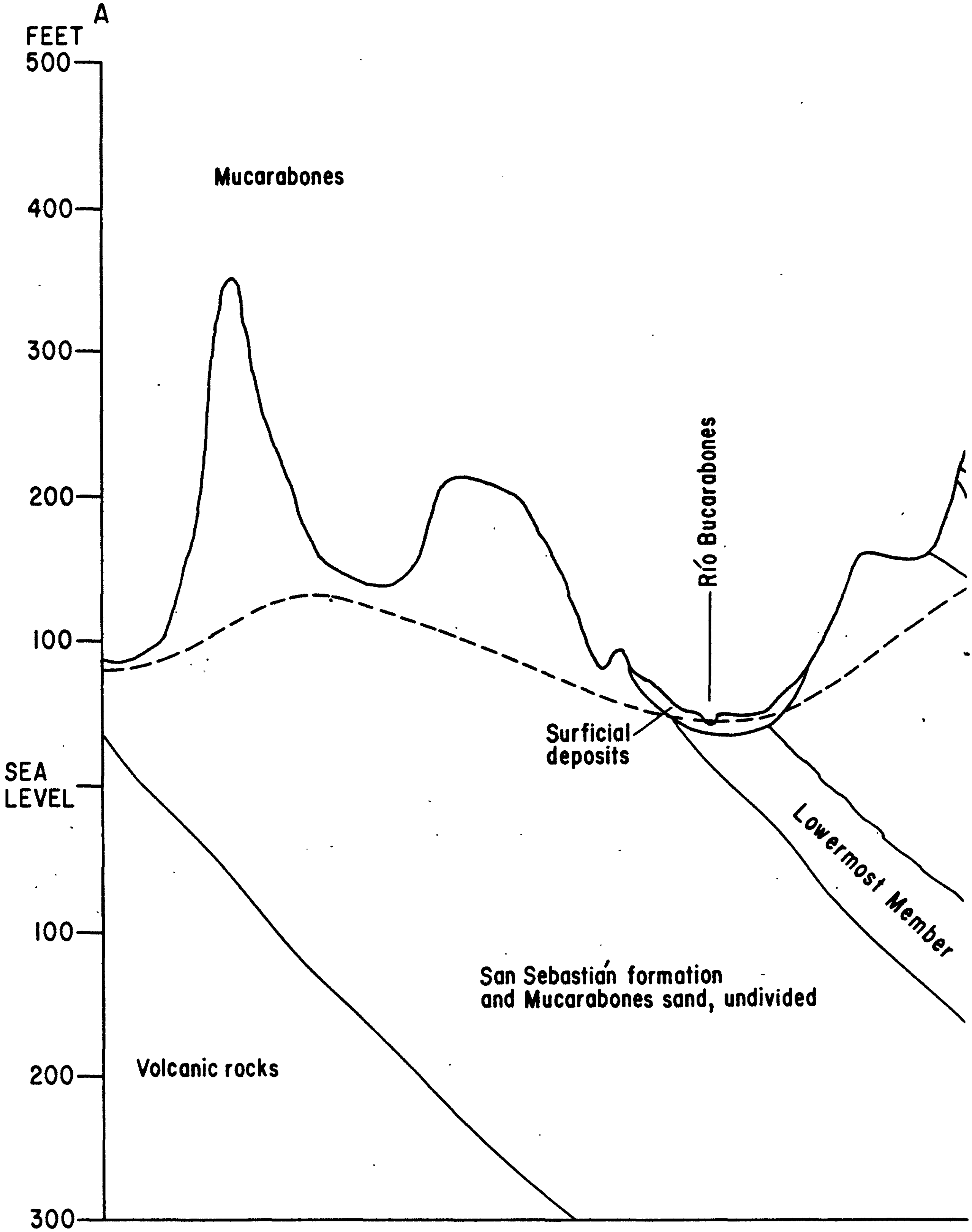
A — A'
Geologic section

●37
Well and number

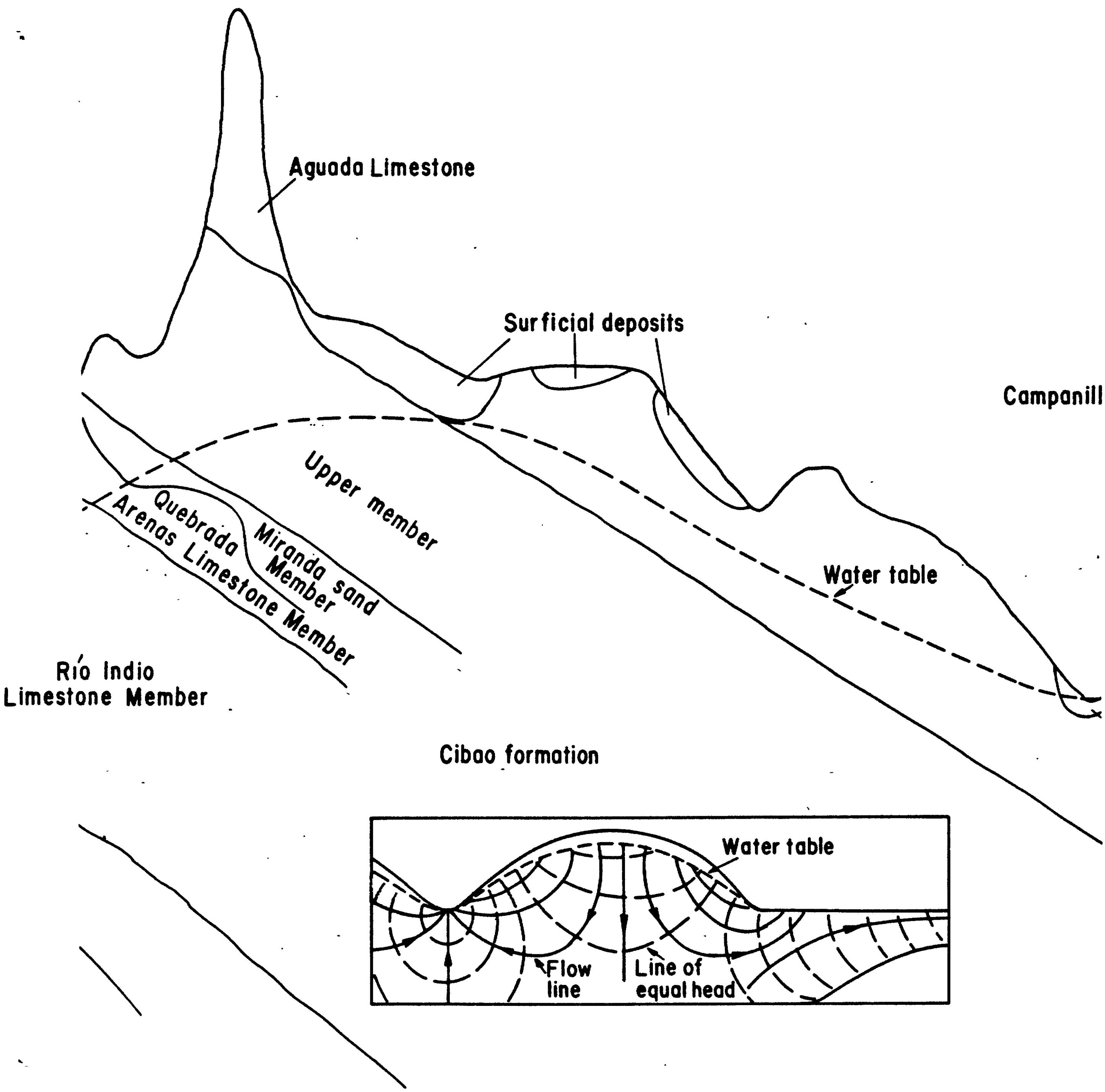
40

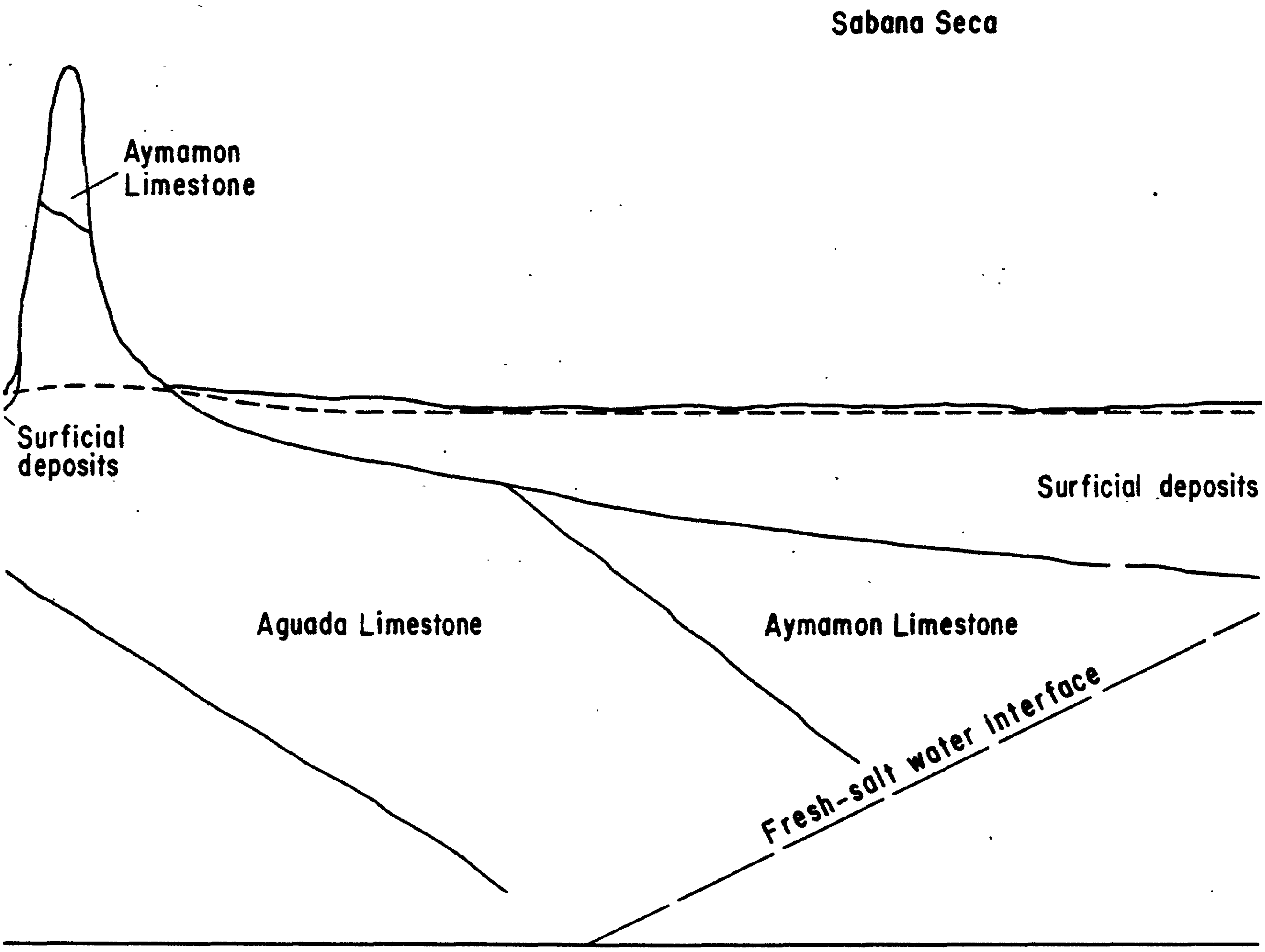


(SECTIONS A-A' AND B-B' COMPOSE THIS FIG. 3b IN A 18"x 24" PLATE)

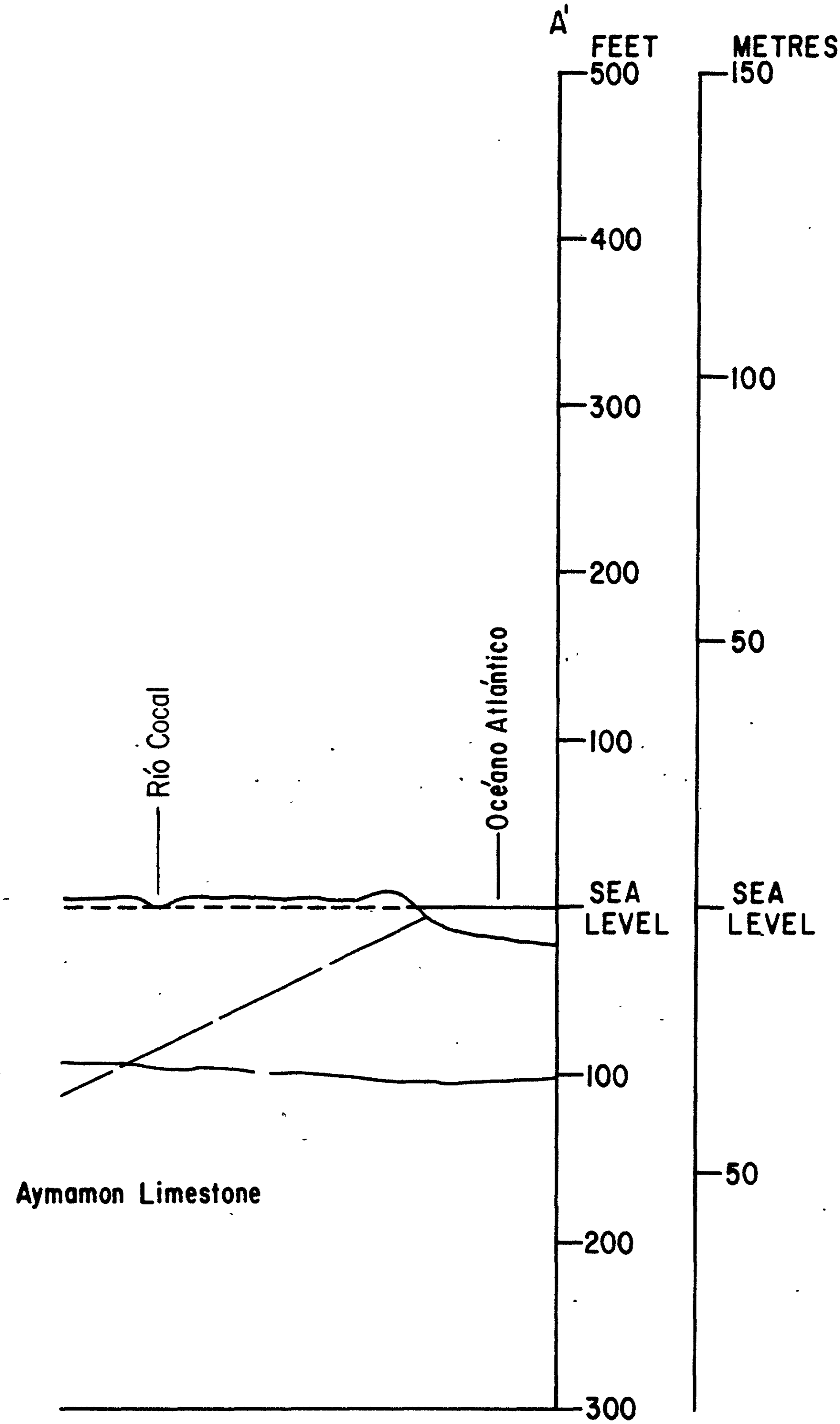

A
FEET
500
400
300
200
100
SEA LEVEL
100
200
300
Mucarabones
Río Bucarabones
Surficial deposits
Lowermost Member
San Sebastián formation and Mucarabones sand, undivided
Volcanic rocks

42


Aguada Limestone
Surficial deposits
Campanilla
Upper member
Quebrada Arenas Limestone Member
Miranda sand Member
Water table
Río Indio Limestone Member
Cibao formation
Water table
Flow line
Line of equal head


Sabana Seca
Aymamon
Limestone
Surficial
deposits
Surficial deposits
Aguada Limestone
Aymamon Limestone
Fresh-salt water interface

3b-3



A'
FEET
METRES
500
400
300
200
100
SEA LEVEL
100
200
300
150
100
50
SEA LEVEL
50
Río Cocal
Océano Atlántico
Aymamon Limestone

3b-4

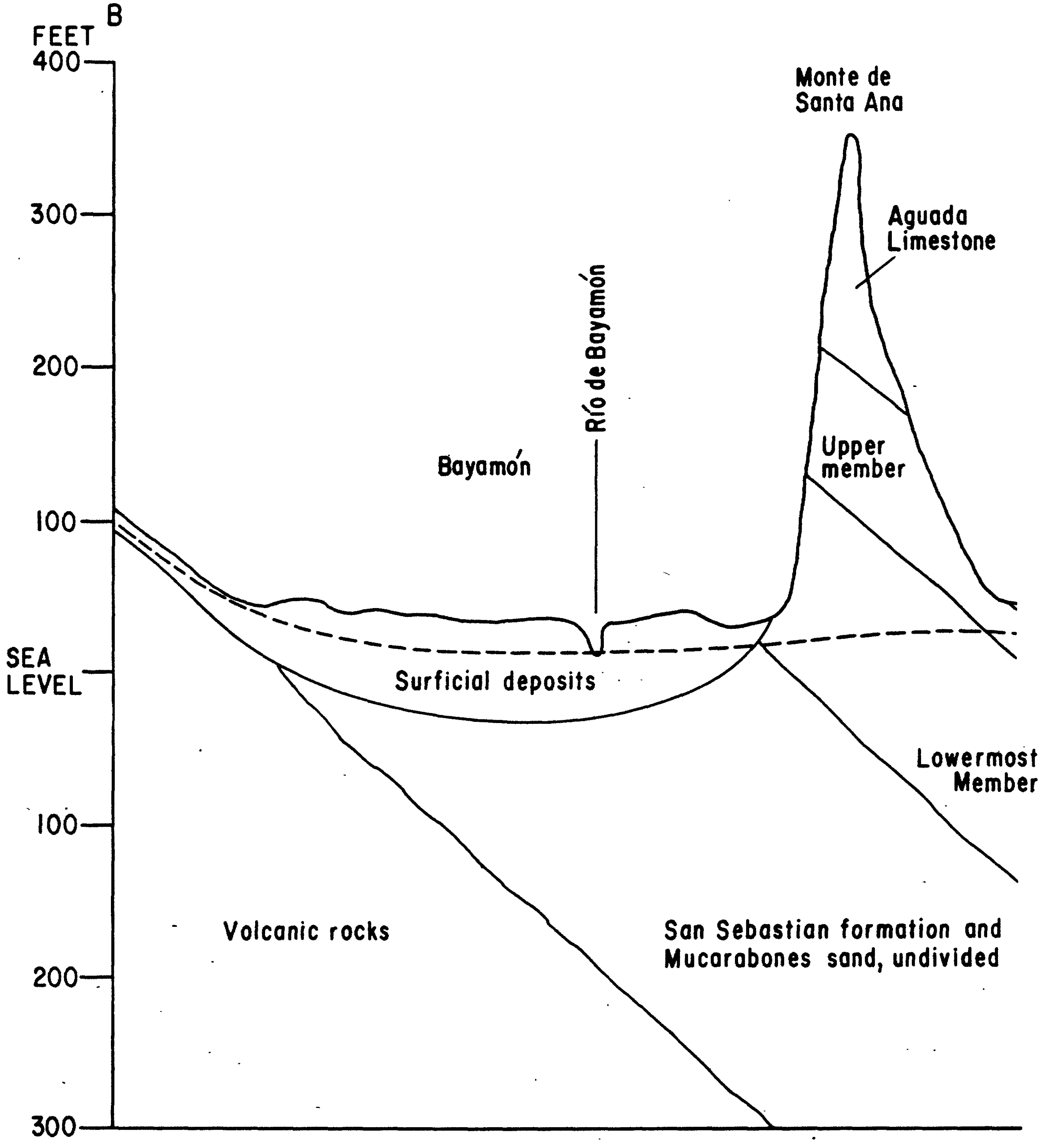
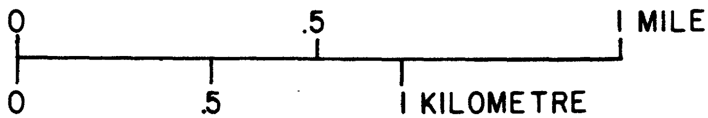


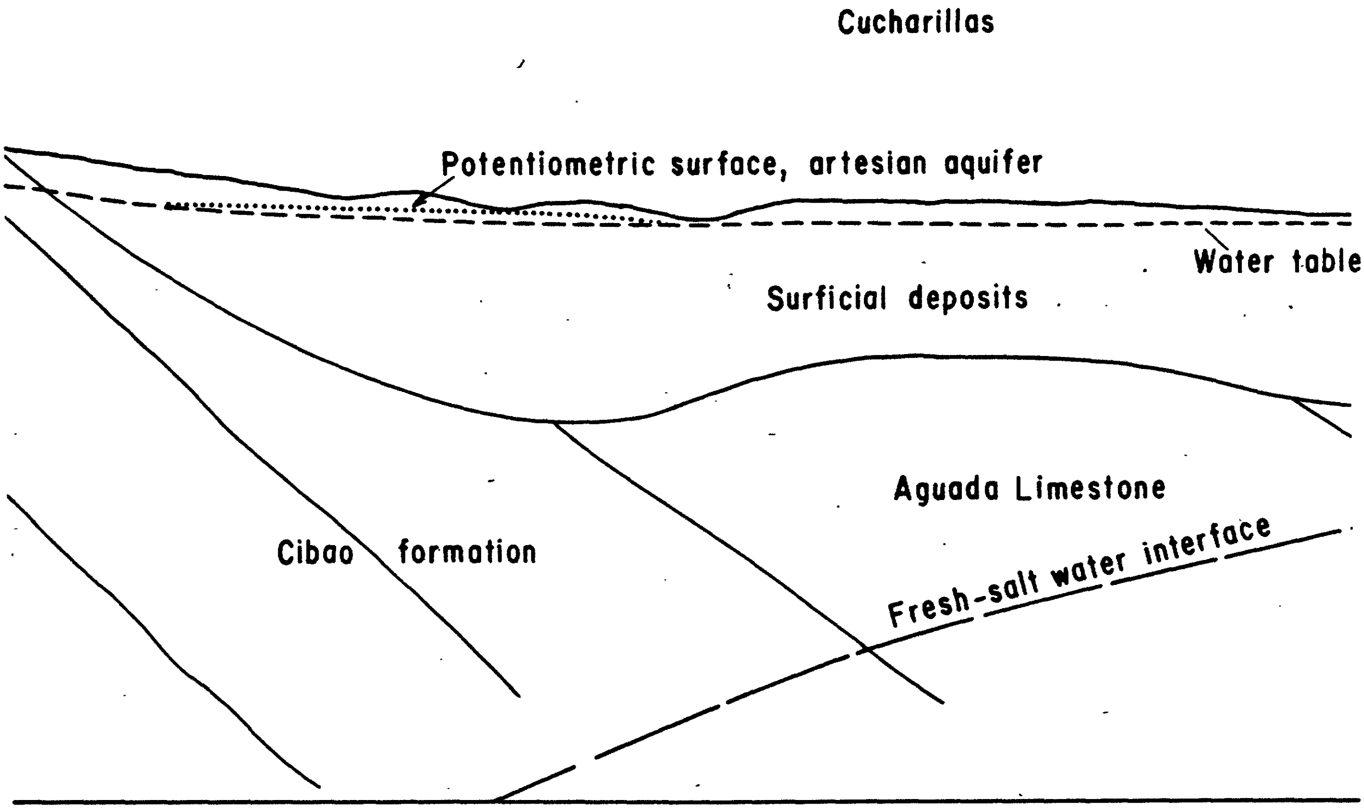
FIGURE 3b -- CROSS-SECTIONS

SEE LOCATION ON FIG. 3a

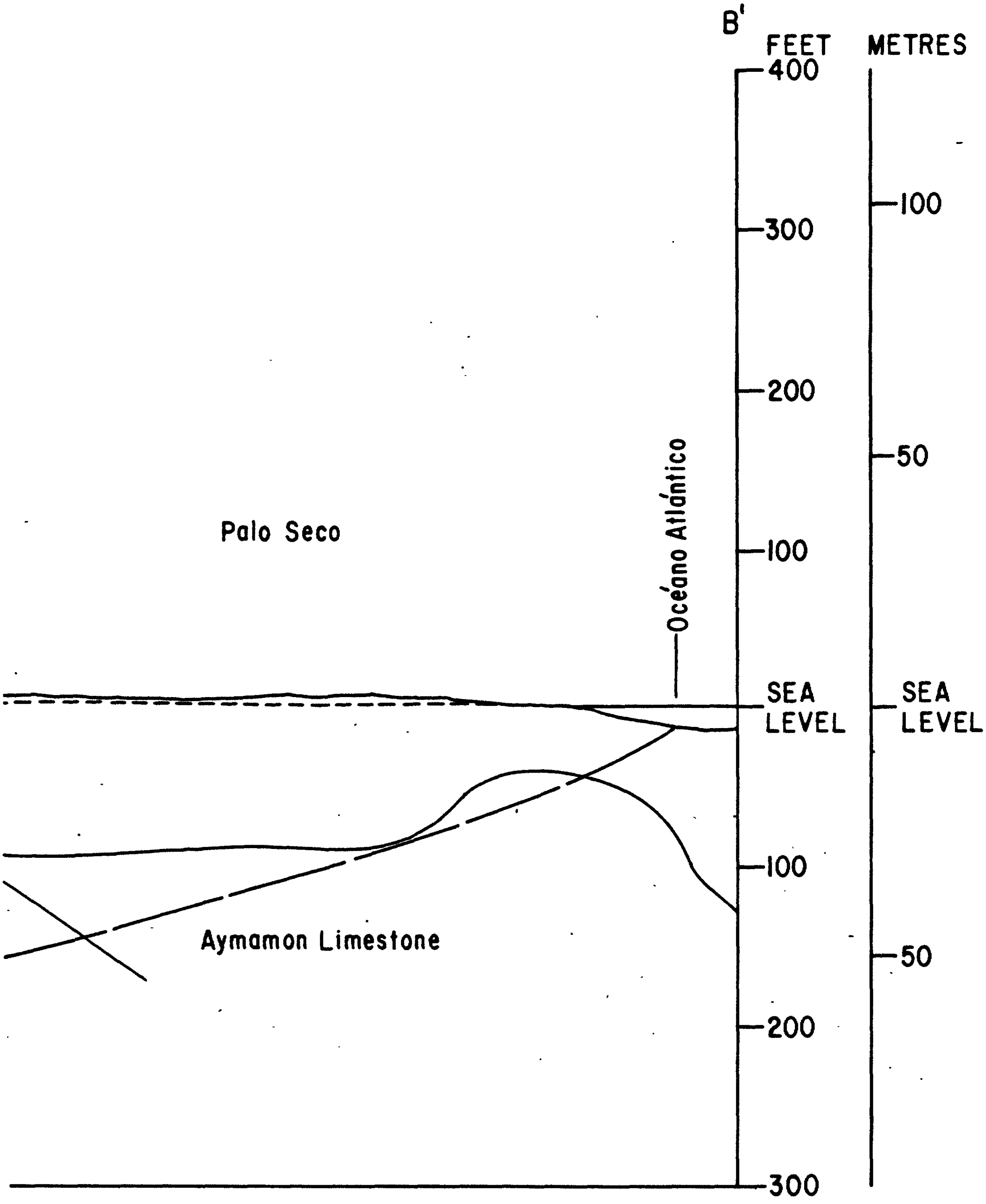


HORIZONTAL SCALE FOR BOTH SECTIONS

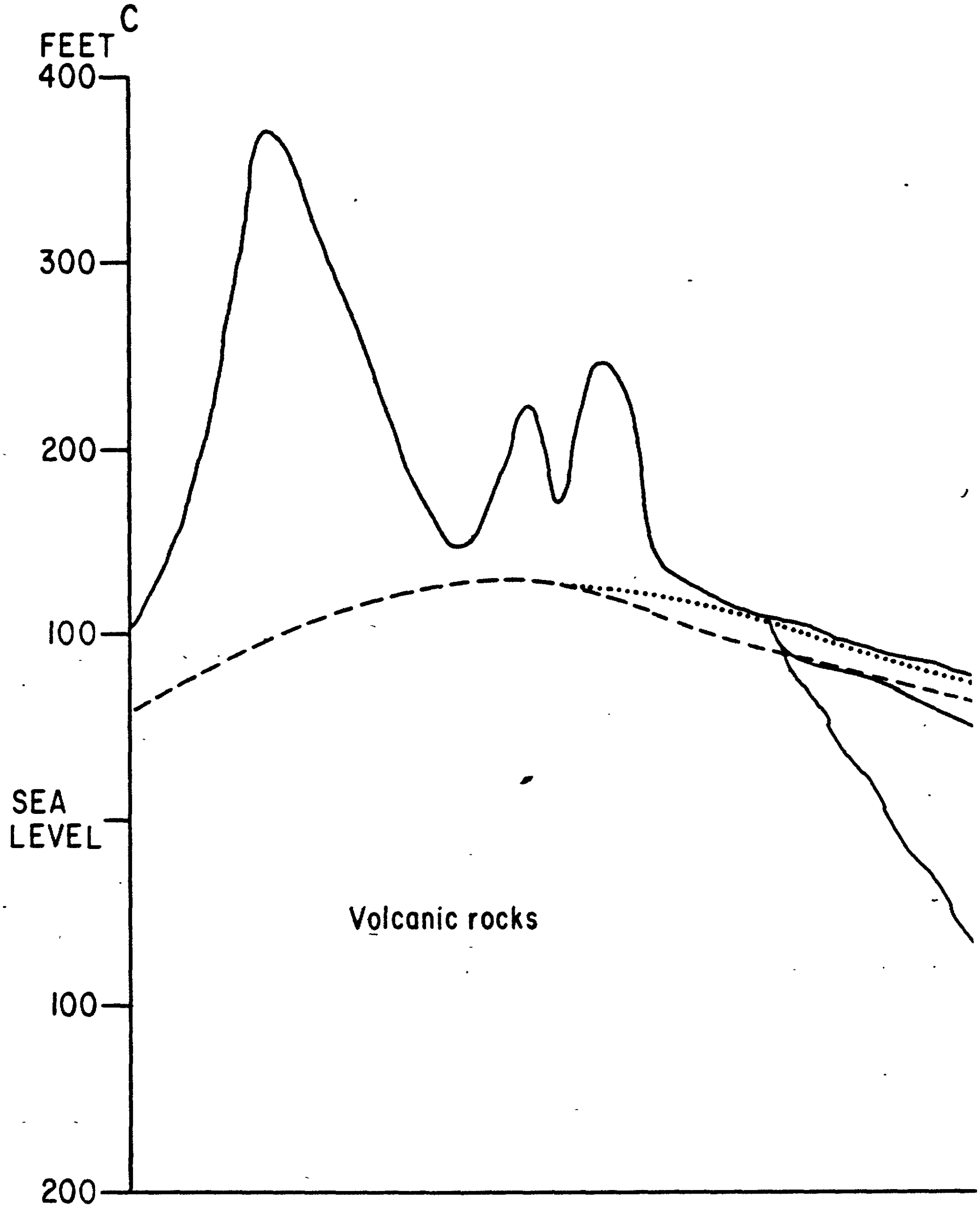
See fig 3a for definitions of the geologic formations



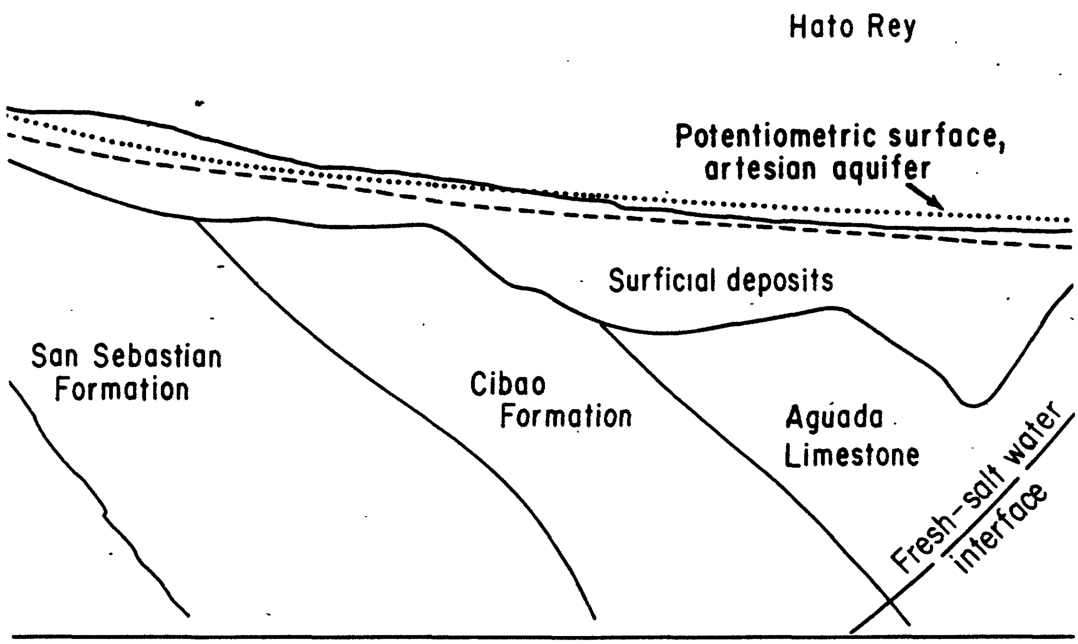
3b-6


B'
FEET
METRES
400
300
100
200
50
100
Oceáno Atlántico
Palo Seco
SEA LEVEL
SEA LEVEL
100
Aymamon Limestone
50
200
300

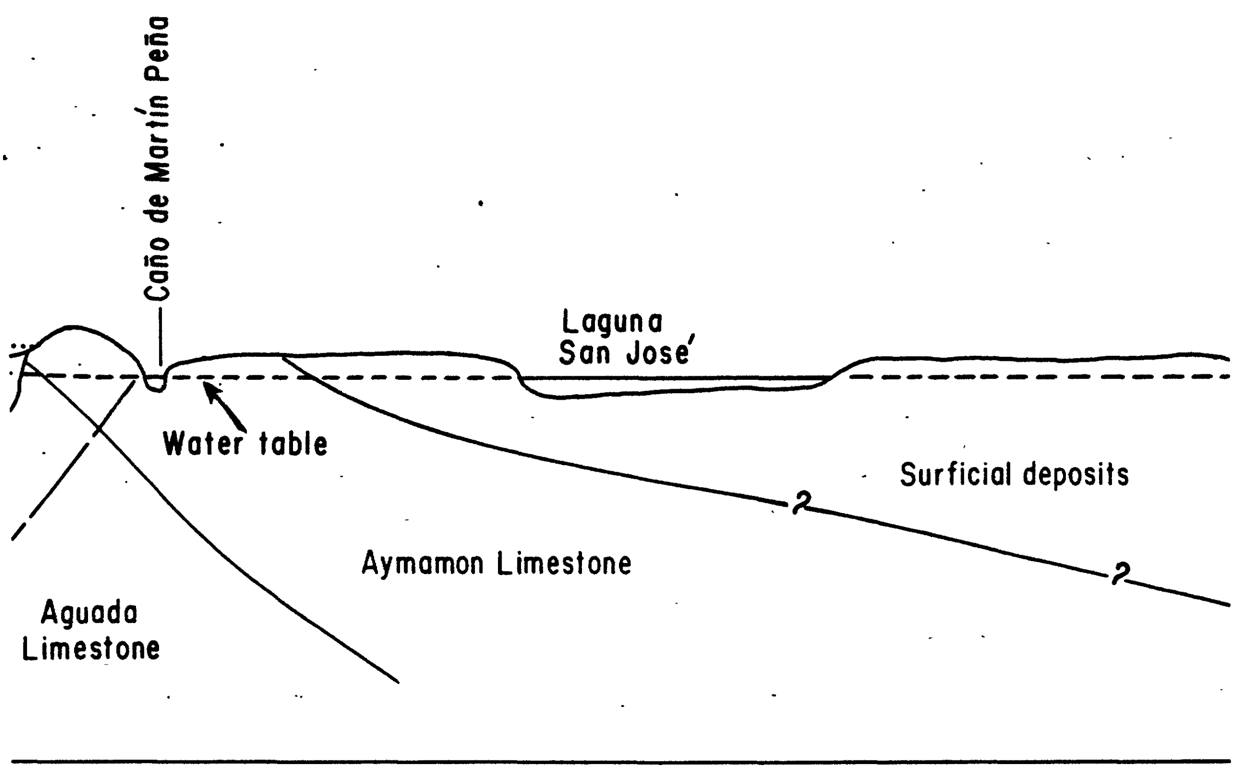
3b -7

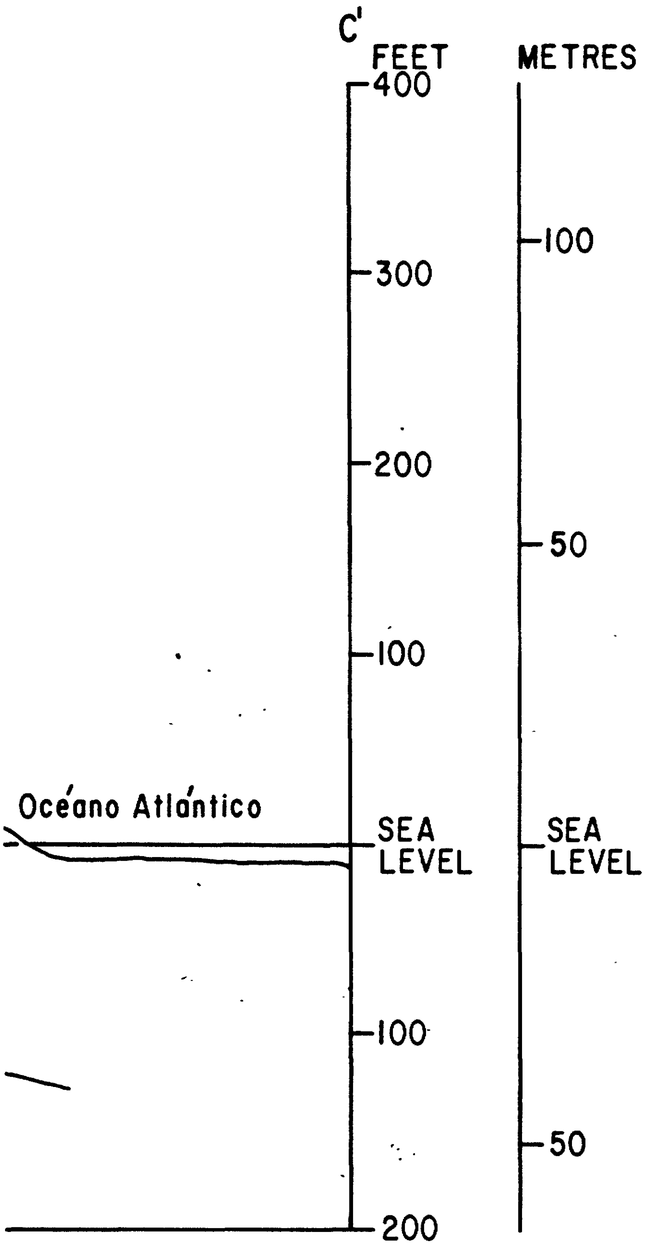


3c - 1


Hato Rey
Potentiometric surface, artesian aquifer
Surficial deposits
San Sebastian Formation
Cibao Formation
Aguada Limestone
Fresh-salt water interface

3c-2


Caño de Martín Peña
Laguna
San José
Water table
Surficial deposits
Aymamon Limestone
Aguada
Limestone
?
?


C'
FEET
METRES
400
300
100
200
50
100
Océano Atlántico
SEA LEVEL
SEA LEVEL
100
50
200

3c - 4

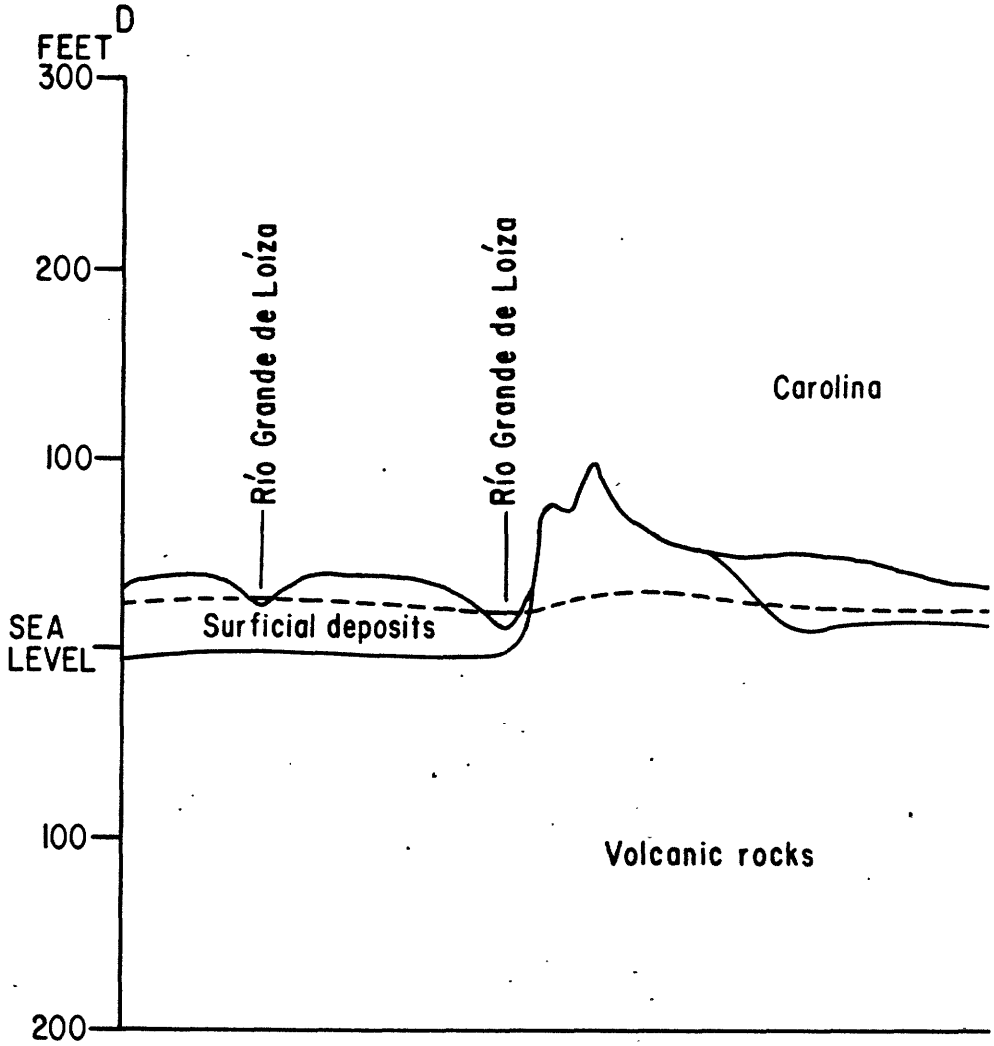
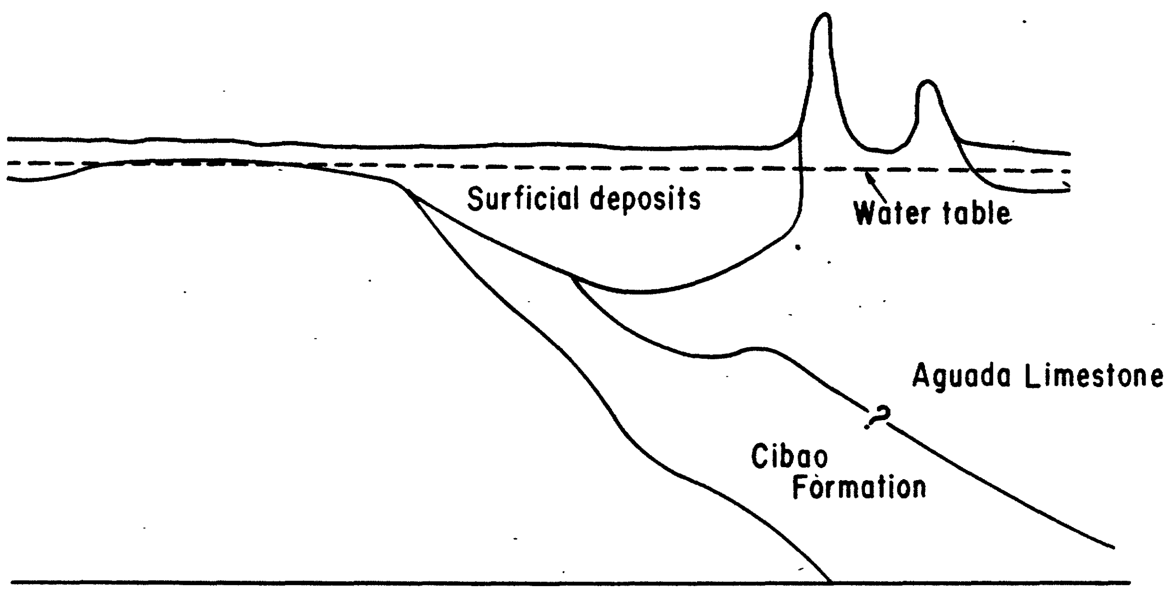
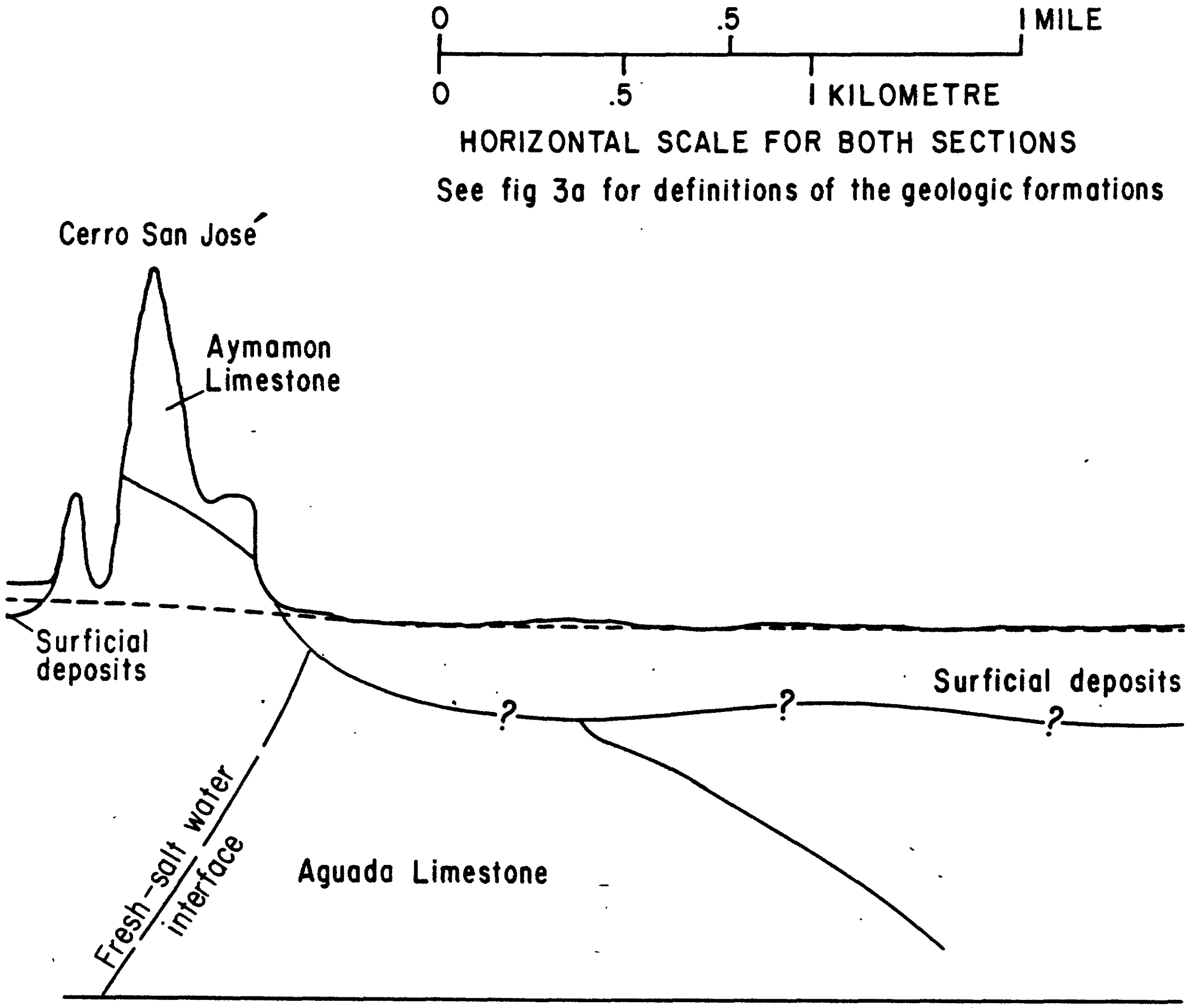


FIGURE 3c -- CROSS-SECTIONS

SEE LOCATION ON FIG. 3a

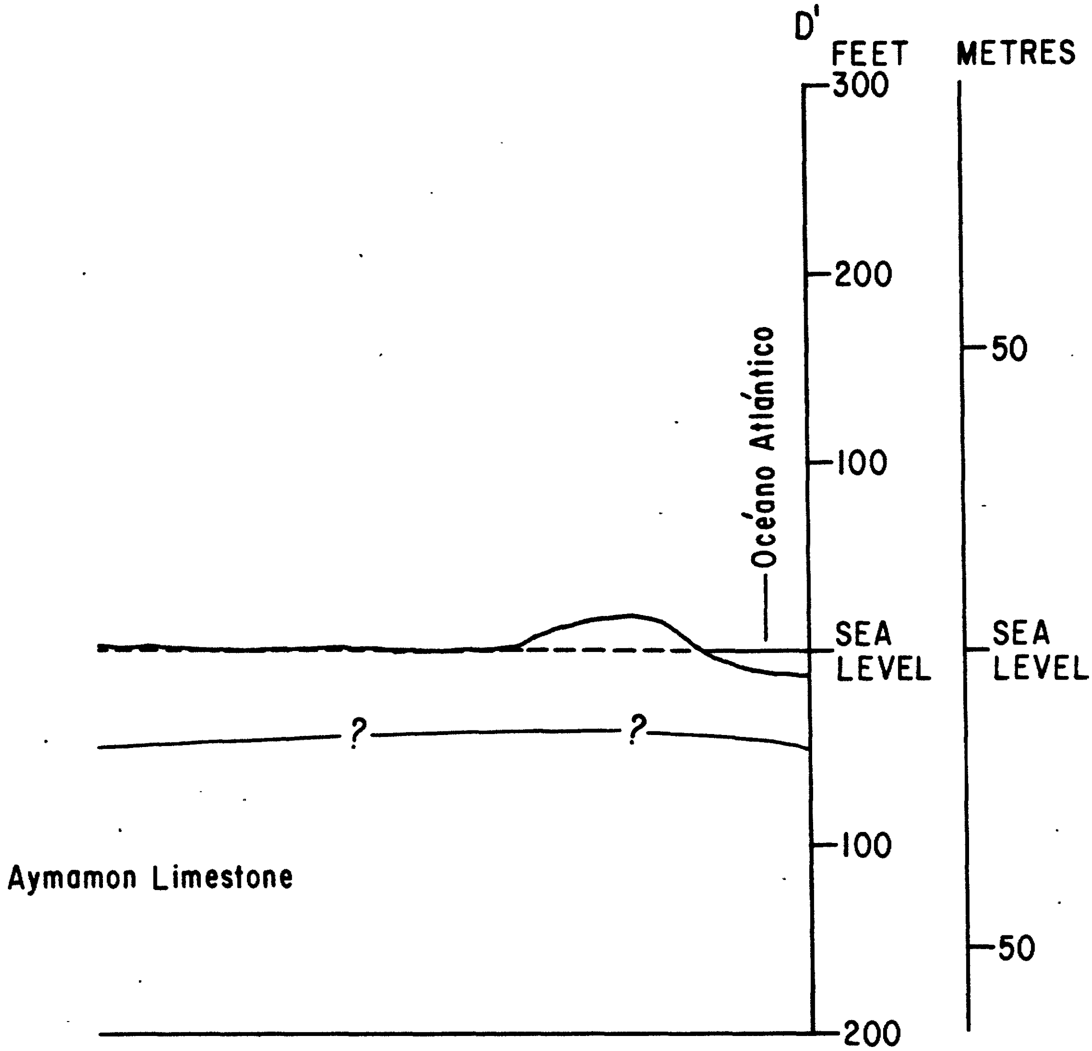

Surficial deposits
Water table
Aguada Limestone
?
Cibao
Formation

3c-6

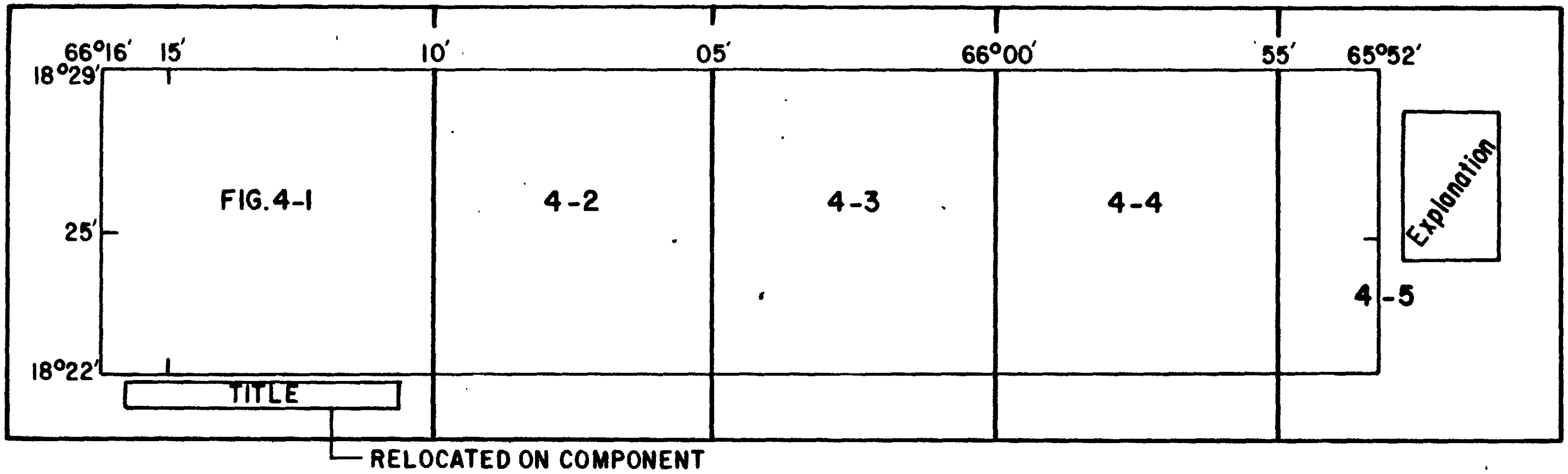

0
.5
1 MILE
0
.5
1 KILOMETRE
HORIZONTAL SCALE FOR BOTH SECTIONS
See fig 3a for definitions of the geologic formations
Cerro San José
Aymamon Limestone
Surficial deposits
Surficial deposits
?
?
?
Fresh-salt water interface
Aguada Limestone

3c -7

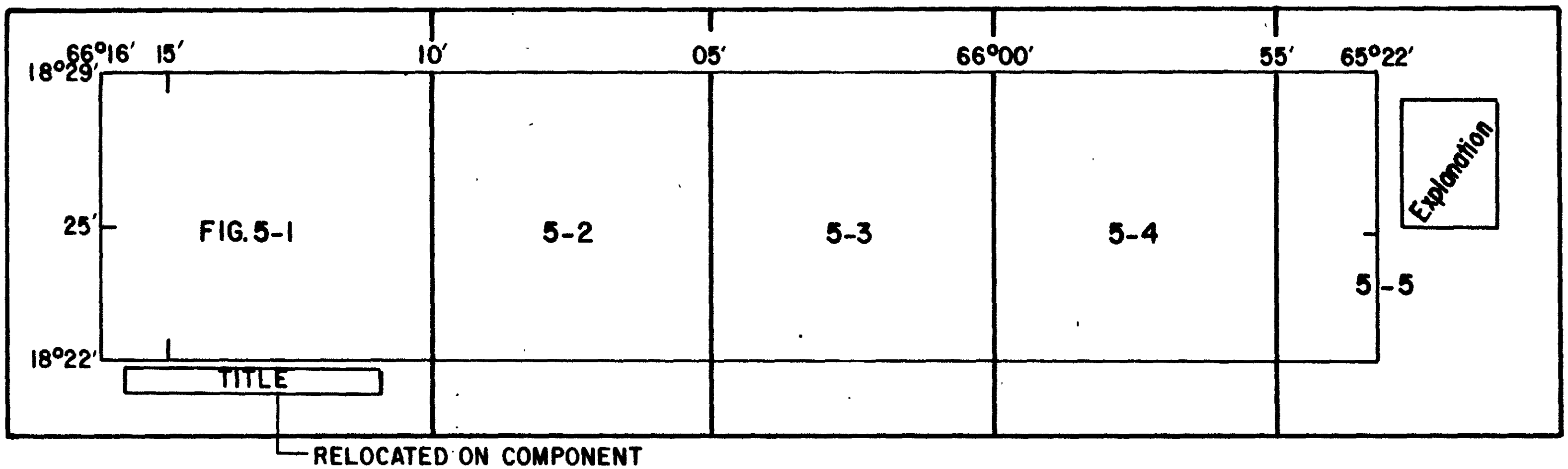
55


D'
FEET
METRES
300
200
100
SEA LEVEL
100
200
50
SEA LEVEL
50
Océano Atlántico
?
?
Aymamon Limestone

3c – 8



4-0
5-0



(FIGURES 4 AND 5 COMPOSE THIS 18" x 24" PLATE)

57

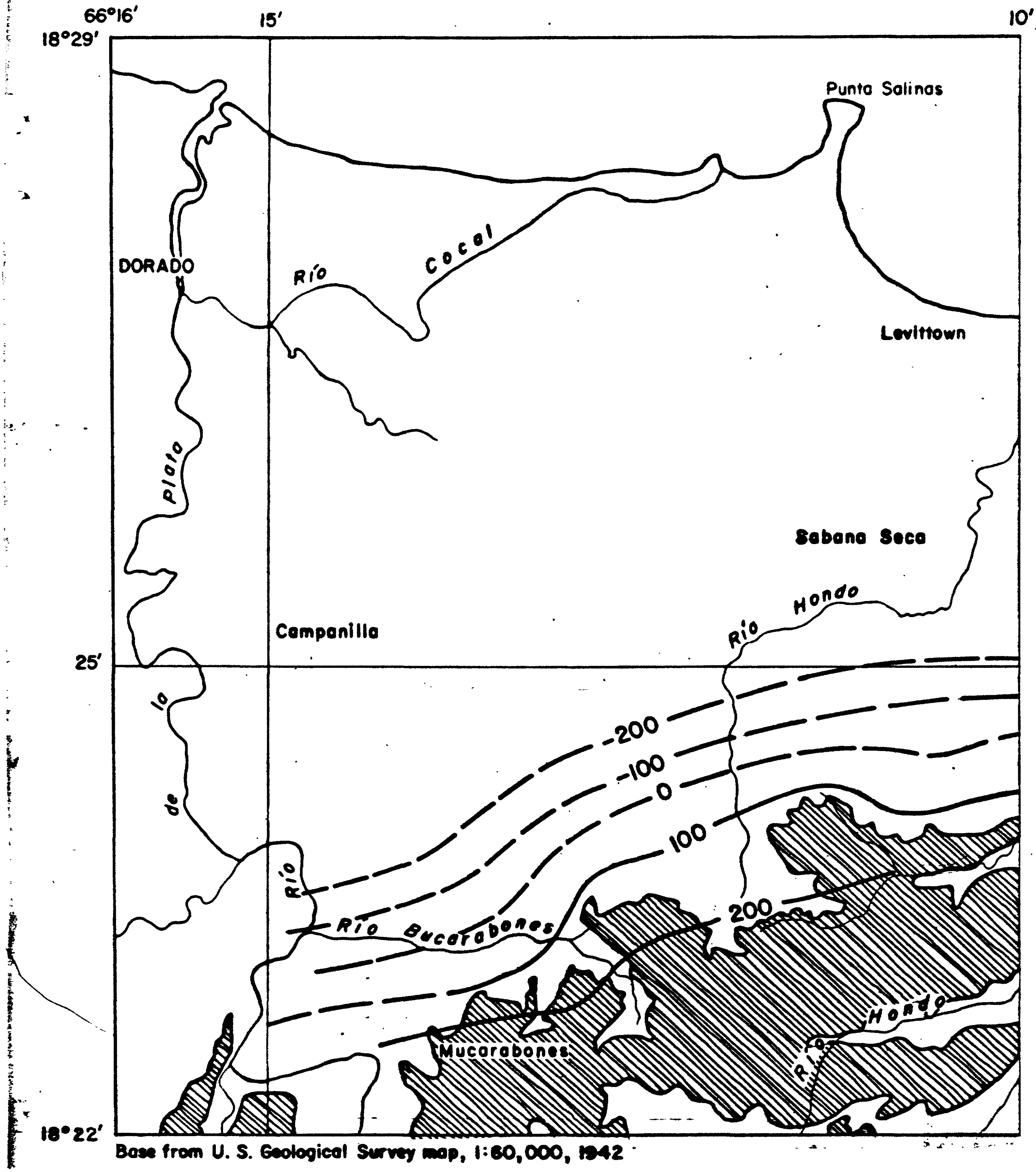
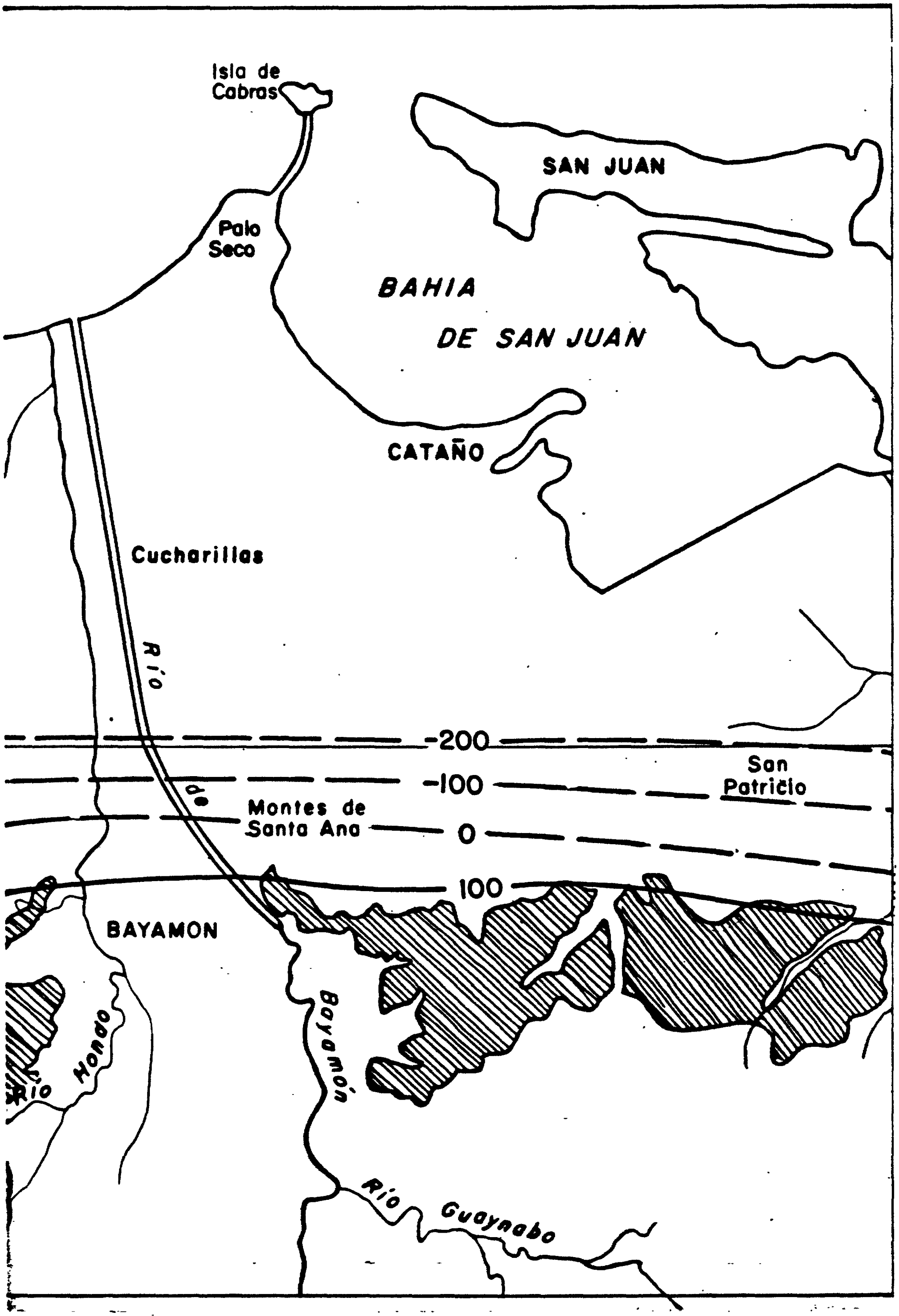
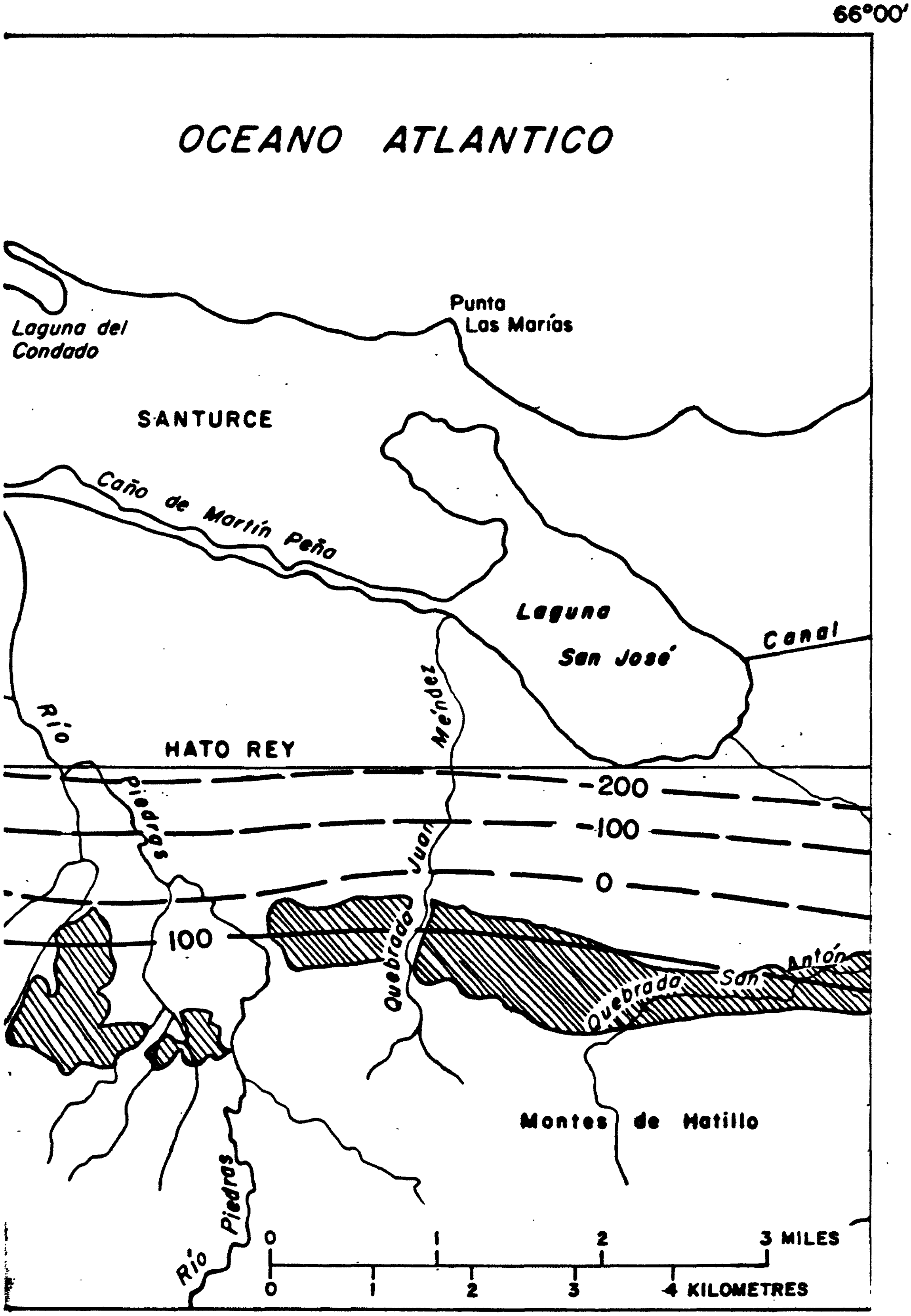


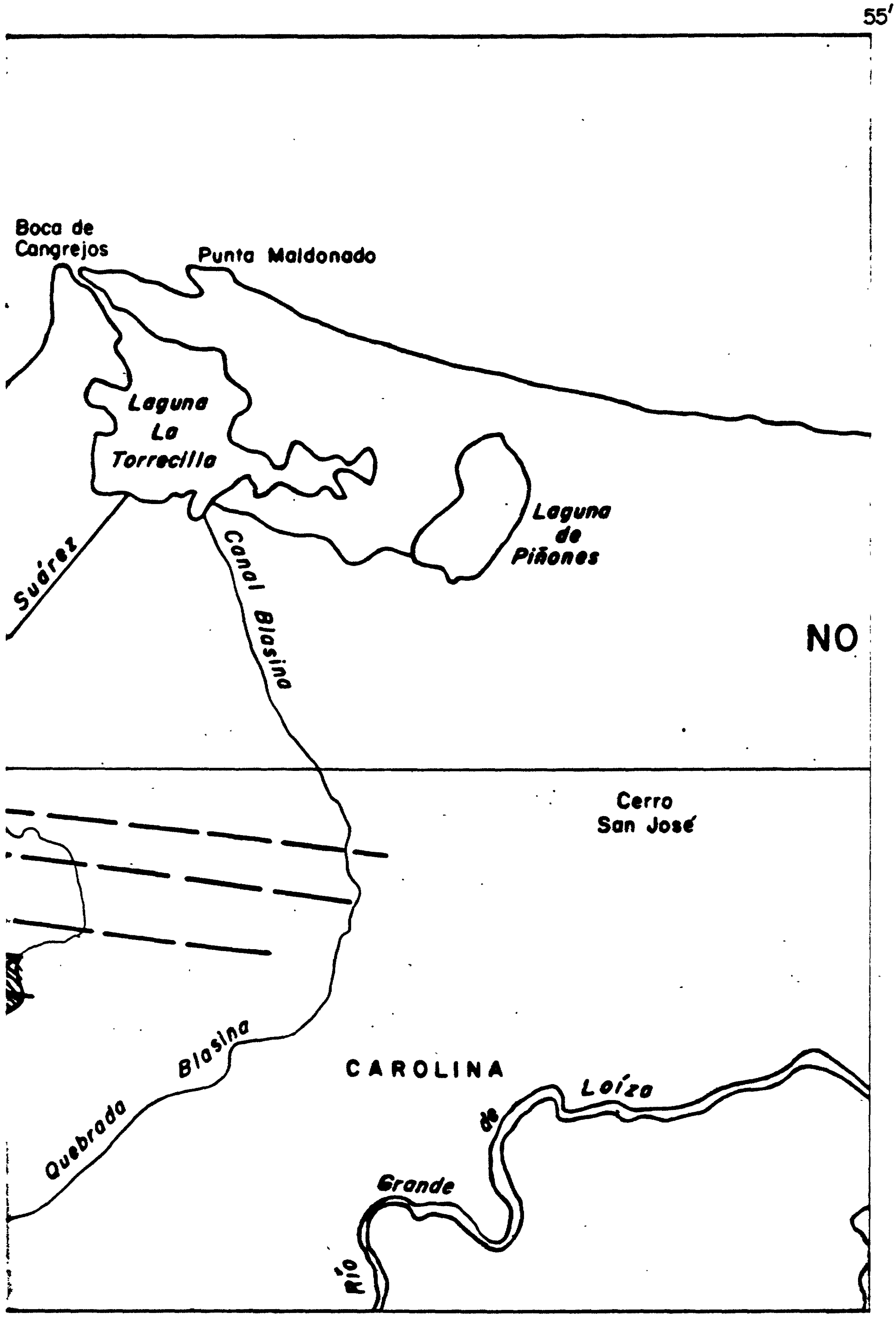
FIGURE 4 -- OUTCROP AREAS AND ALTITUDE OF THE TOP OF THE SAN SEBASTIAN FORMATION.

05′

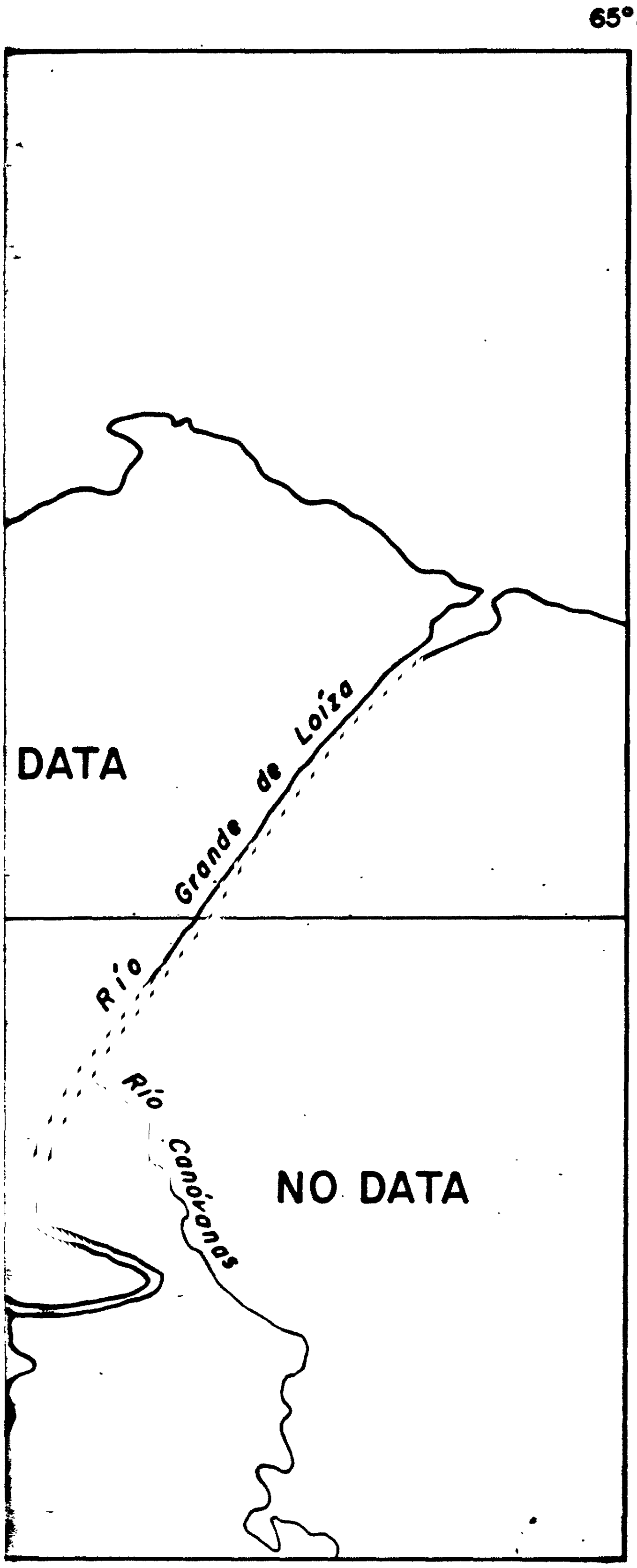

Isla de Cabras
Palo Seco
SAN JUAN
BAHIA DE SAN JUAN
CATAÑO
Cucharillas
Río de Bayamón
-200
-100
0
100
San Patricio
Montes de Santa Ana
BAYAMON
Río Hondo
Bayamón
Río Guaynabo


66°00'
OCEANO ATLANTICO
Laguna del Condado
Punta Las Marías
SANTURCE
Caño de Martín Peña
Laguna San José
Canal
Río Piedras
Méndez
HATO REY
-200
-100
0
100
Juan
Quebrada
Quebrada San Antón
Montes de Hatillo
Río Piedras
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

60


55′
Boca de
Cangrejos
Punta Maldonado
Laguna
La
Torrecilla
Laguna
de
Piñones
Suárez
Canal Blasina
NO
Cerro
San José
CAROLINA
Quebrada Blasina
Río Grande de Loíza

61



EXPLANATION

Area of outcrop

—— 100 —— ——

STRUCTURE CONTOUR

Shows altitude of top of San Sebastian Formation. Dashed where approximately located. Contour interval 100 feet (30 metres). Datum is mean sea level.

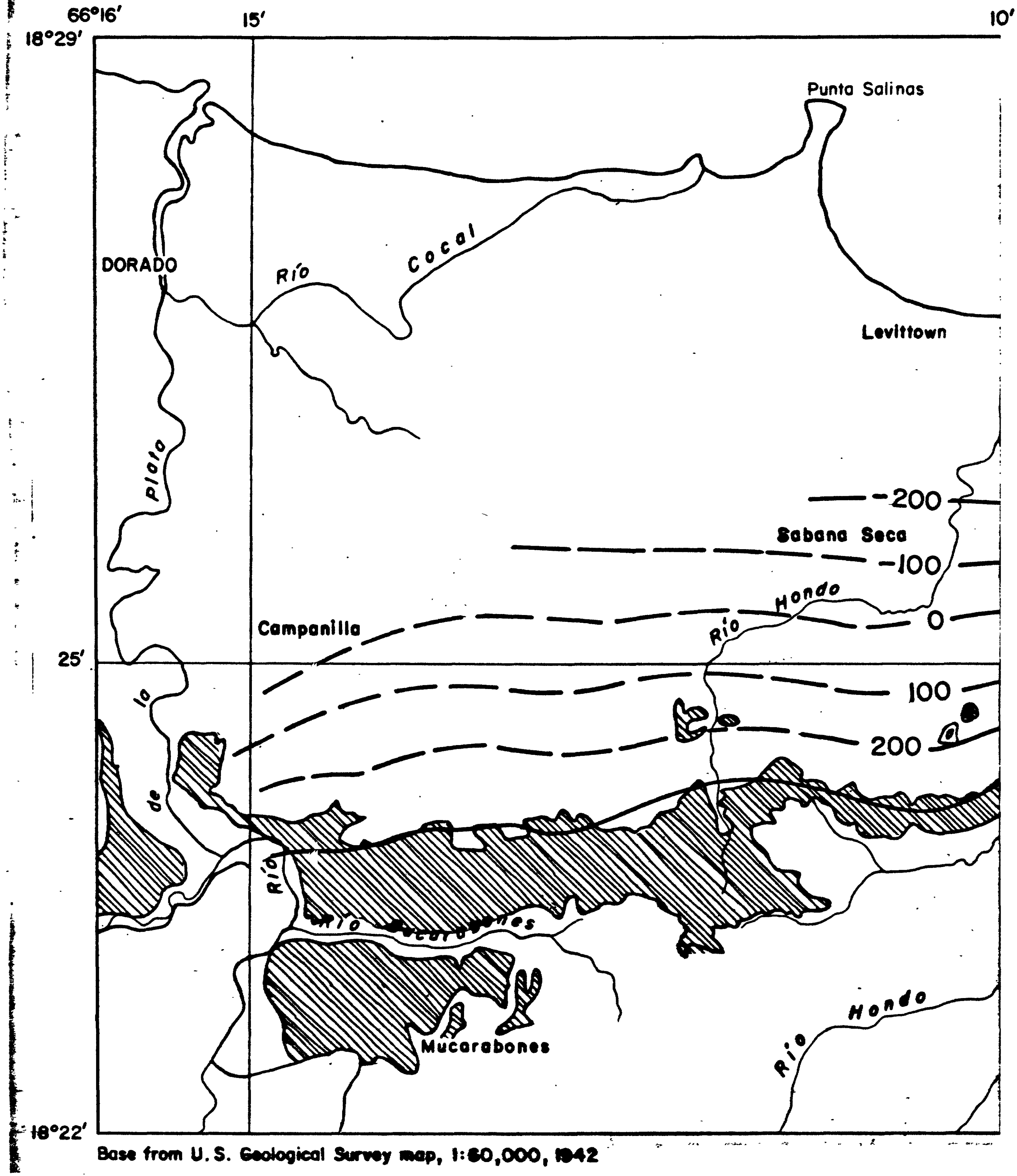
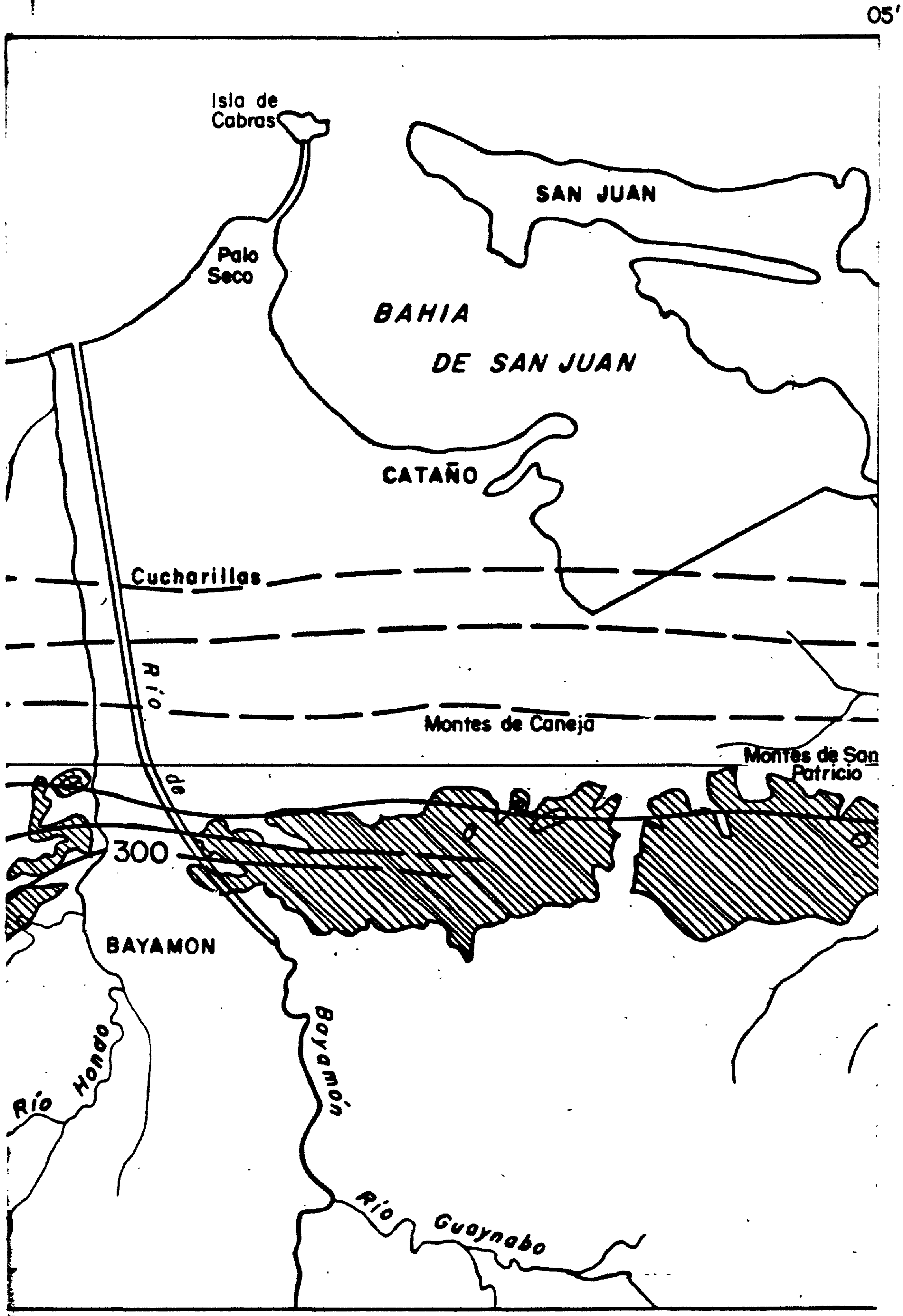


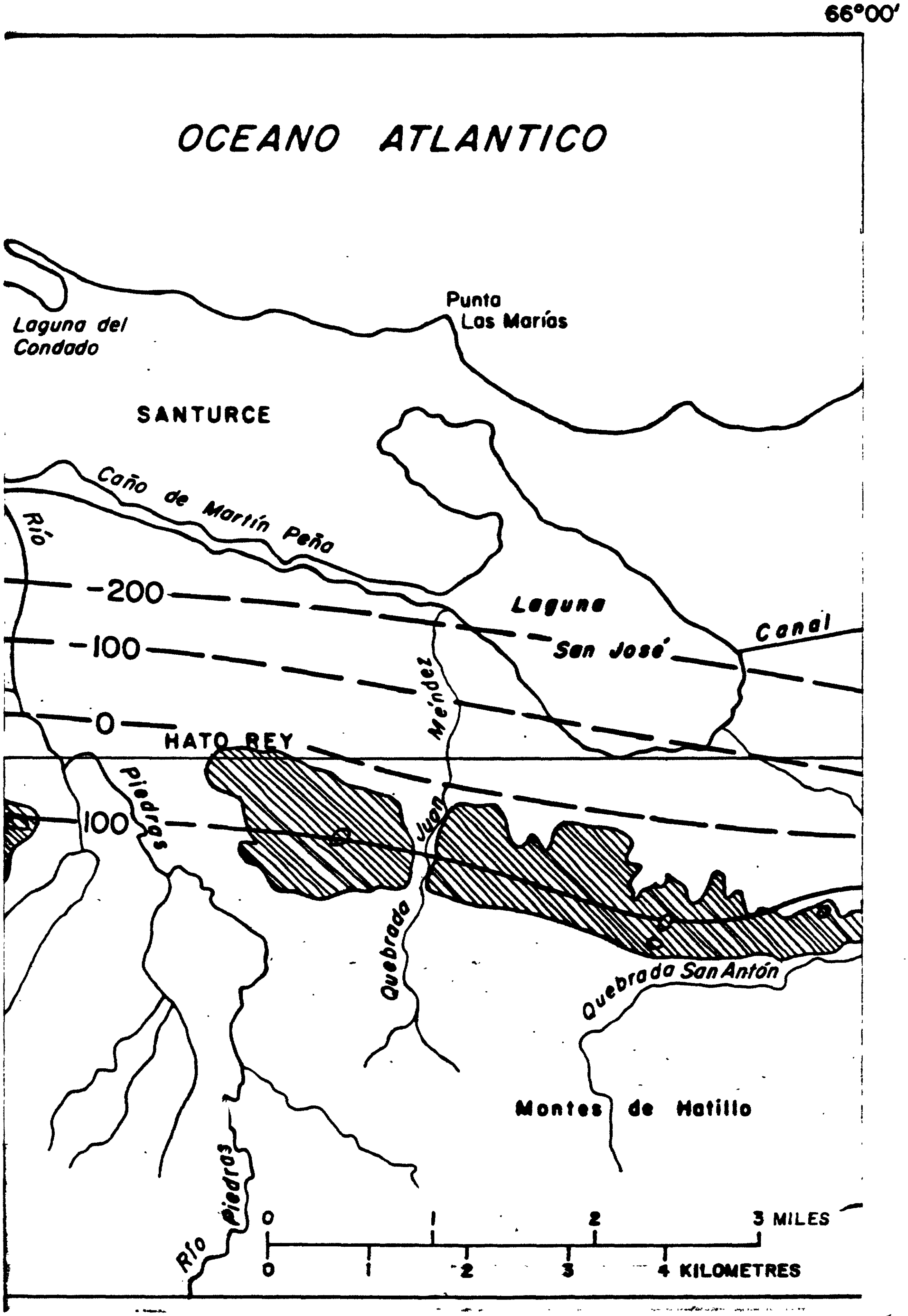
FIGURE 5 -- OUTCROP AREAS AND ALTITUDE OF THE TOP OF THE CIBAO FORMATION.

5-1

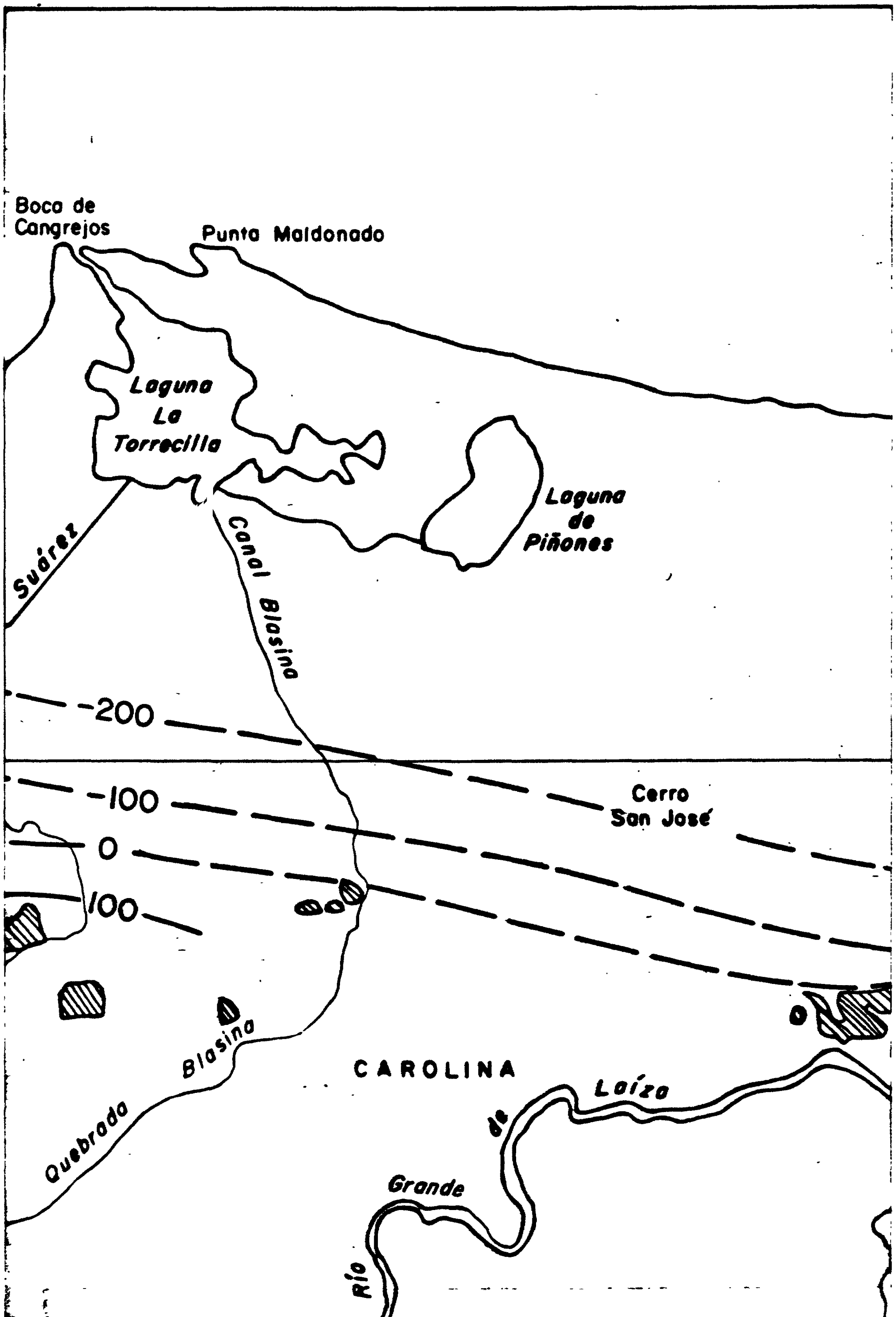
63


05'
Isla de Cabras
SAN JUAN
Palo Seco
BAHIA DE SAN JUAN
CATAÑO
Cucharillas
Río de Bayamón
Montes de Caneja
Montes de San Patricio
300
BAYAMON
Río Hondo
Río Guaynabo

64


66°00′
OCEANO ATLANTICO
Laguna del Condado
Punta Las Marías
SANTURCE
Caño de Martín Peña
Río
-200
-100
0
100
Laguna San José
Canal
HATO REY
Piedras
Méndez
Juan
Quebrada
Quebrada San Antón
Montes de Hatillo
Río Piedras
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

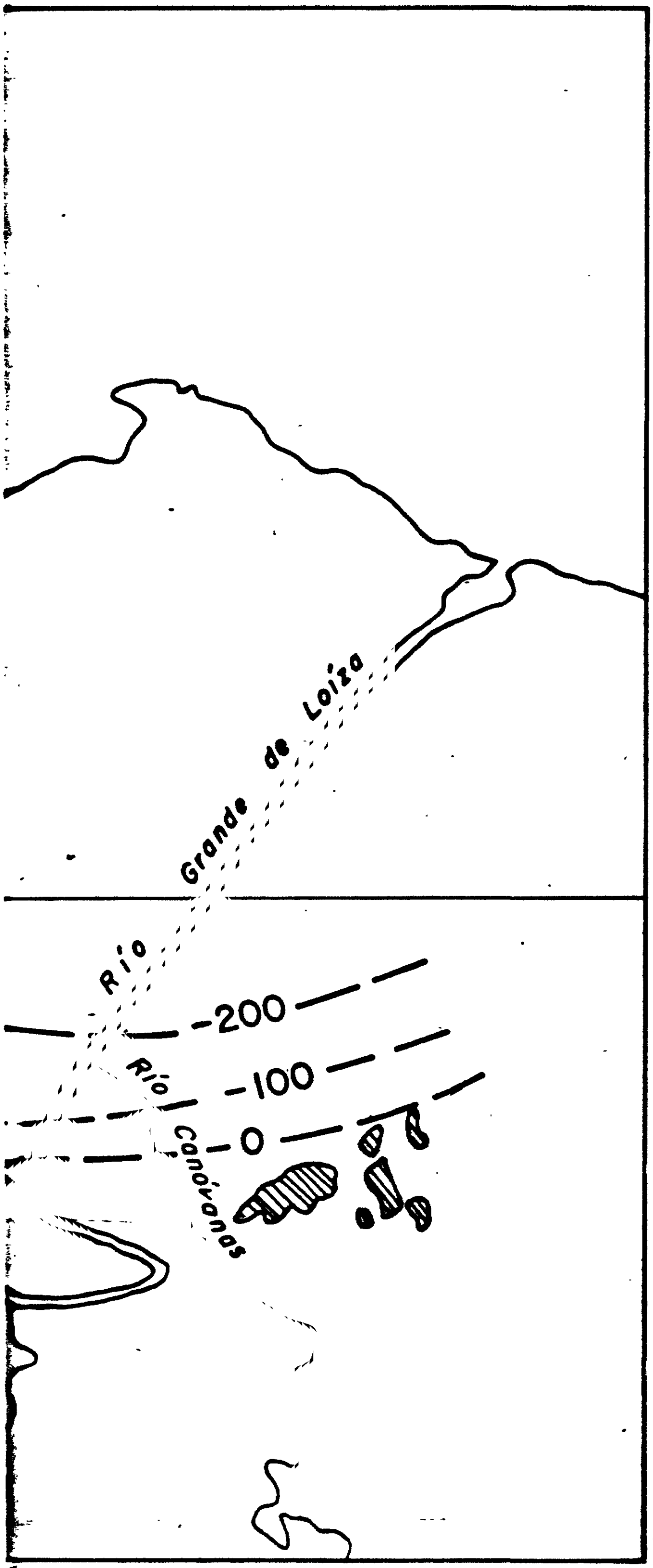
55′



Boca de
Cangrejos
Punta Maldonado
Laguna
La
Torrecilla
Laguna
de
Piñones
Suárez
Canal Blasina
-200
-100
0
100
Cerro
San José
CAROLINA
Quebrada Blasina
Río Grande de Loíza

66

65°52′



EXPLANATION

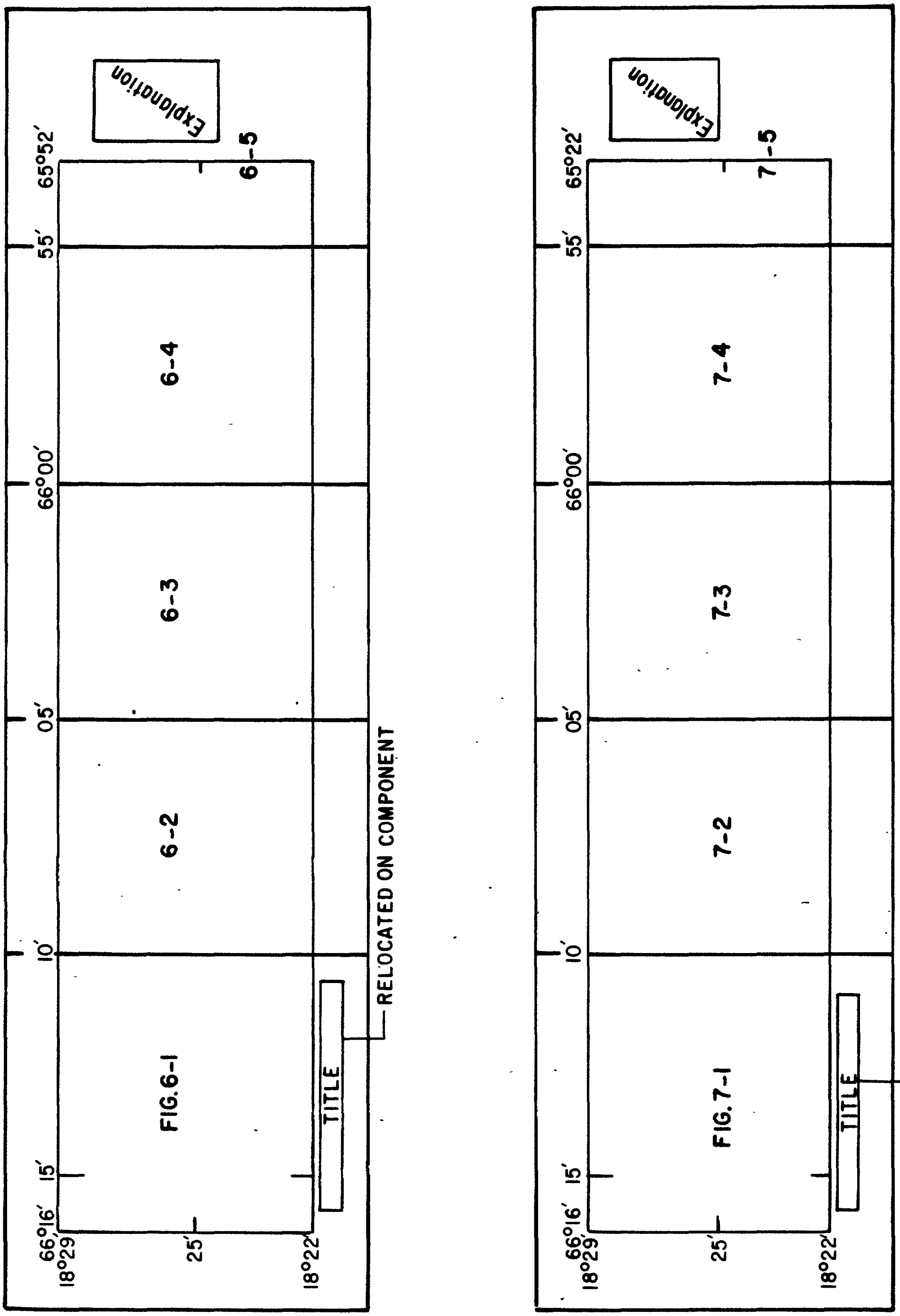
Area of outcrop

——100——

STRUCTURE CONTOUR–

Shows altitude of top of Cibao Formation. Dashed where approximately located. Contour 100 feet (30 metres). Datum is mean sea level

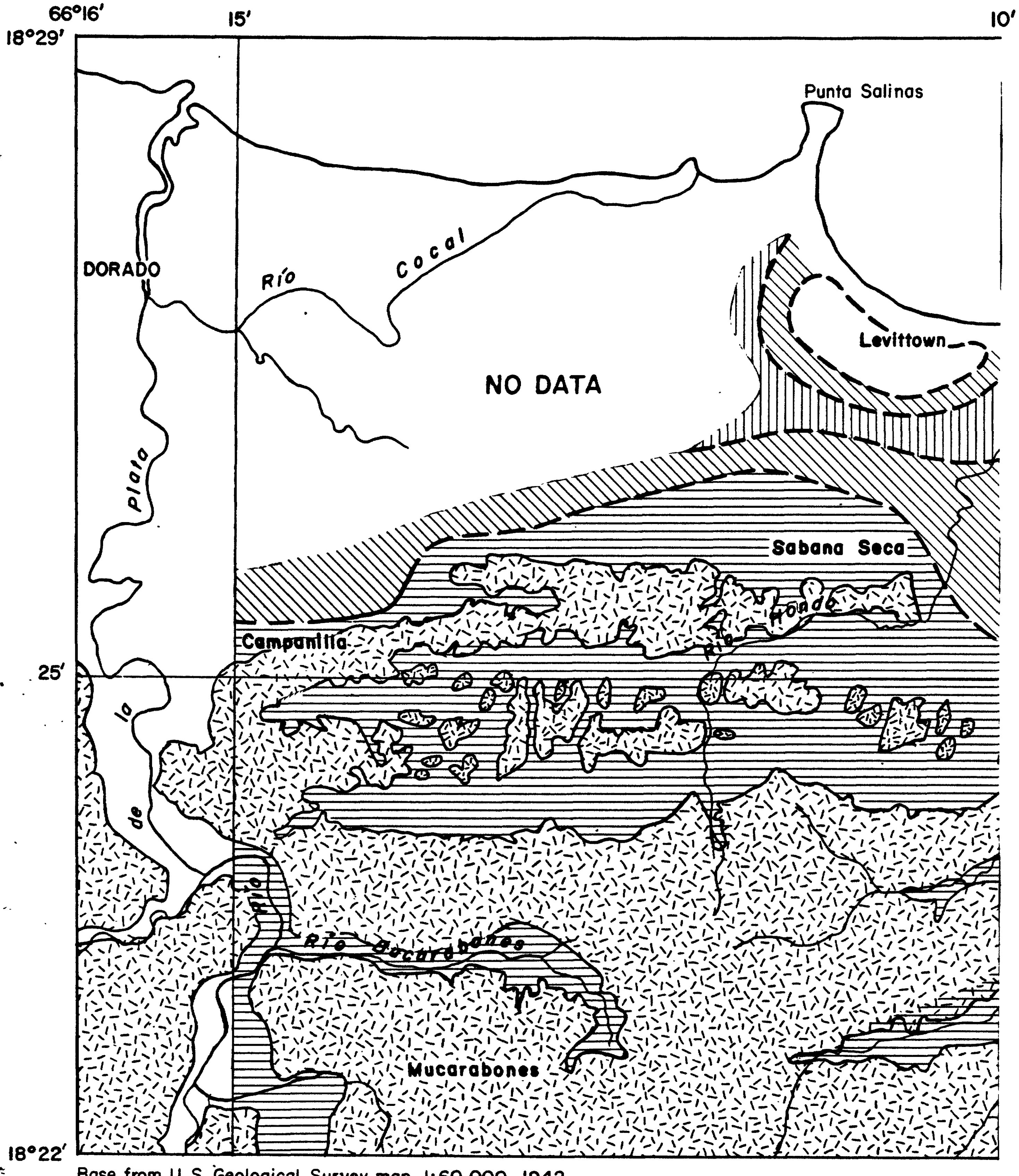
67



(FIGURES 6 AND 7 COMPOSE THIS 18"x 24" PLATE)

68

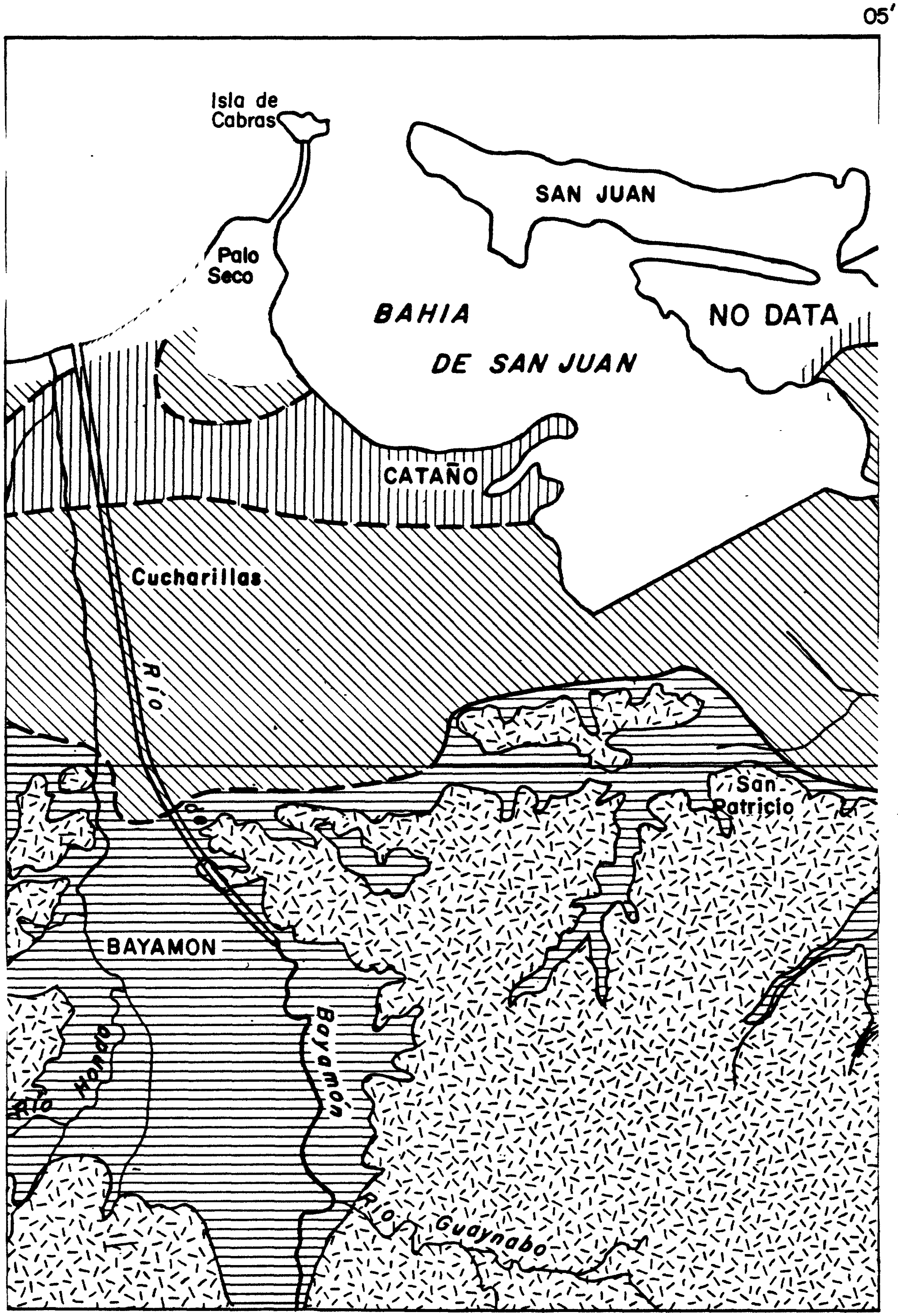
6-0
7-0



Base from U. S. Geological Survey map, 1:60,000, 1942

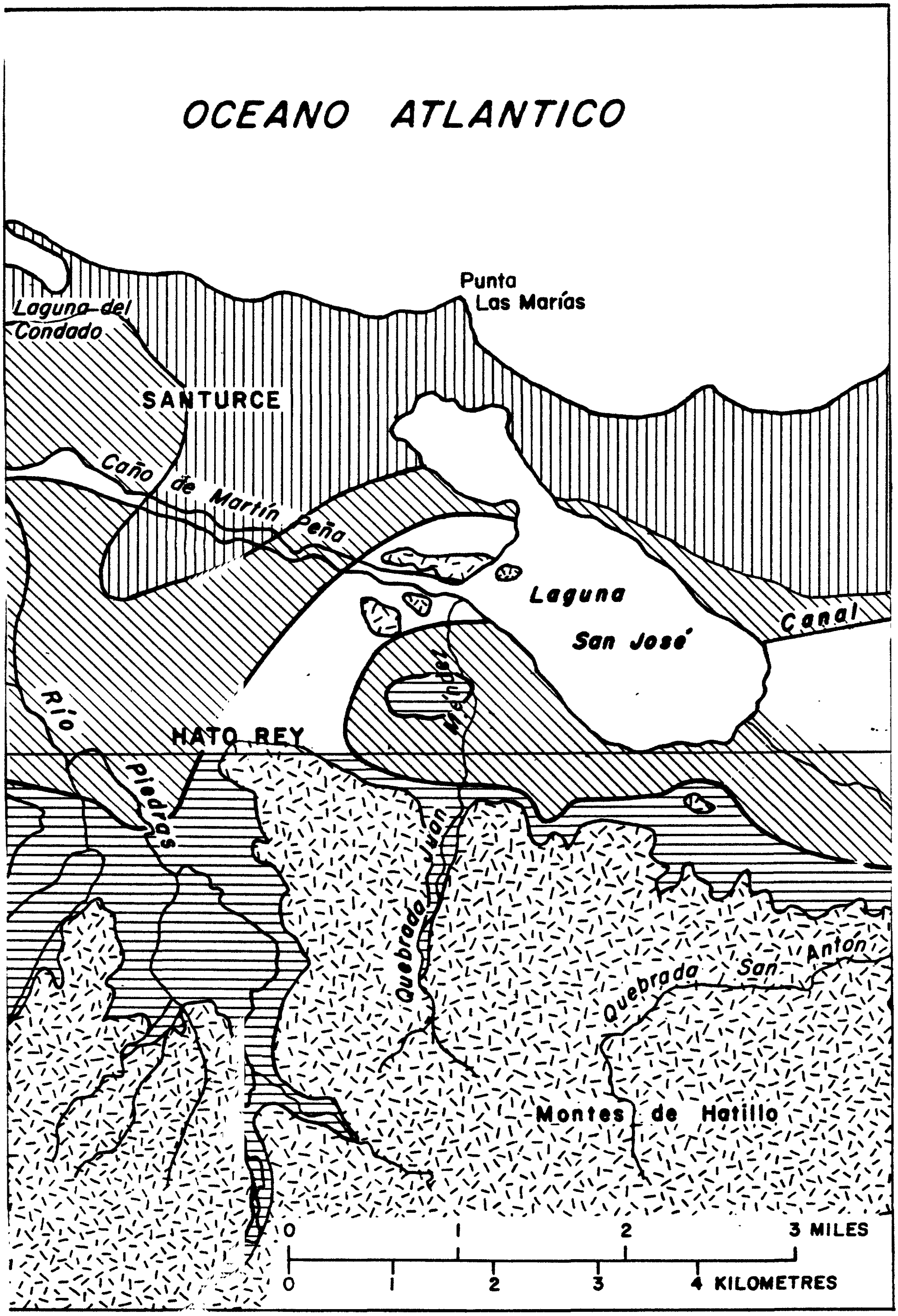
FIGURE 6 -- THICKNESS OF SURFICIAL DEPOSITS IN THE SAN JUAN AREA.

6-1 69


05'
Isla de Cabras
SAN JUAN
Palo Seco
BAHIA DE SAN JUAN
NO DATA
CATAÑO
Cucharillas
Rio de Bayamon
San Patricio
BAYAMON
Rio Hondo
Rio Bayamon
Rio Guaynabo

70

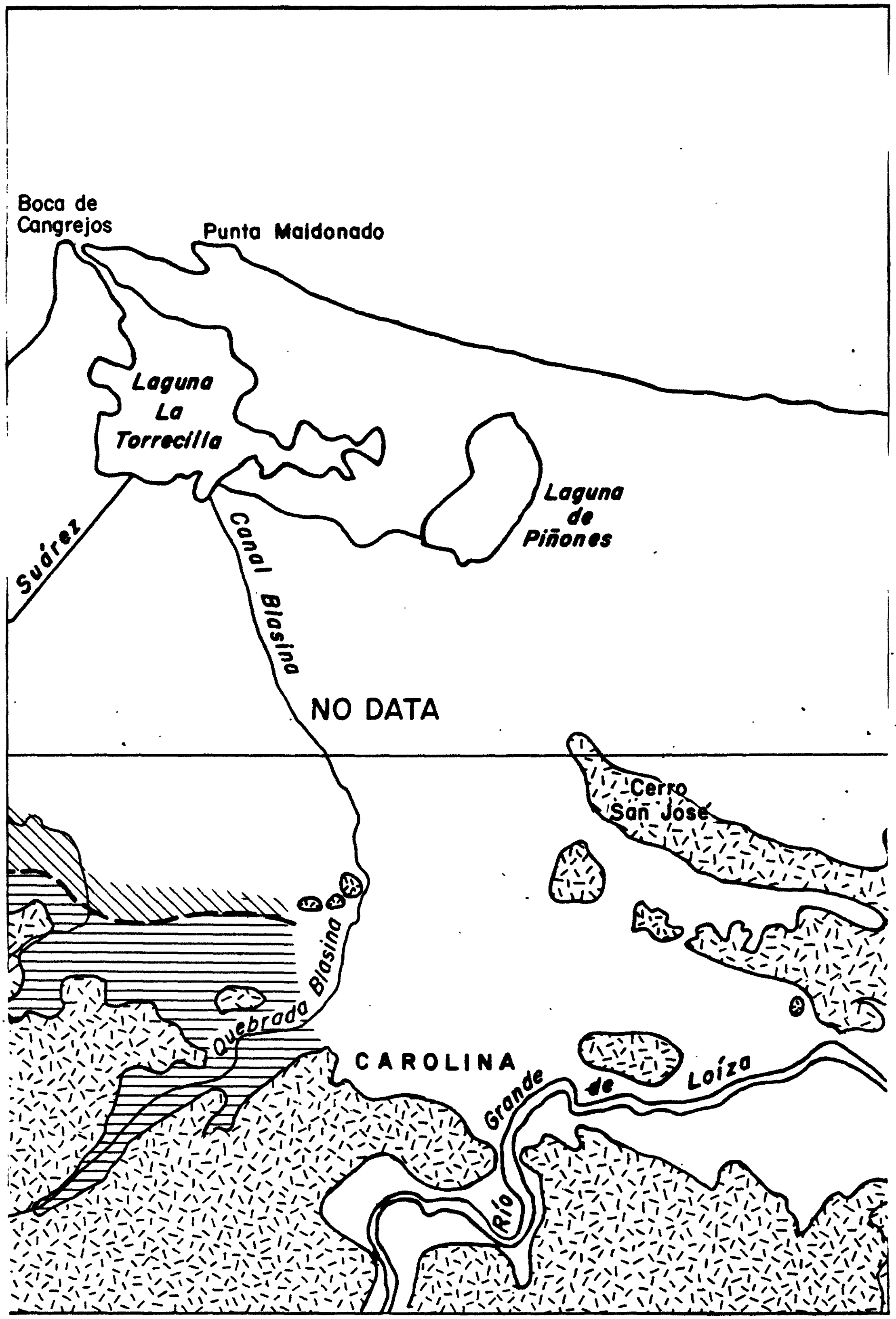
66°00′



OCEANO ATLANTICO
Punta
Las Marías
Laguna del
Condado
SANTURCE
Caño de Martín Peña
Laguna
San José
Canal
Río Piedras
HATO REY
Quebrada Juan Méndez
Quebrada San Antón
Montes de Hatillo
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

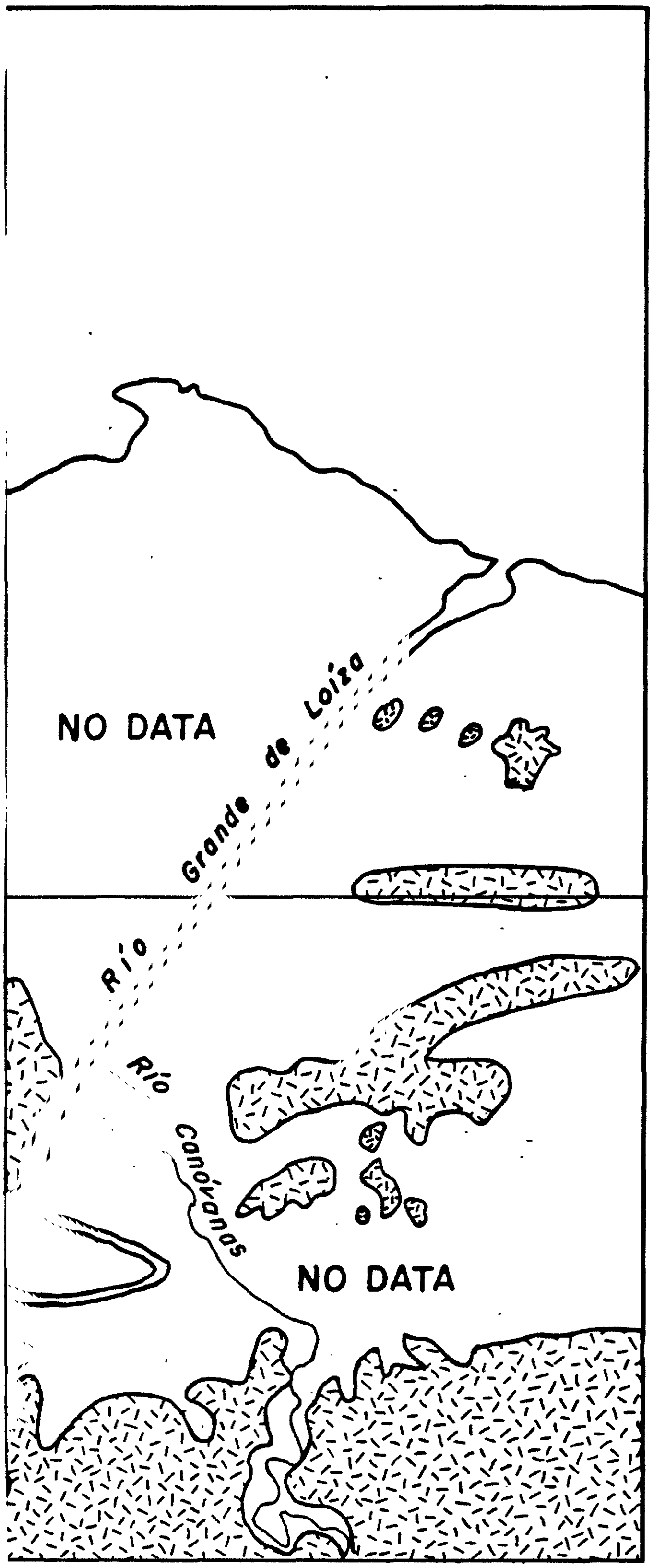
71

55′


Boca de
Cangrejos
Punta Maldonado
Laguna
La
Torrecilla
Laguna
de
Piñones
Suárez
Canal Blasina
NO DATA
Cerro
San José
Quebrada Blasina
CAROLINA
Río Grande de Loíza

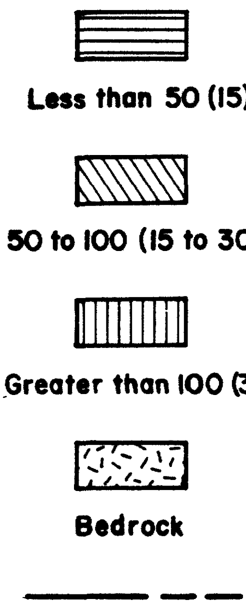
72

65°52′



EXPLANATION

Thickness of surficial deposits, in feet (metres)



Less than 50 (15)

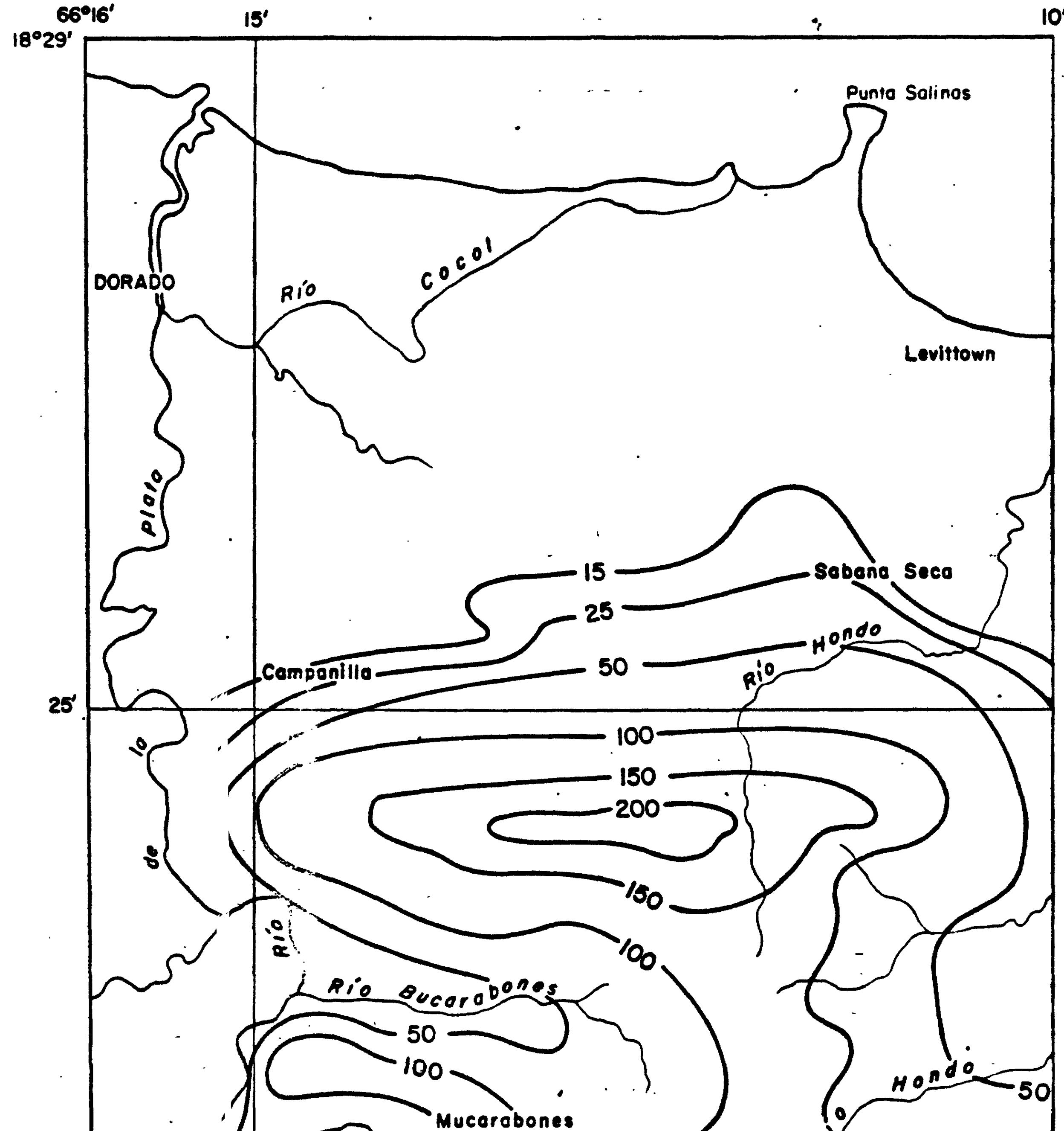
50 to 100 (15 to 30)

Greater than 100 (30)

Bedrock

Contact, dashed where undefined

73

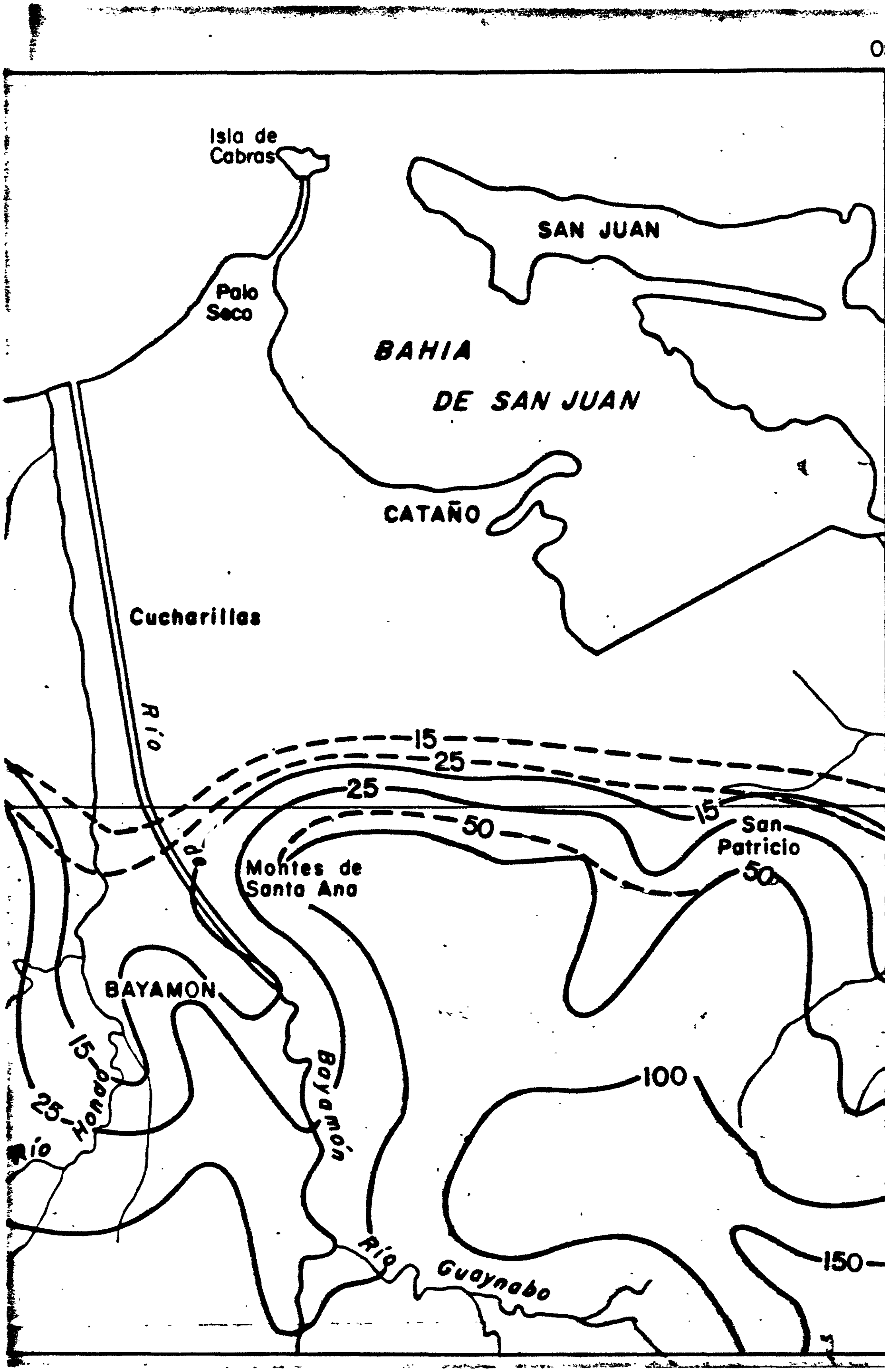


Base from U. S. Geological Survey map, 1:60,000, 1942

FIGURE 7 -- GENERALIZED CONFIGURATION OF THE WATER SURFACE OF THE UNCONFINED AQUIFER AND THE POTENTIOMETRIC SURFACE OF THE CONFINED AQUIFER IN THE SAN JUAN AREA.

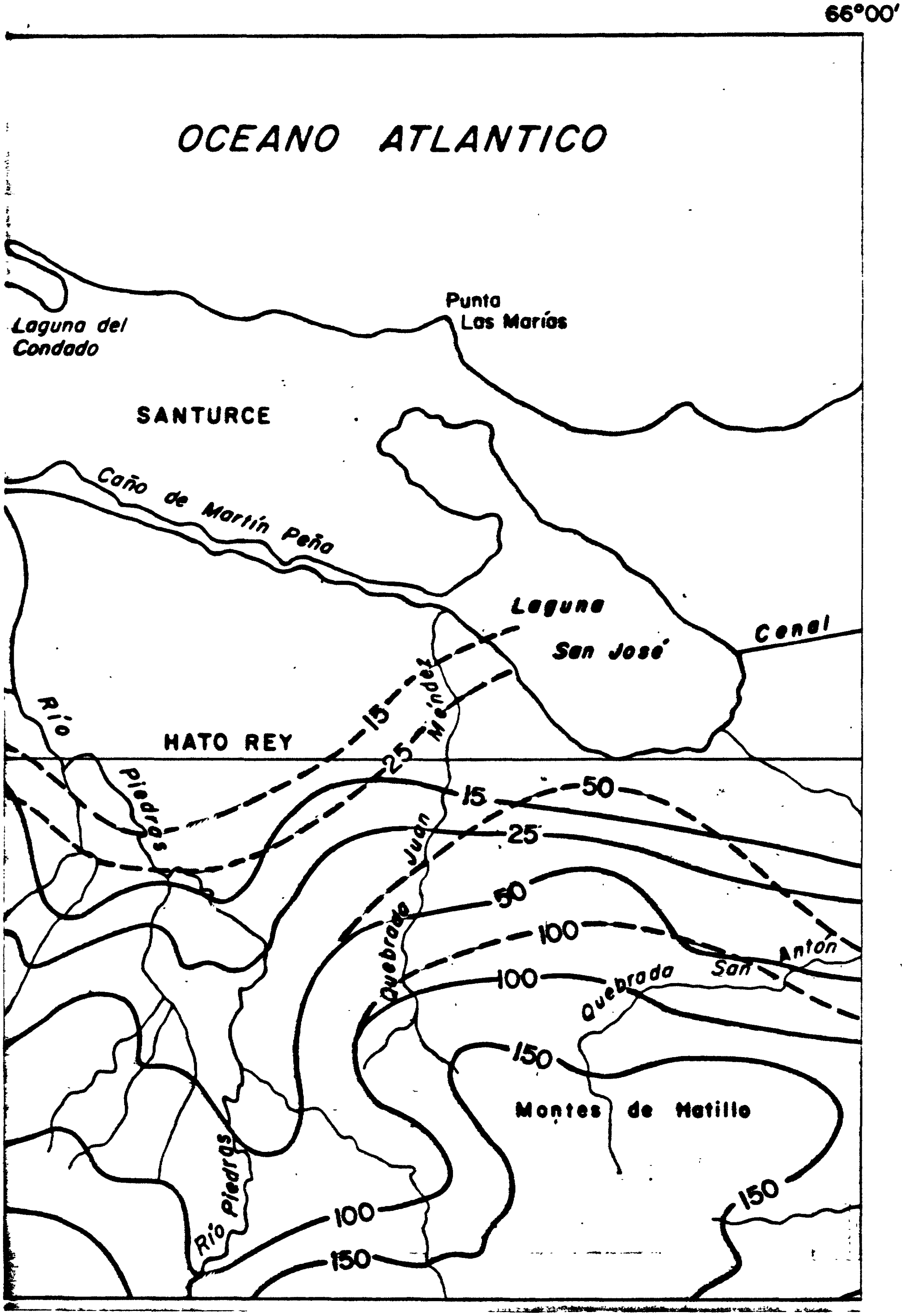
74

7-1



05'
Isla de Cabras
SAN JUAN
Palo Seco
BAHIA DE SAN JUAN
CATAÑO
Cucharillas
Río de Bayamón
15
25
25
50
15
San Patricio
50
Montes de Santa Ana
BAYAMON
15
25
Río Hondo
Bayamón
100
Río Guaynabo
150

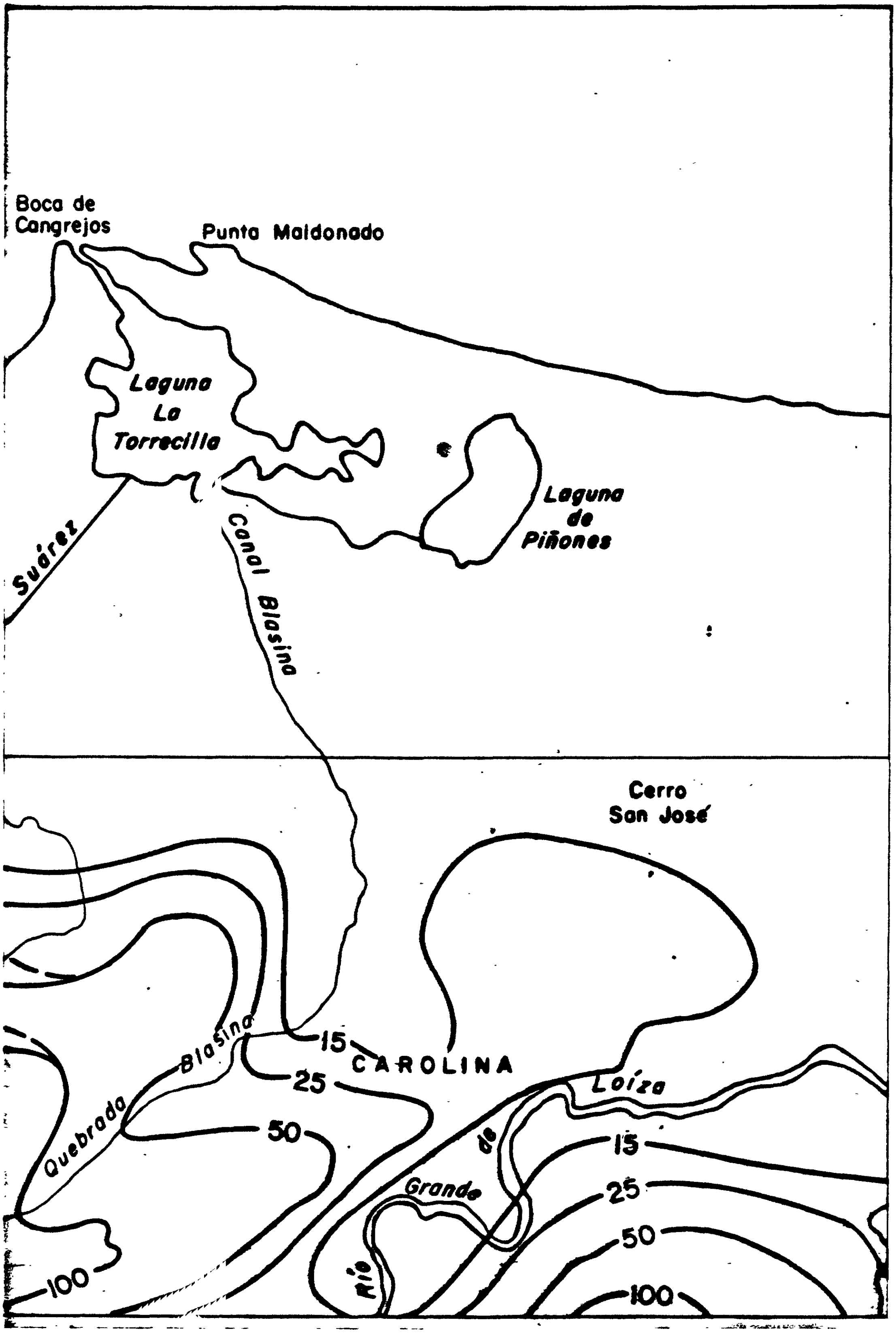
75



66°00'
OCEANO ATLANTICO
Laguna del
Condado
Punta
Las Marías
SANTURCE
Caño de Martín Peña
Laguna
San José
Canal
Río
Piedras
HATO REY
Méndez
Juan
Quebrada
15
25
50
100
150
Quebrada San Antón
Montes de Matillo
Río Piedras

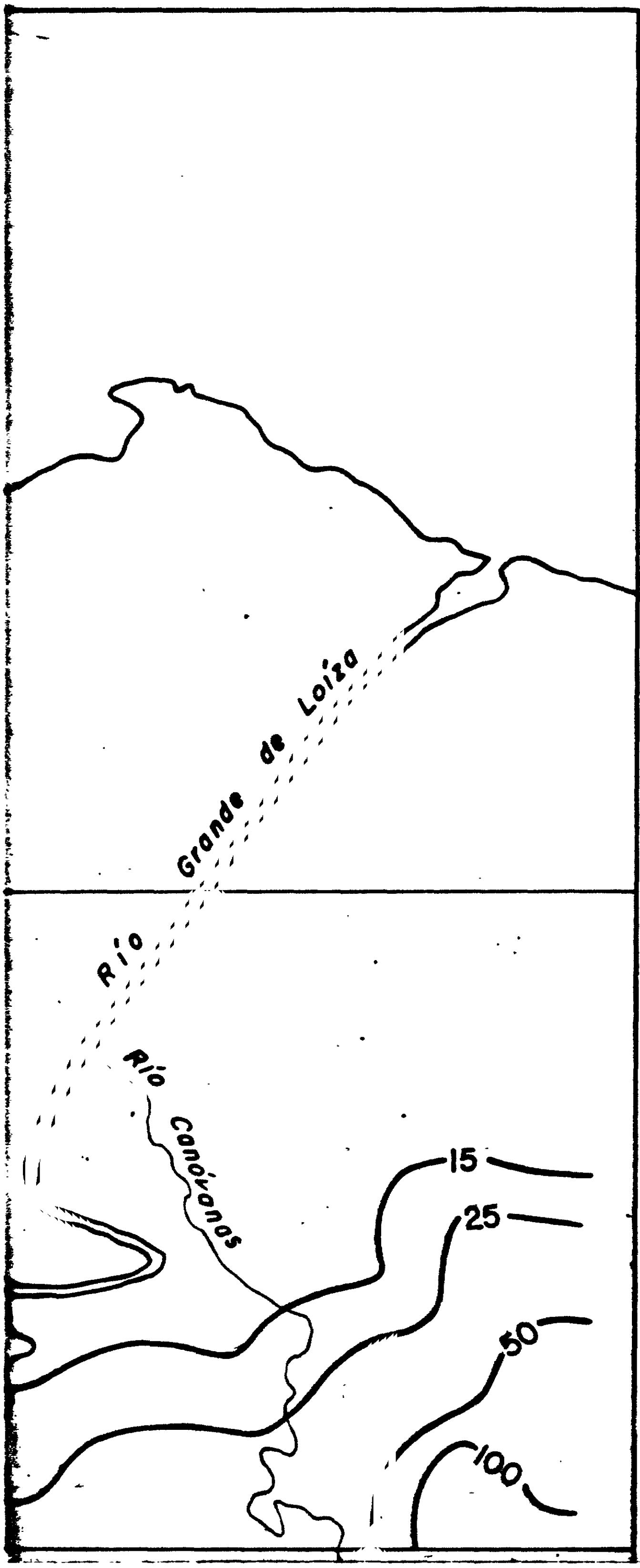
76

55′


Boca de
Cangrejos
Punta Maldonado
Laguna
La
Torrecilla
Laguna
de
Piñones
Suárez
Canal Blasina
Cerro
San José
15
CAROLINA
25
50
100
Blasina
Quebrada
Loíza
de
Grande
Río
15
25
50
100

77

65°52′



EXPLANATION

——15——

WATER-TABLE CONTOUR

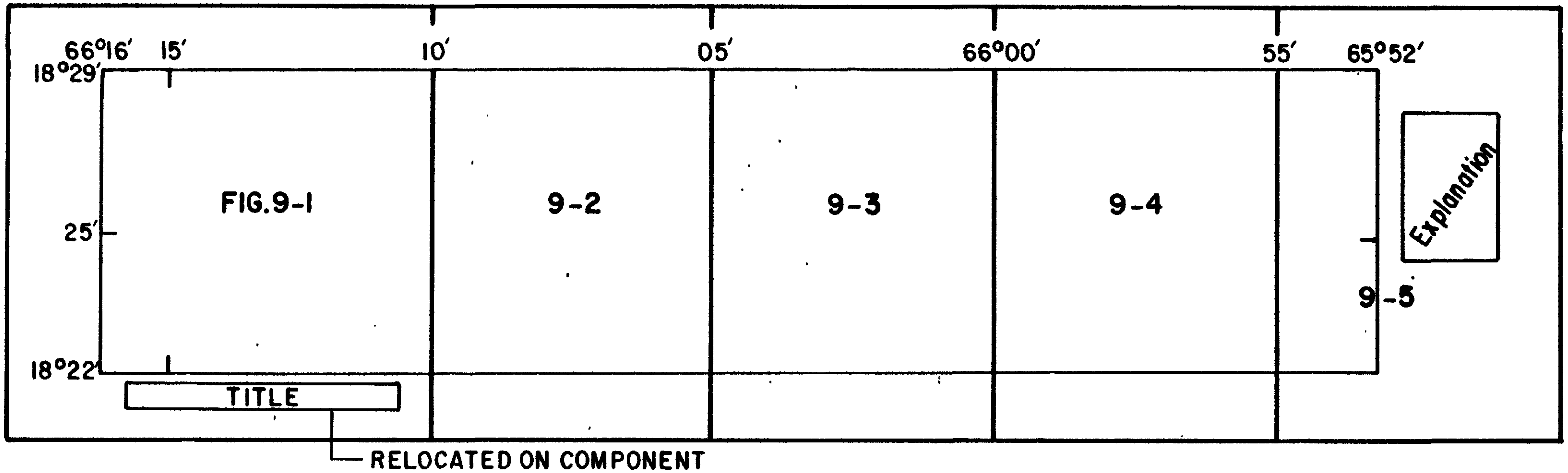
Shows altitude of water in water-table aquifer. Contour interval, in feet (metres), is variable. Datum is mean sea level.

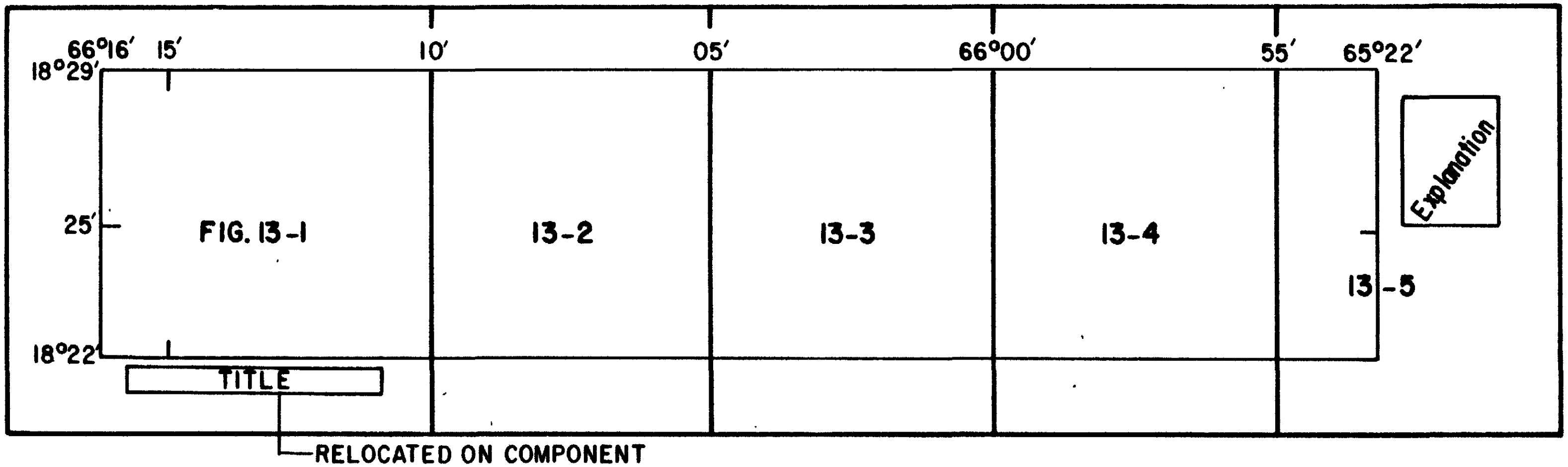
— — —15— — —

POTENTIOMETRIC CONTOUR

Shows altitude at which water level would have stood in tightly used wells in the artesian aquifer, (1971). Contour interval, in feet (metres), is variable. Datum is mean sea level.

78

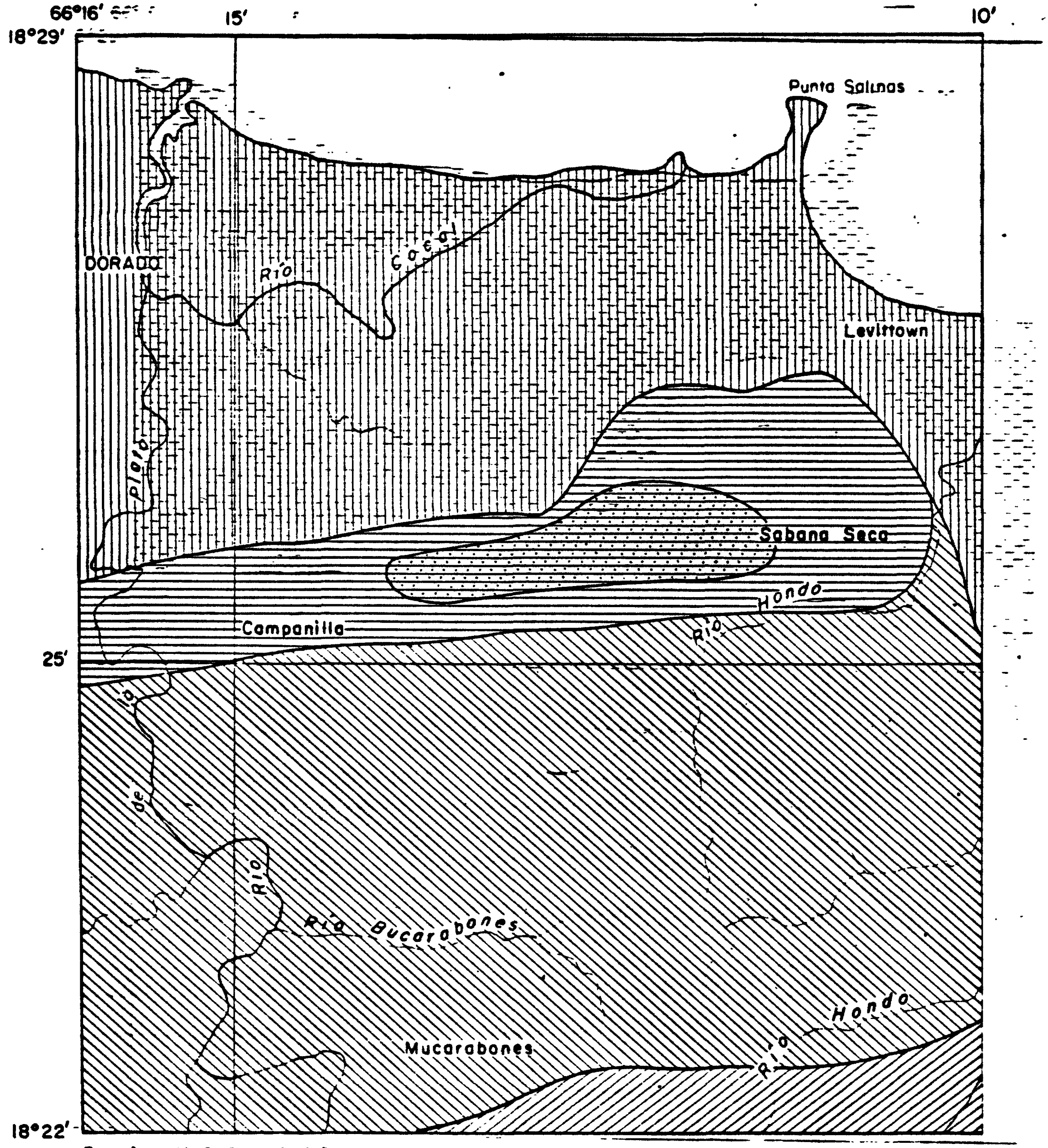




(FIGURES 9 AND 13 COMPOSE THIS 18"x 24" PLATE)

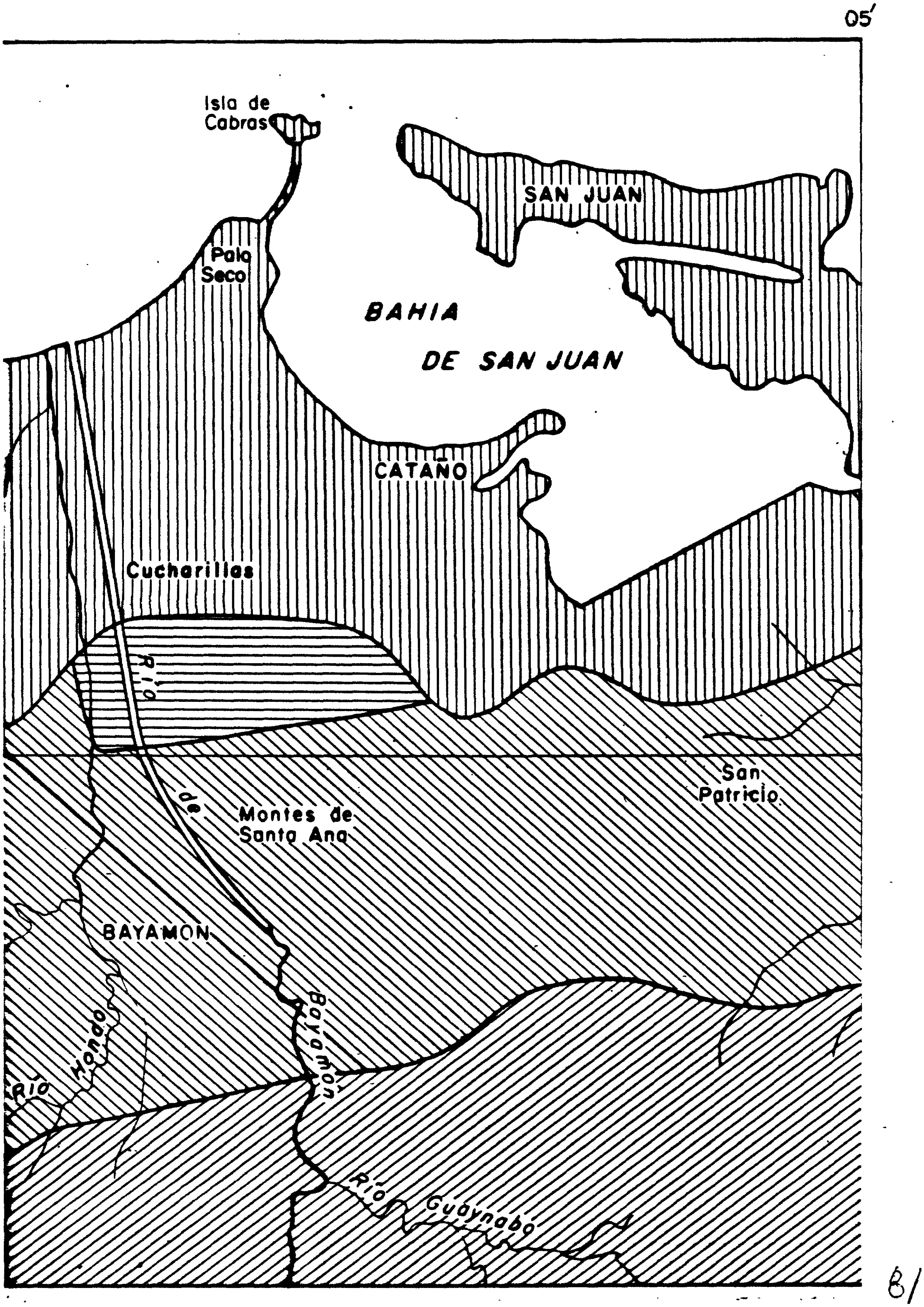
9-0
13-0

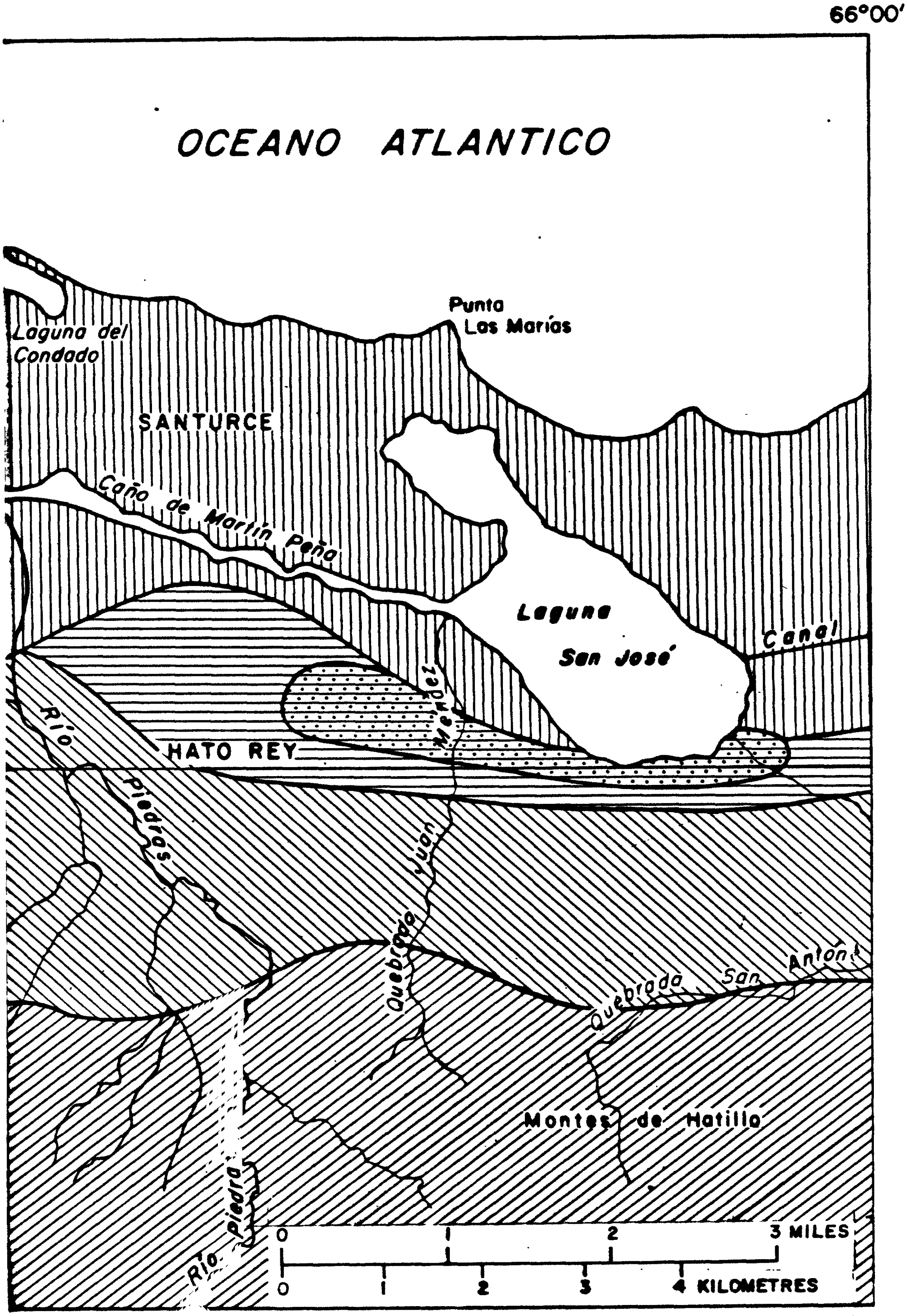
49



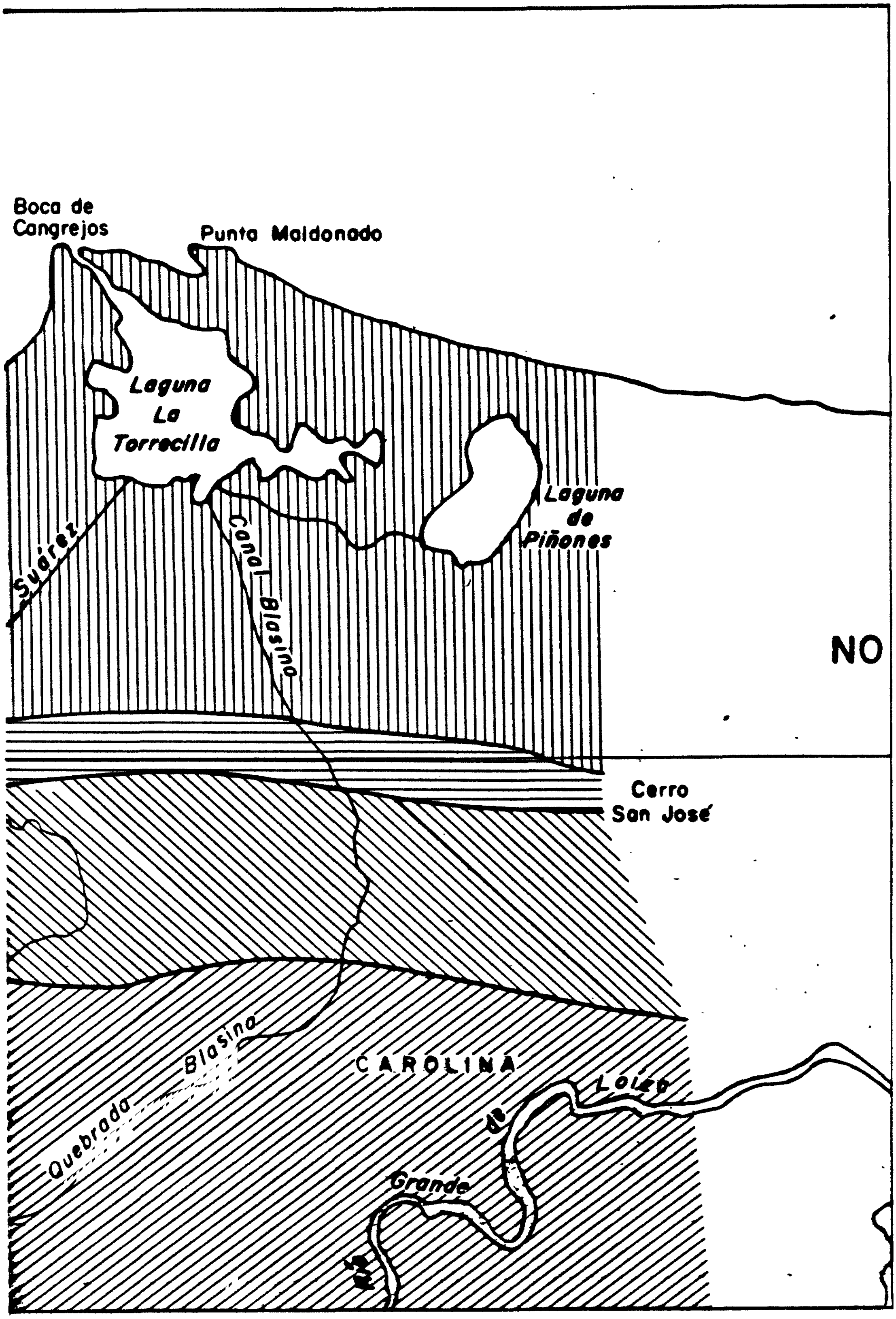
Base from U. S. Geological Survey map, 1:60,000, 1942

FIGURE 9 -- WATER-BEARING CHARACTERISTICS OF AQUIFERS IN THE SAN JUAN AREA. 9-1-80

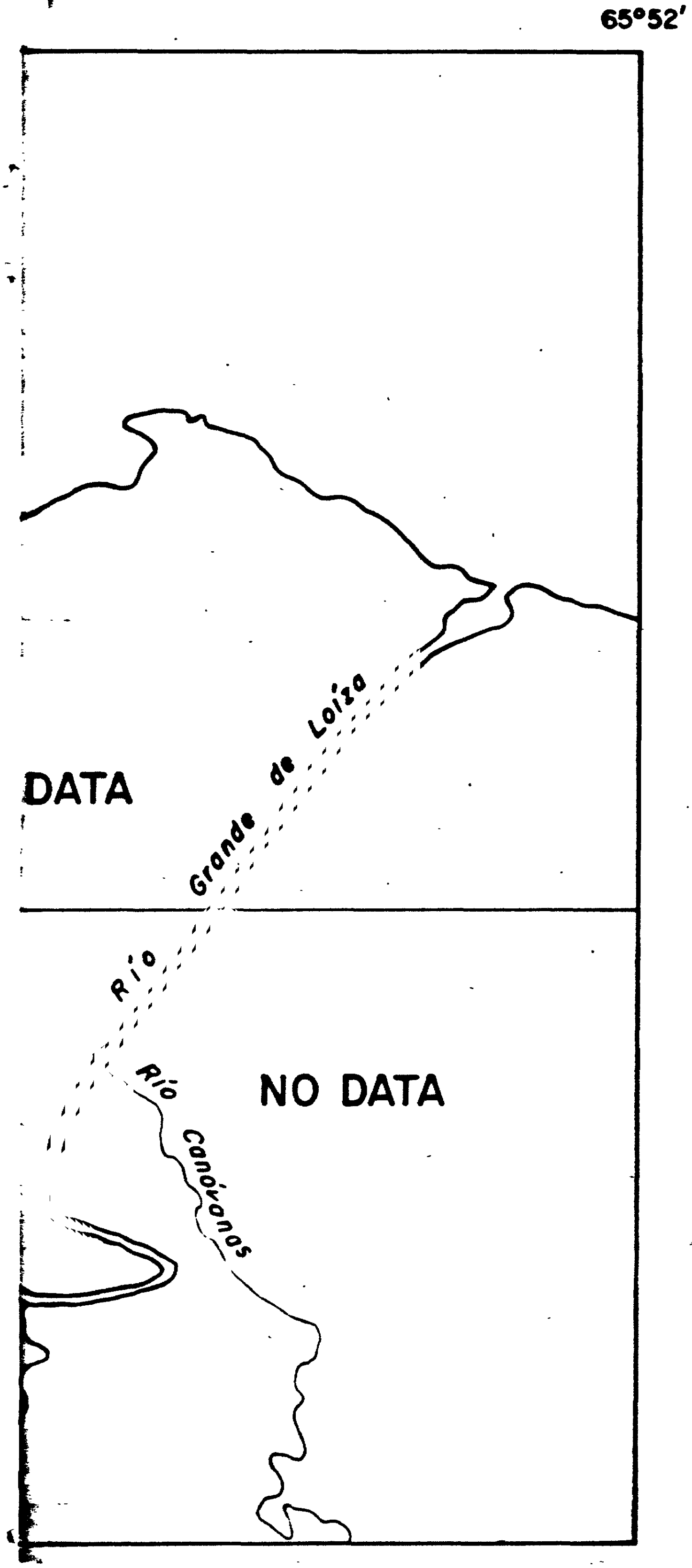

05'
Isla de
Cabras
SAN JUAN
Palo
Seco
BAHIA
DE SAN JUAN
CATAÑO
Cucharillas
Río de Bayamón
San
Patricio
Montes de
Santa Ana
BAYAMON
Río Hondo
Río Guaynabo
81


66°00′
OCEANO ATLANTICO
Punta Las Marías
Laguna del Condado
SANTURCE
Caño de Martín Peña
Laguna San José
Canal
HATO REY
Río Piedras
Quebrada Juan Méndez
Quebrada San Antón
Montes de Hatillo
Río Piedra
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

82


Boca de Cangrejos
Punta Maldonado
Laguna La Torrecilla
Laguna de Piñones
Suárez
Canal Blasina
NO
Cerro San José
CAROLINA
Quebrada Blasina
Loiza
Grande
Río

83



EXPLANATION

Low yields and salty water from surficial deposits. Large yields of salty water from underlying limestone. Possible moderate yields of freshwater from artesian sand aquifer below limestone.

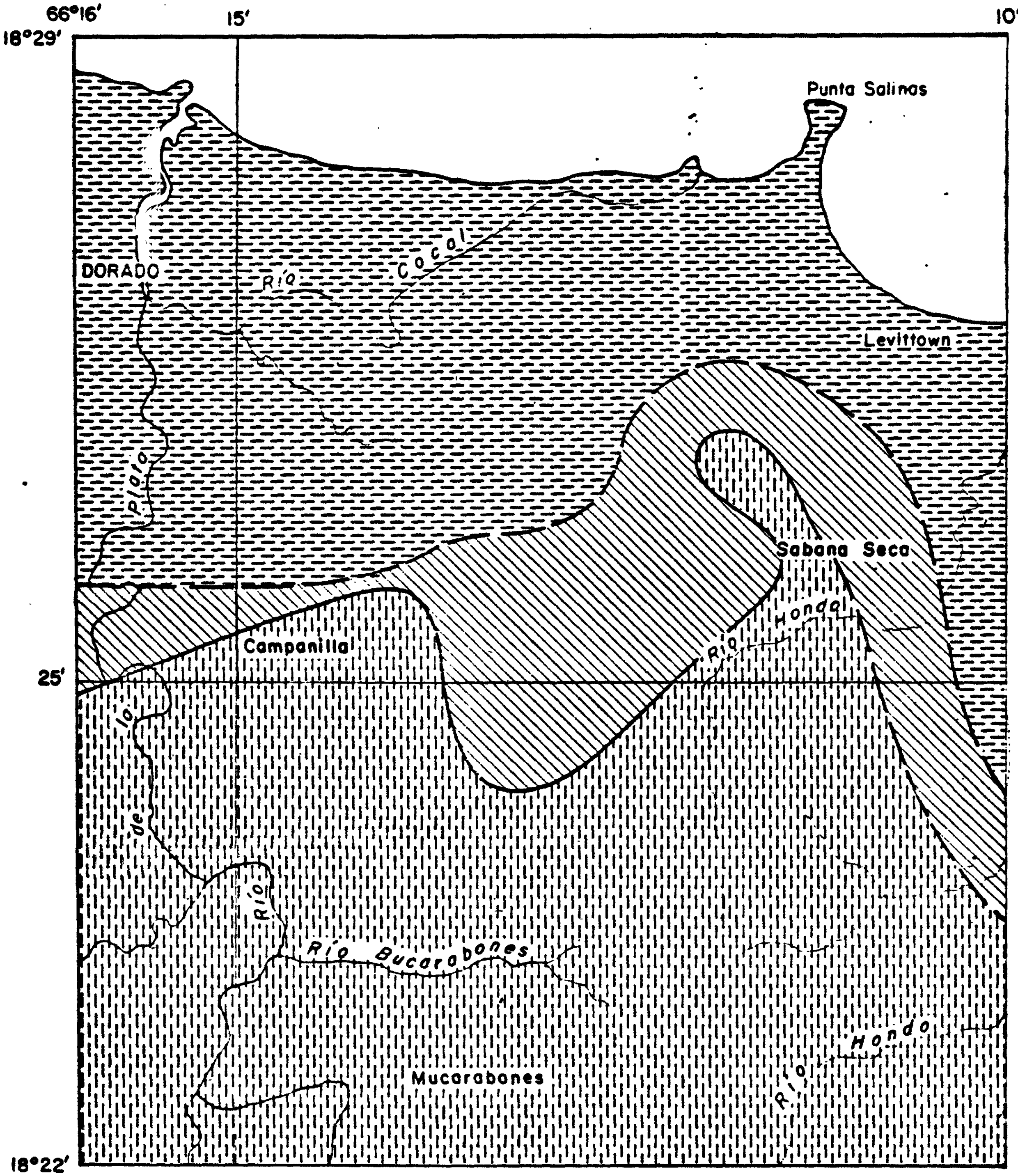
Yields 30 to 2500 gal/min (2 to 160 l/s) freshwater from Aguada and Aymamon Limestones. Chance for salt-water intrusion lessens but yield declines to south. Average yield 515 gal/min (32 l/s). Specific capacity of wells 40 (gal/min)/ft [8.3 (l/s)/m] of drawdown.

Yields 0 to 800 gal/min (0 to 50 l/s) of freshwater from Cibao and San Sebastian Formations. Average yield 120 gal/min (7.6 l/s) from Cibao and 244 gal/min (15 l/s) from San Sebastian. Specific capacity of wells 3.1 (gal/min)/ft [0.64 (l/s)/m] of drawdown for both formations.

Generally low yields 0 to 300 gal/min (19 l/s). Average yield 50 gal/min (3 l/s) from weathered zone and fractures of volcanic rock.

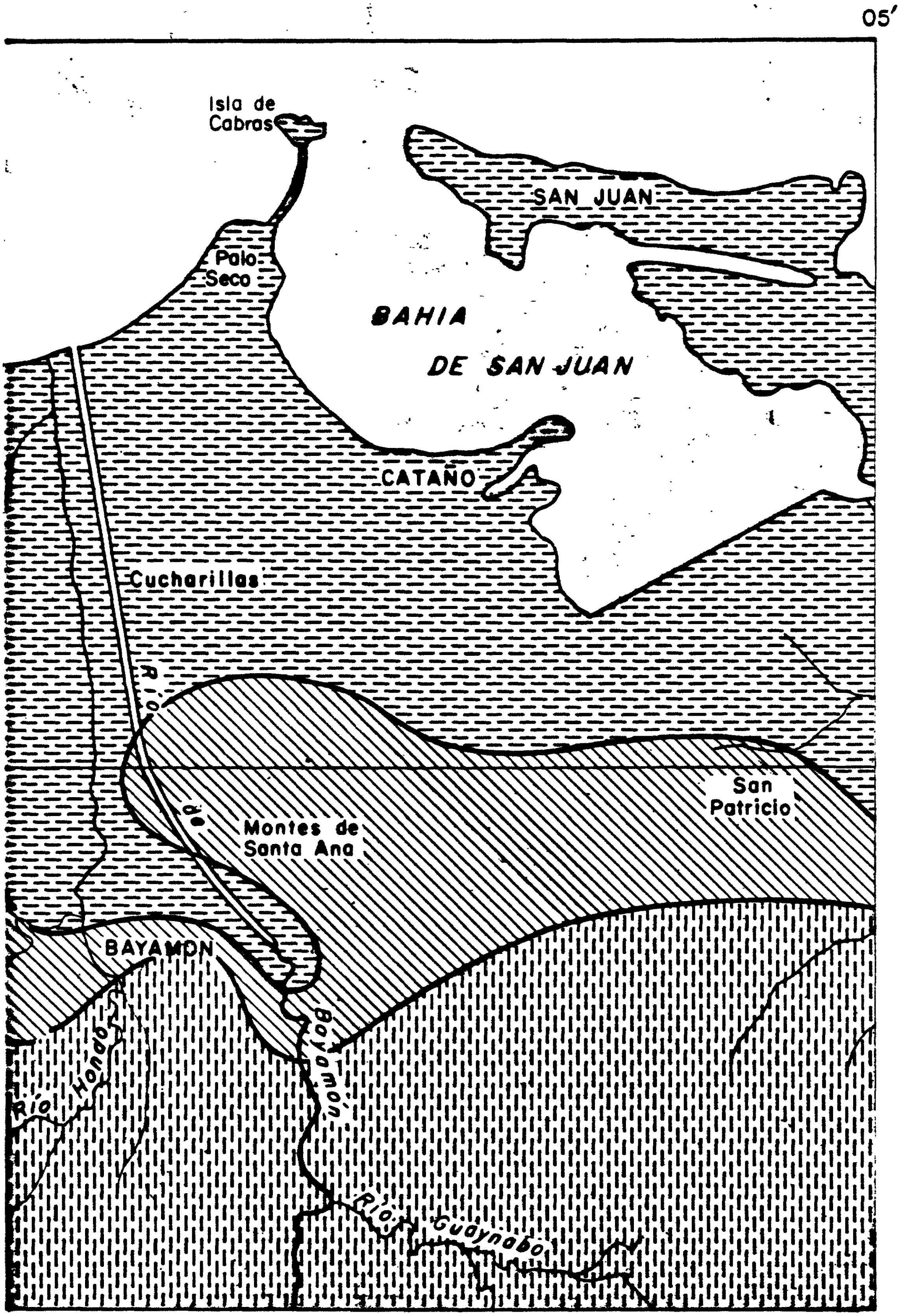
Possible areas for development of major supplies of ground water.

84

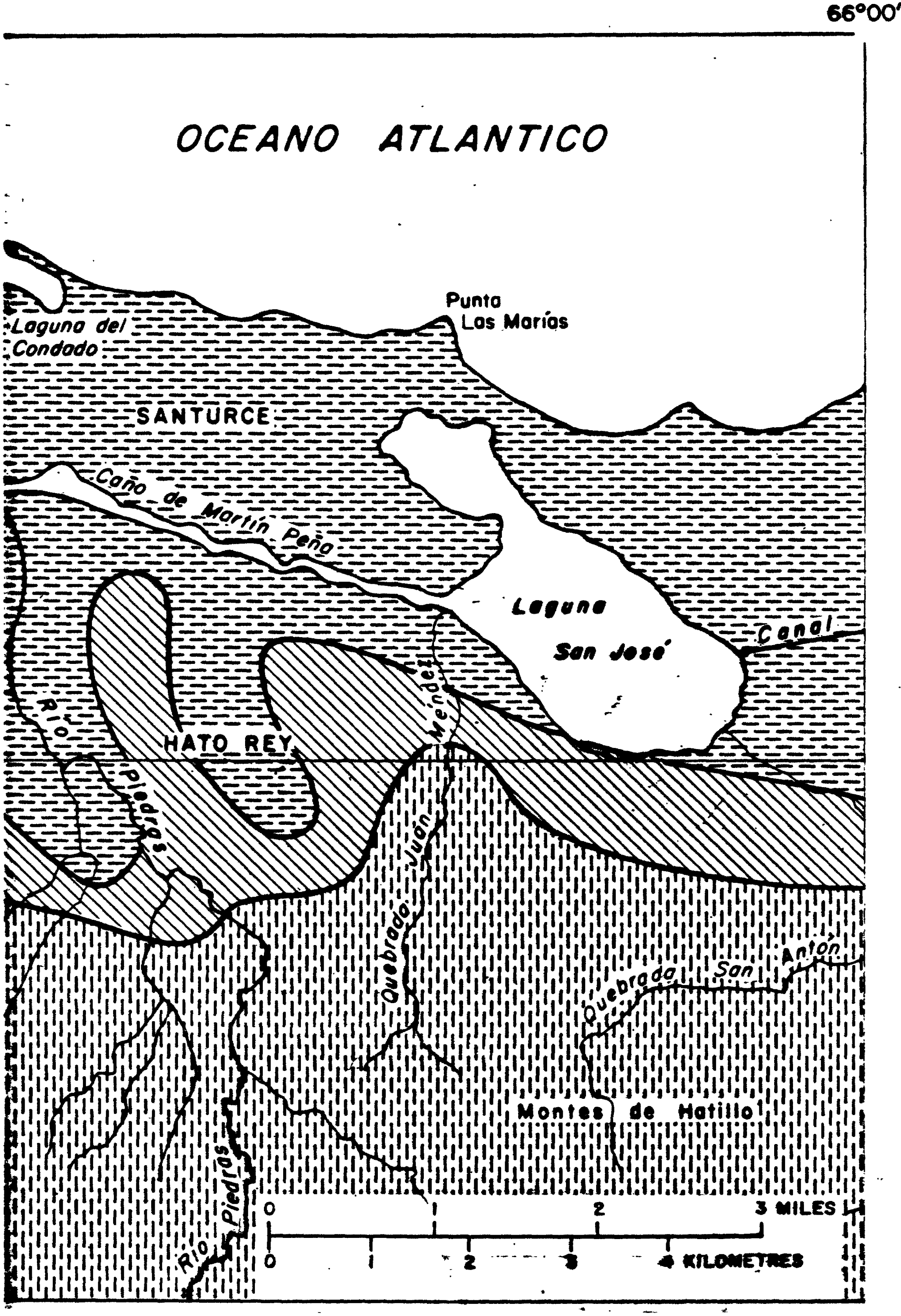


Base from U. S. Geological Survey map, 1:60,000, 1942

FIGURE 13 -- DISSOLVED-SOLIDS CONCENTRATION IN GROUND WATER, SAN JUAN AREA.

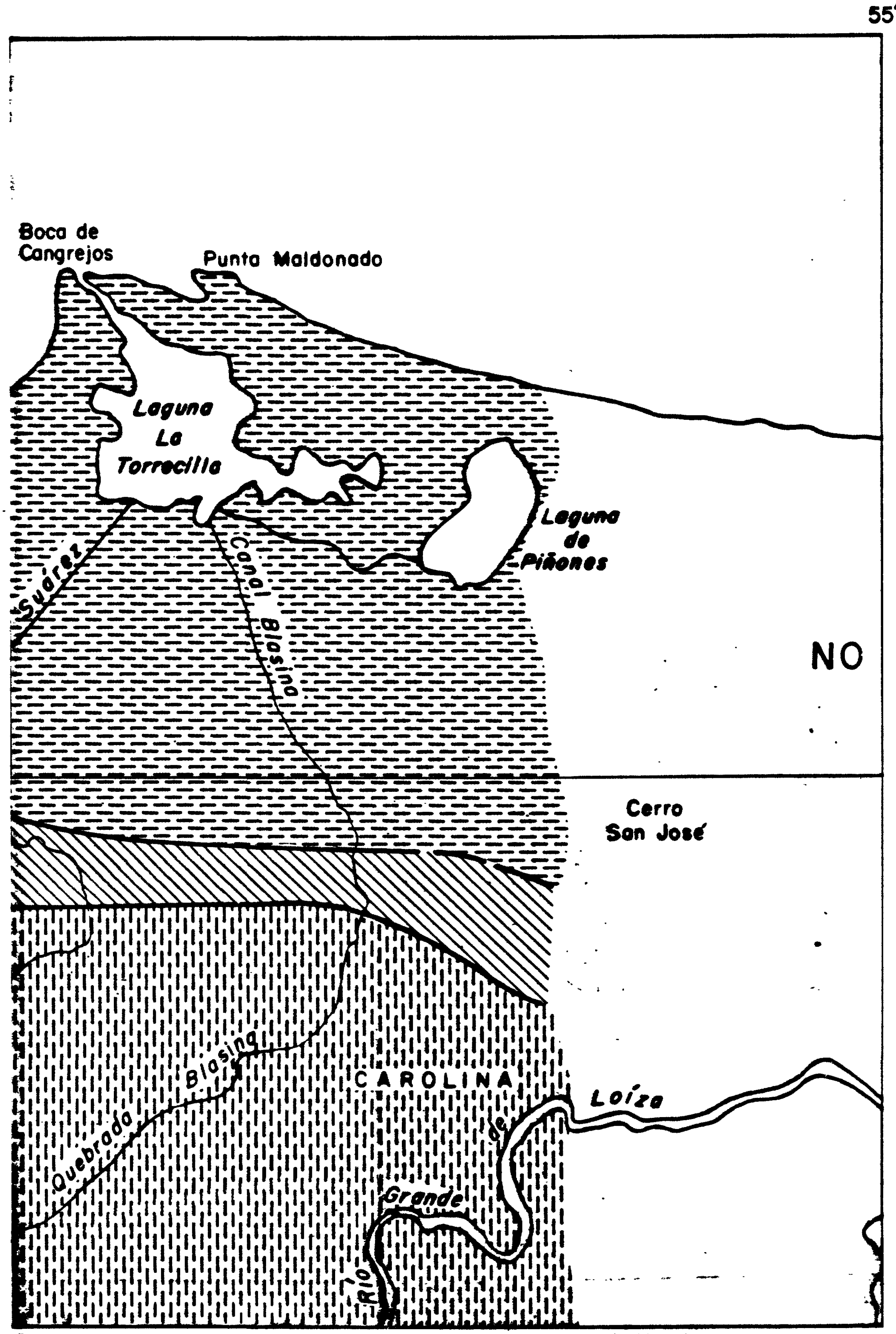

05′
Isla de Cabras
SAN JUAN
Palo Seco
BAHIA DE SAN JUAN
CATAÑO
Cucharillas
Río de Bayamón
San Patricio
Montes de Santa Ana
BAYAMON
Río Hondo
Río Guaynabo

86

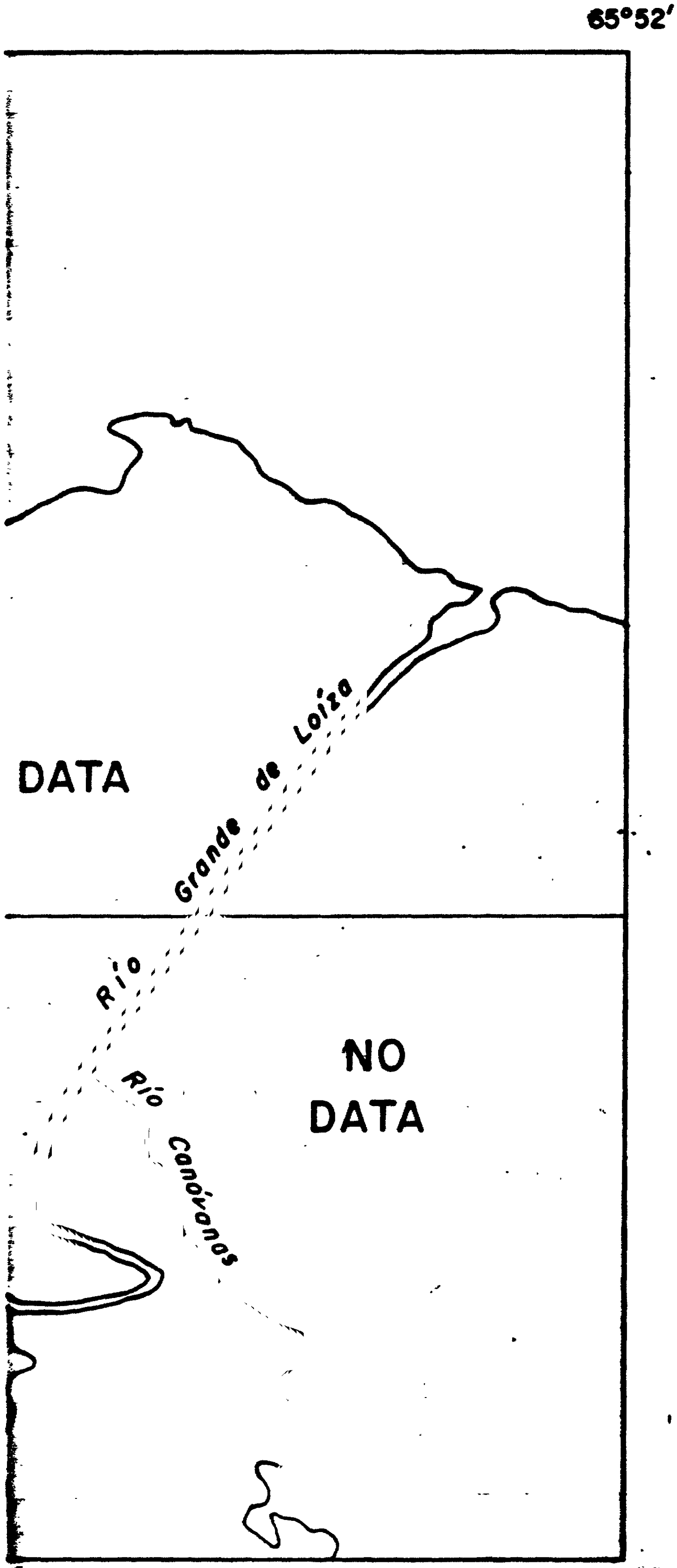

66°00'
OCEANO ATLANTICO
Punta
Las Marías
Laguna del
Condado
SANTURCE
Caño de Martín Peña
Laguna
San José
Canal
HATO REY
Río Piedras
Méndez
Quebrada Juan
Quebrada San Antón
Montes de Hatillo
Río Piedras
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

87

13-3


55′
Boca de Cangrejos
Punta Maldonado
Laguna La Torrecilla
Laguna de Piñones
Suárez
Canal Blasina
NO
Cerro San José
Quebrada Blasina
CAROLINA
Loíza
Río Grande
de

88



EXPLANATION

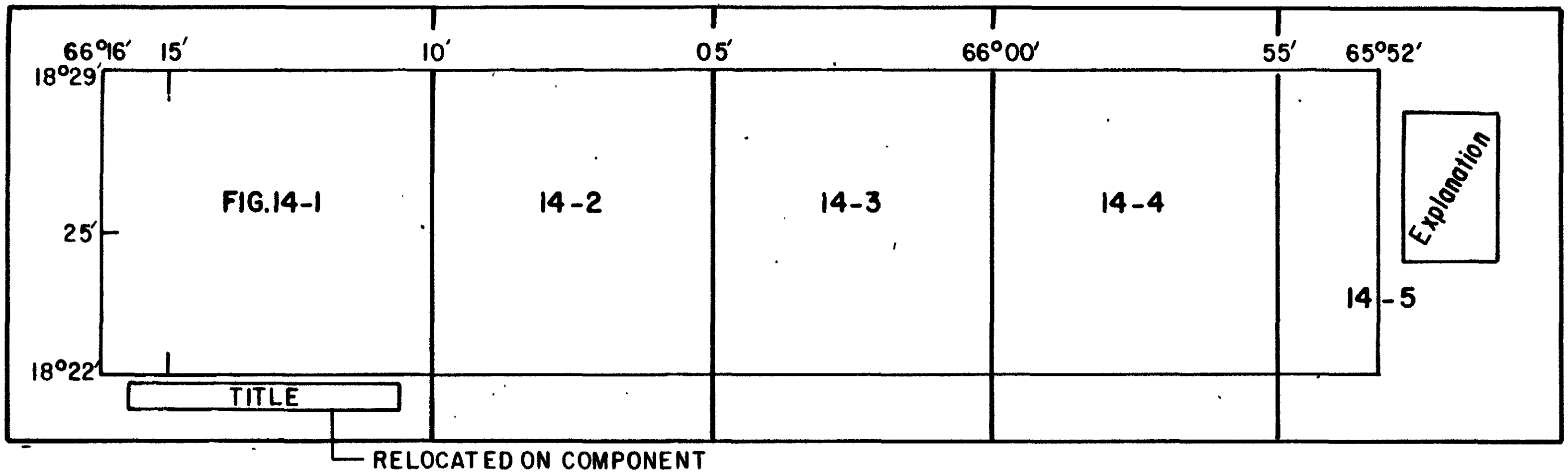
Concentration of dissolved solids, in milligrams per litre

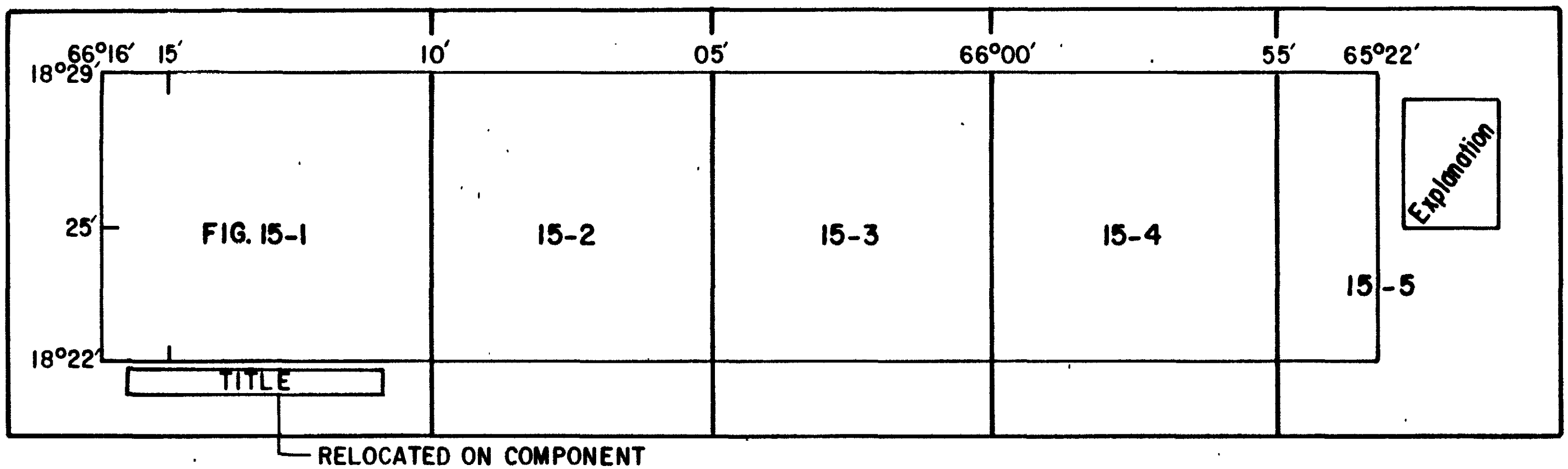
Less than 300

300 to 500

Greater than 500

89





(FIGURES 14 AND 15 COMPOSE THIS 18"x 24" PLATE)

14-0
15-0

90

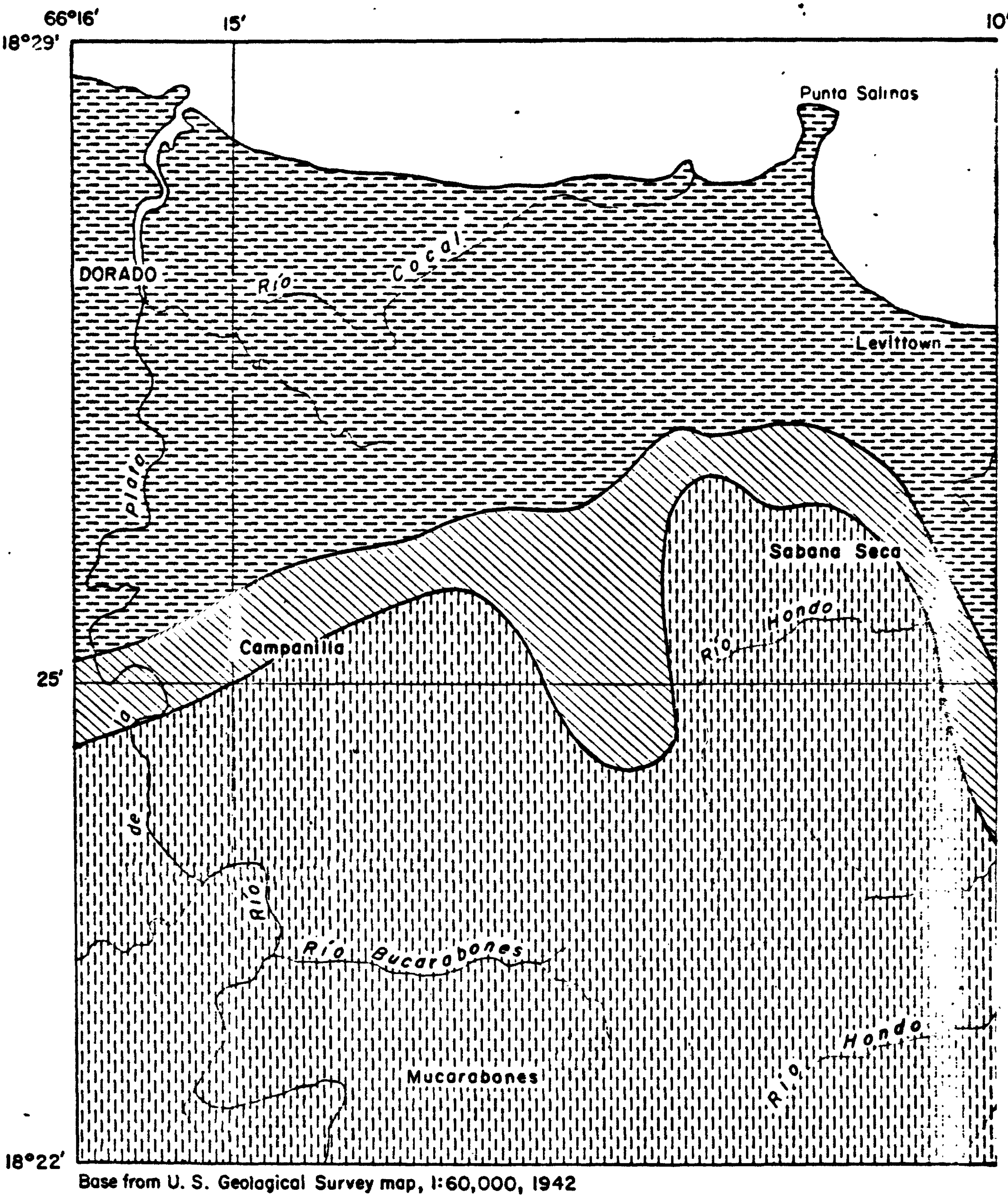
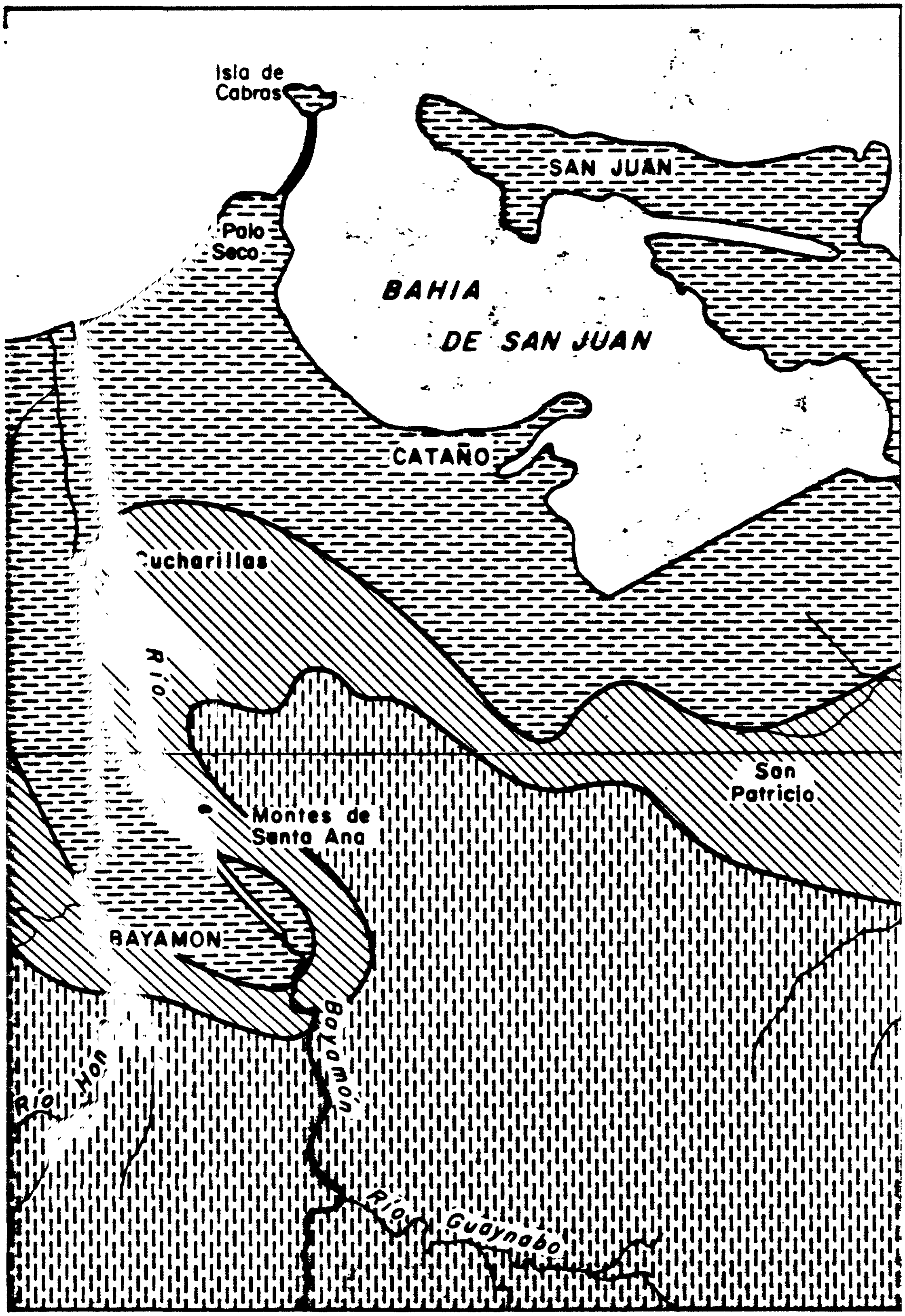


FIGURE 14-- CHLORIDE CONCENTRATION OF GROUND WATER, UNCONFINED AQUIFER, SAN JUAN AREA.

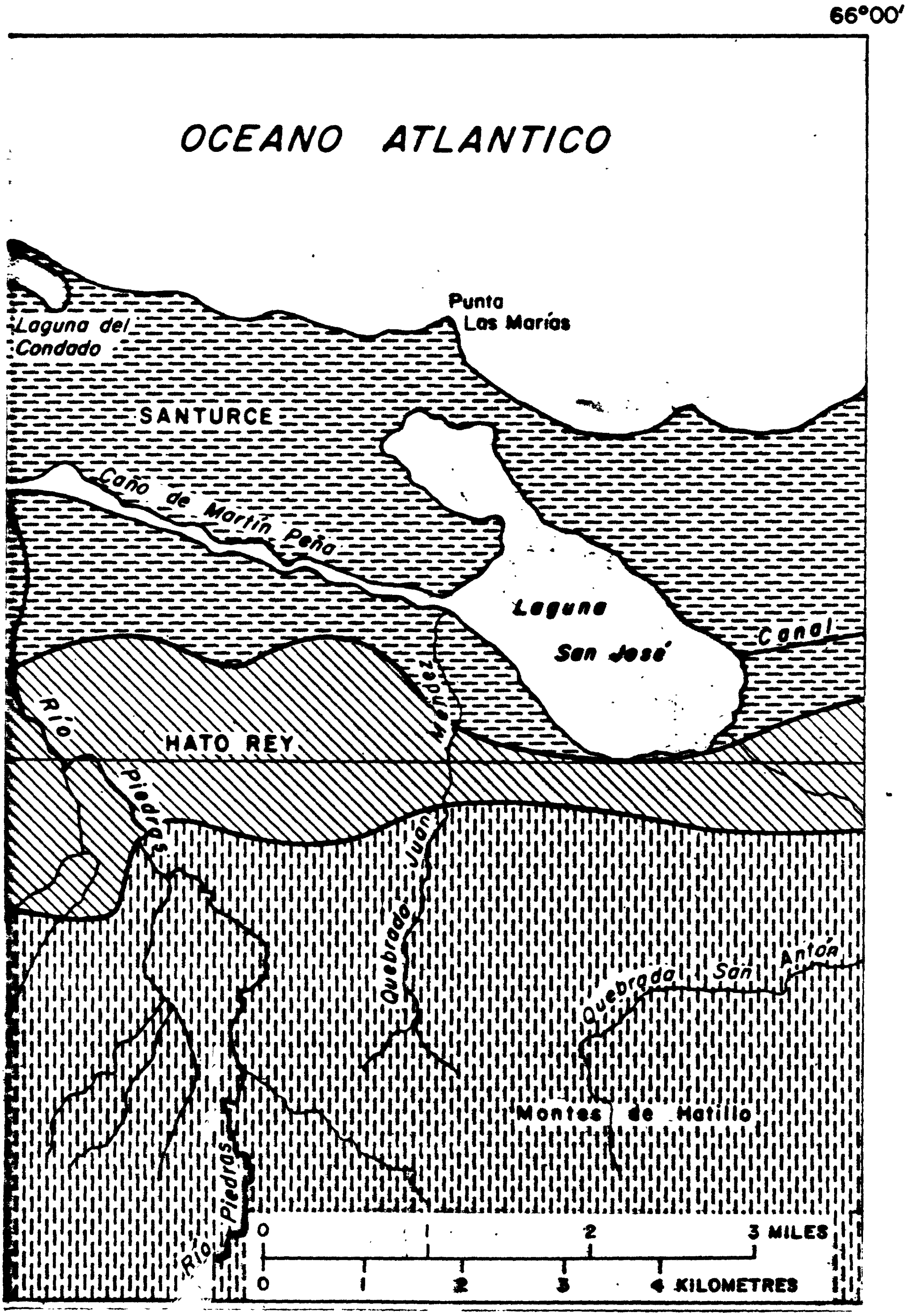
14-1

91

05′

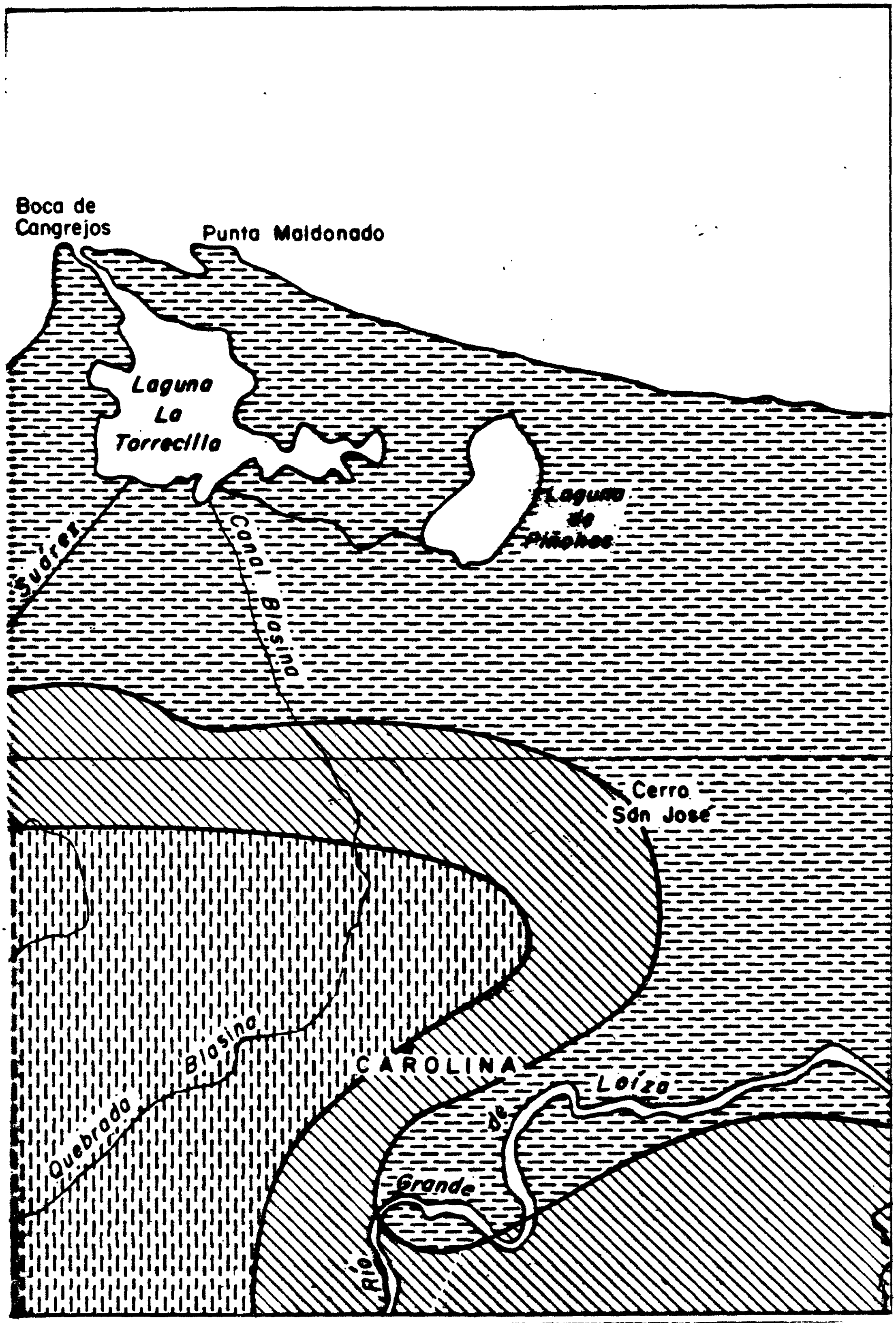

Isla de
Cabras
SAN JUAN
Palo
Seco
BAHIA
DE SAN JUAN
CATAÑO
Cucharillas
Rio
San
Patricio
Montes de
Santa Ana
BAYAMON
Bayamon
Rio Hon
Rio Guaynabo

92


66°00′
OCEANO ATLANTICO
Punta Las Marías
Laguna del Condado
SANTURCE
Caño de Martín Peña
Laguna San José
Canal
Méndez
HATO REY
Río Piedras
Quebrada Juan
Quebrada San Antón
Montes de Hatillo
Río Piedras
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

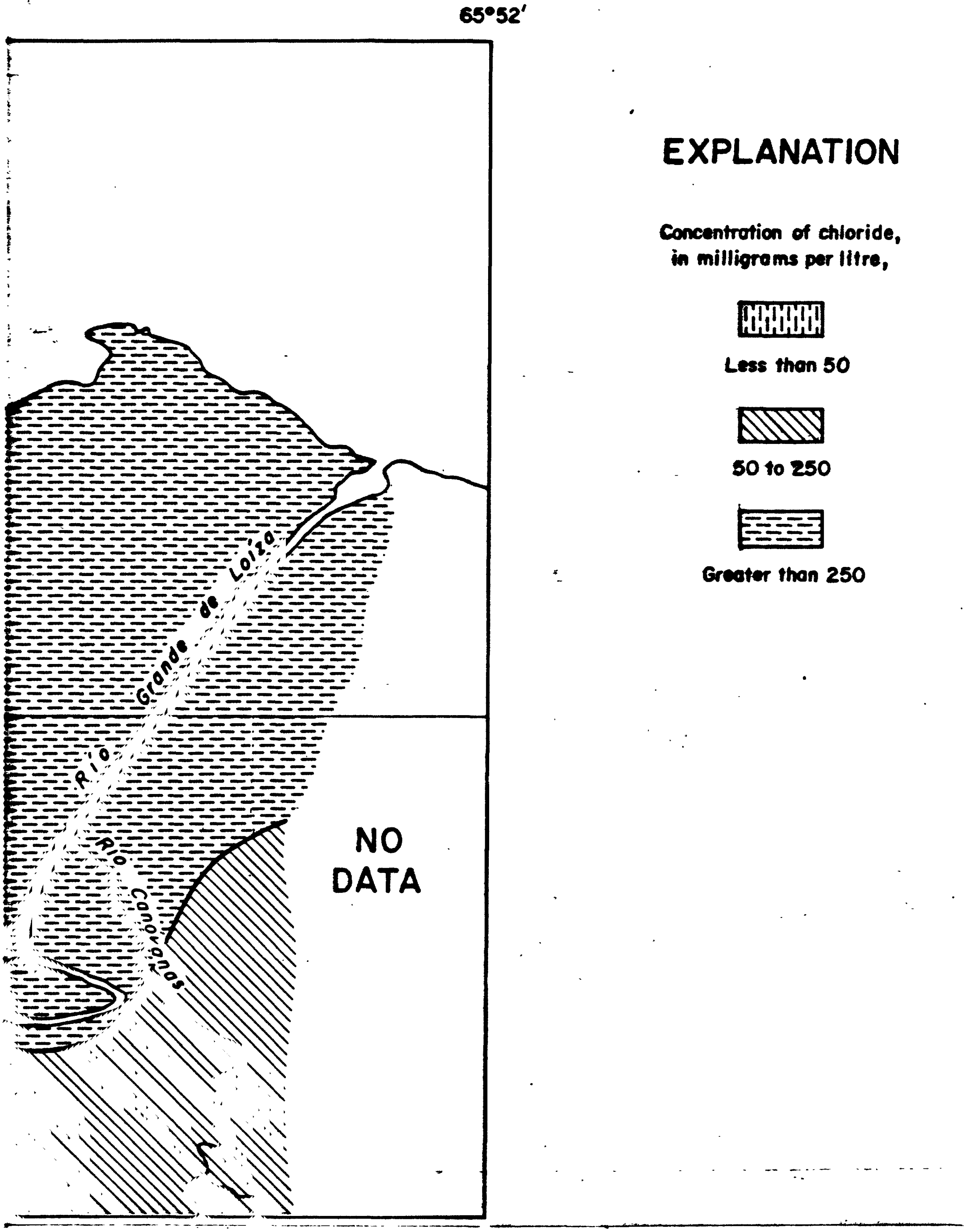
93

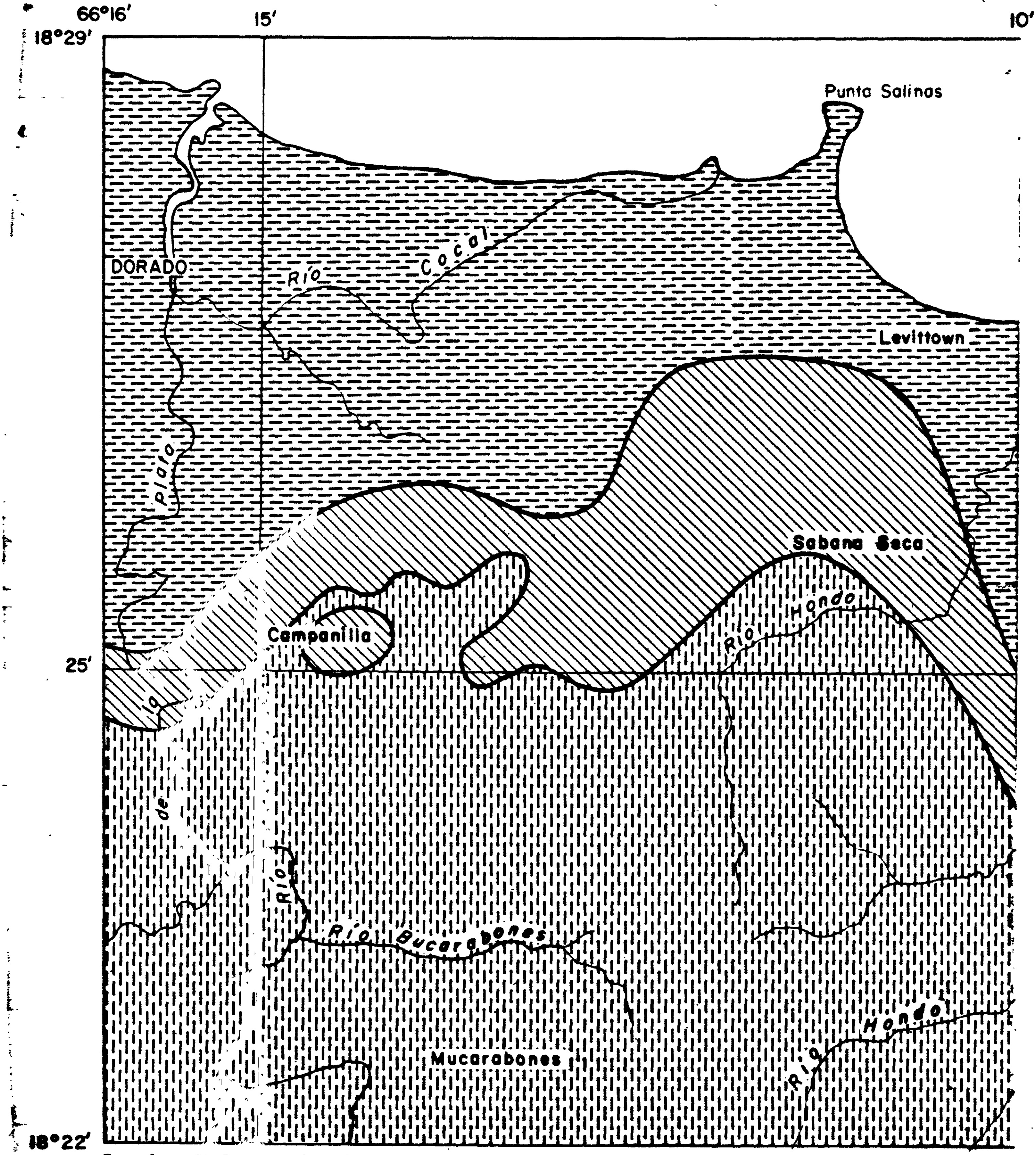
55′



Boca de
Cangrejos
Punta Maldonado
Laguna
La
Torrecilla
Laguna
de
Piñones
Suárez
Canal Blasina
Cerro
San José
CAROLINA
Quebrada Blasina
Río Grande de Loíza

94

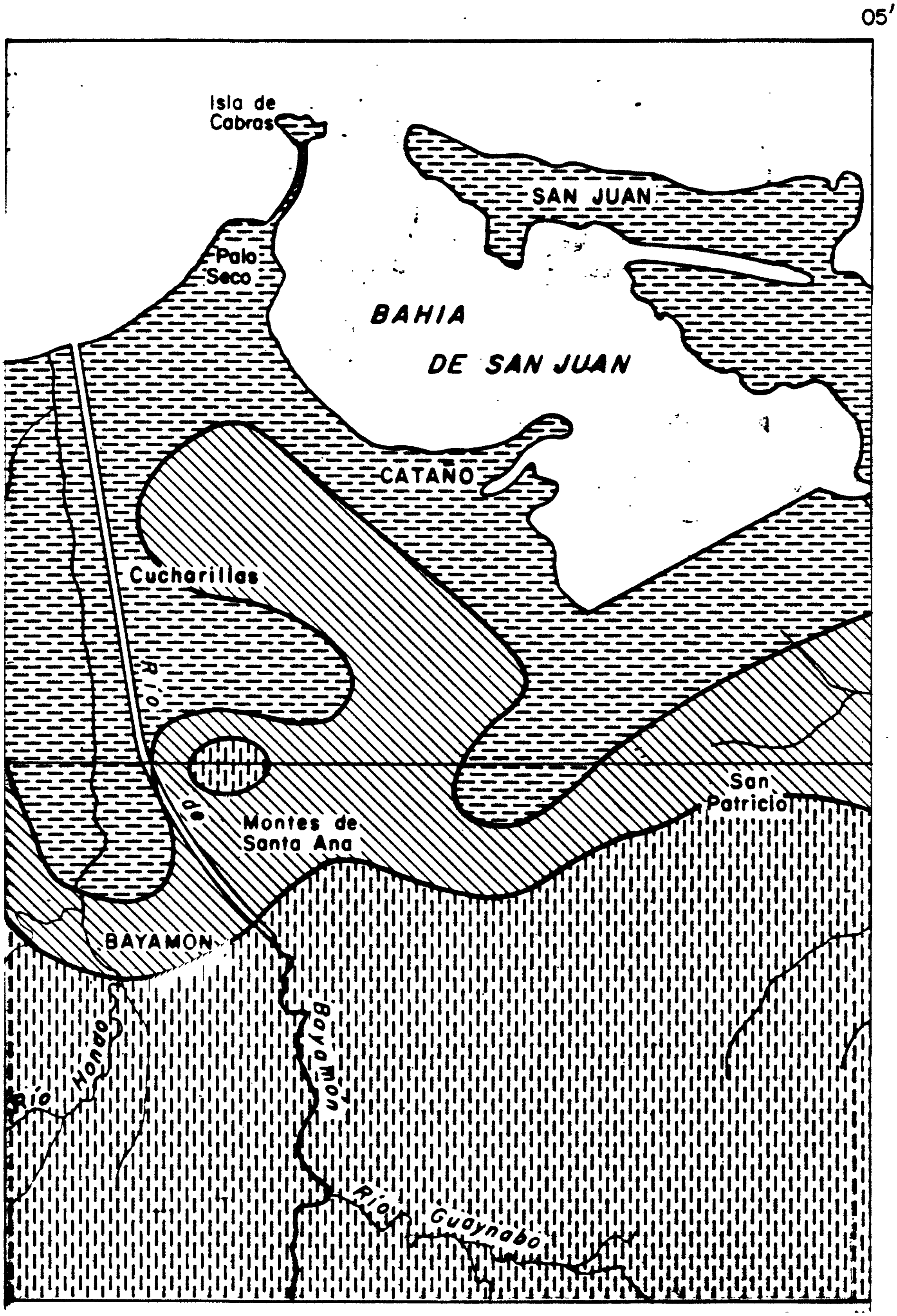

65°52′
Rio Grande de Loiza
Rio Canovanas
NO DATA
EXPLANATION
Concentration of chloride, in milligrams per litre,
Less than 50
50 to 250
Greater than 250



Base from U. S. Geological Survey map, 1:60,000, 1942

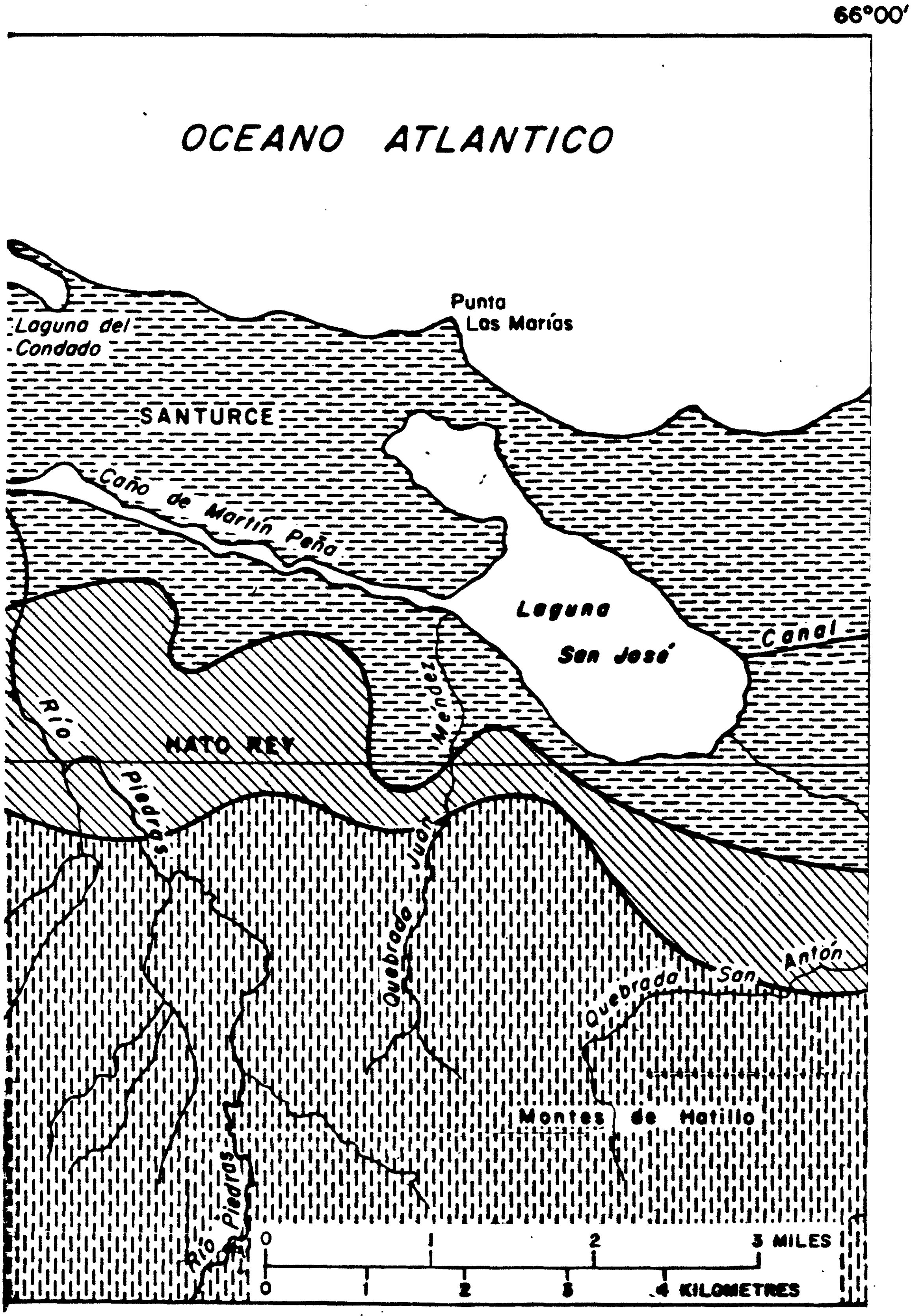
FIGURE 15 -- HARDNESS OF GROUND WATER, UNCONFINED AQUIFER, SAN JUAN AREA.

15-1


05'
Isla de Cabras
SAN JUAN
Palo Seco
BAHIA DE SAN JUAN
CATAÑO
Cucharillas
Rio de
Montes de Santa Ana
San Patricio
BAYAMON
Rio Hondo
Bayamon
Rio Guaynabo

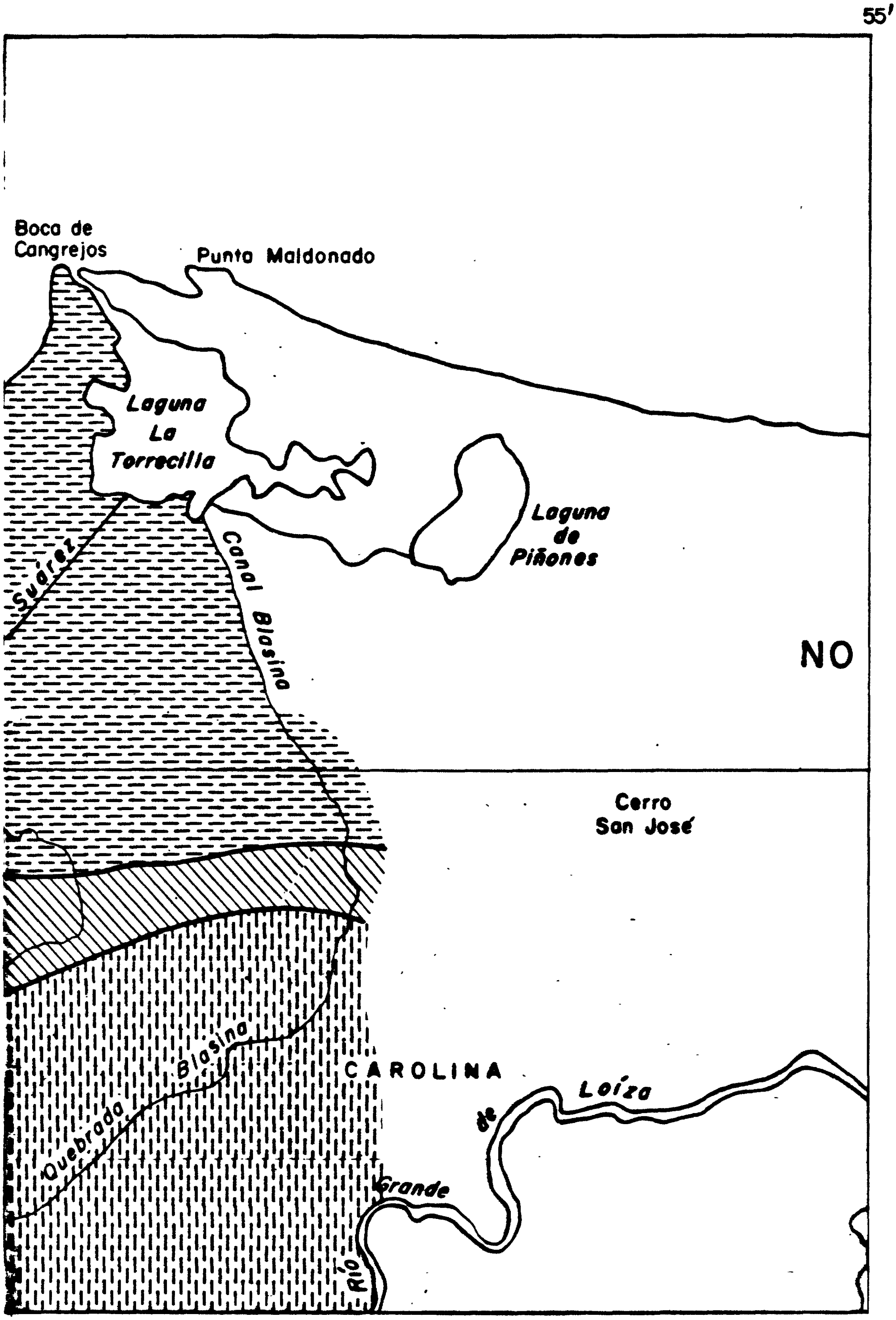
15-2

97


66°00′
OCEANO ATLANTICO
Punta Las Marías
Laguna del Condado
SANTURCE
Caño de Martín Peña
Laguna San José
Canal
Río Piedras
HATO REY
Méndez
Quebrada Juan
Quebrada San Antón
Montes de Hatillo
Río Piedras
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES

98

15-3



55′
Boca de Cangrejos
Punta Maldonado
Laguna La Torrecilla
Laguna de Piñones
Suárez
Canal Blasina
NO
Cerro San José
CAROLINA
Quebrada Blasina
Río Grande de Loíza

99

15-4

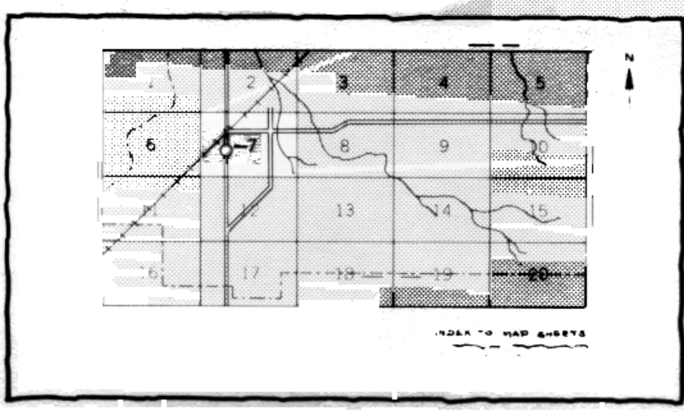
SOIL SURVEY OF

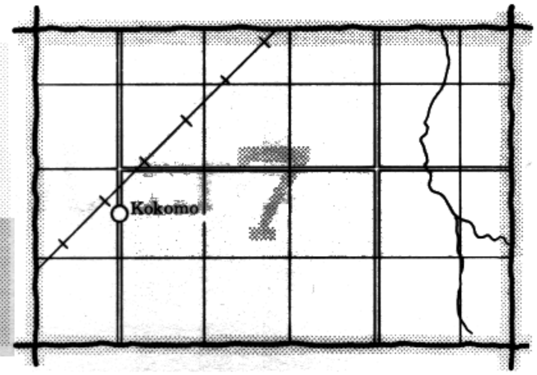
San Juan Area of Puerto Rico

United States Department of Agriculture
Soil Conservation Service
In cooperation with
University of Puerto Rico
Agricultural Experiment Station

HOW TO USE

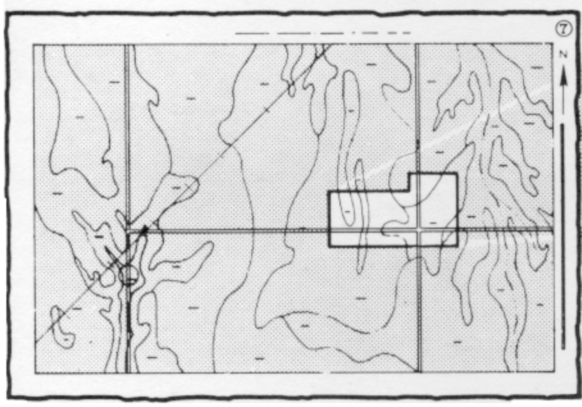
1. Locate your area of interest on the "Index to Map Sheets" (the last page of this publication).

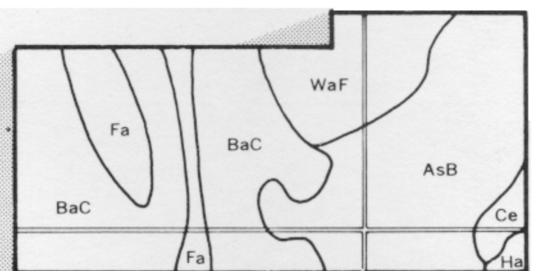




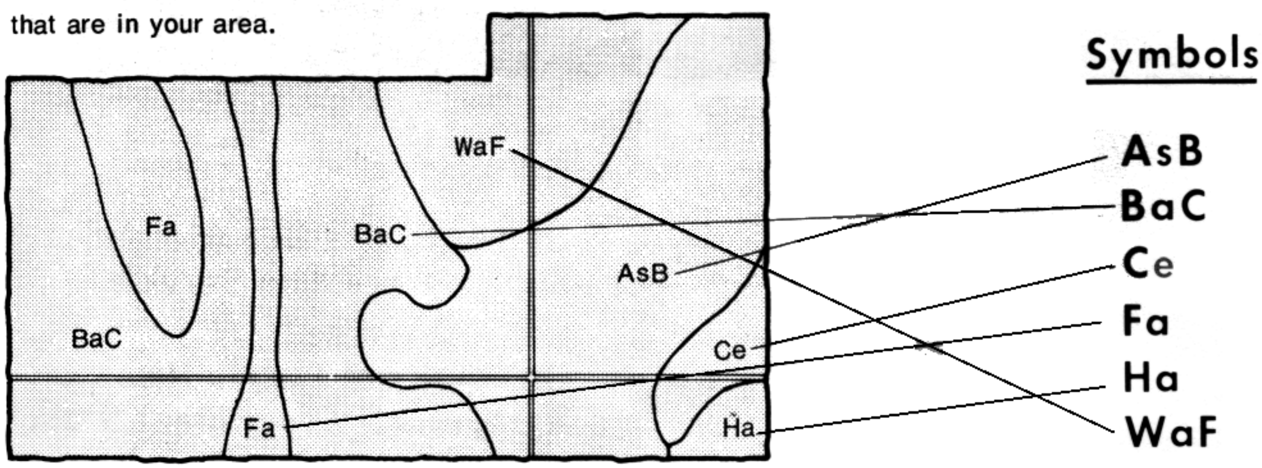
2 Note the number of the map sheet and turn to that sheet.

3. Locate your area of interest on the map sheet.



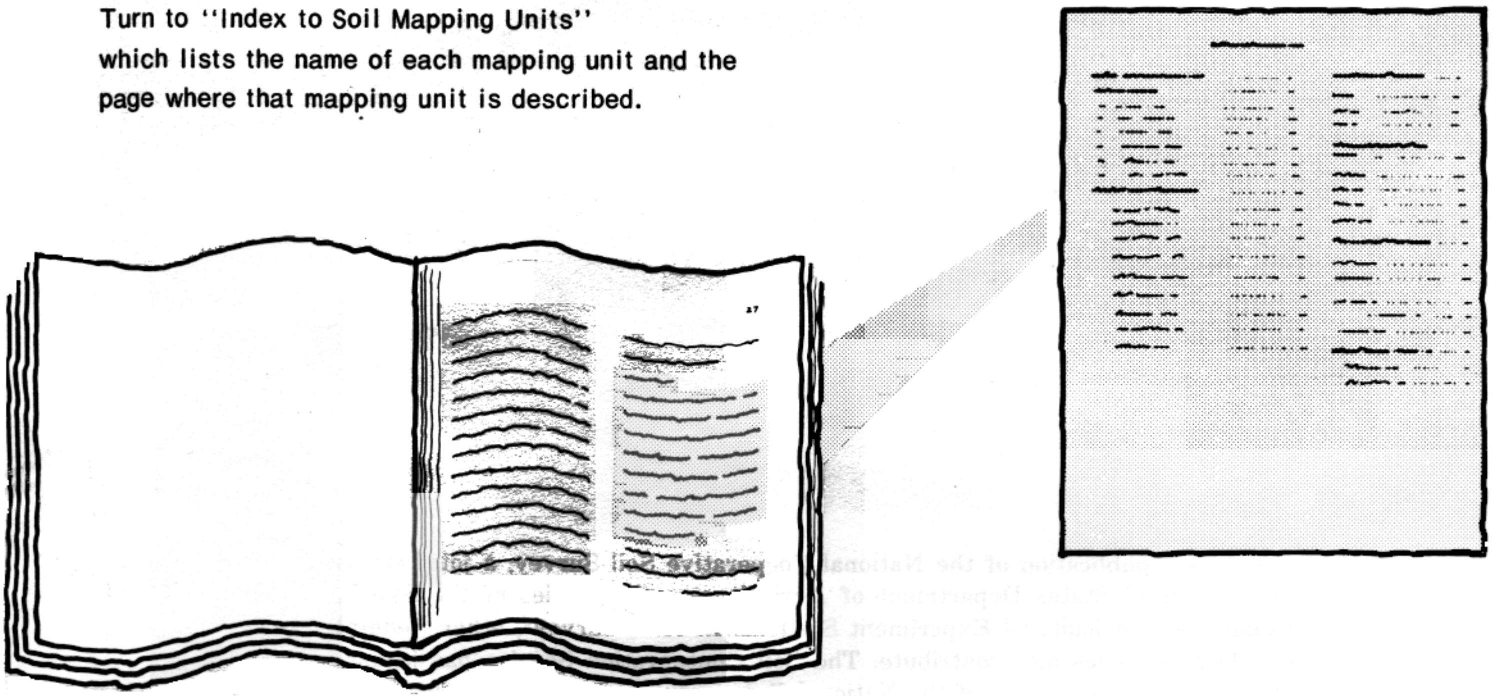


4 List the mapping unit symbols that are in your area.

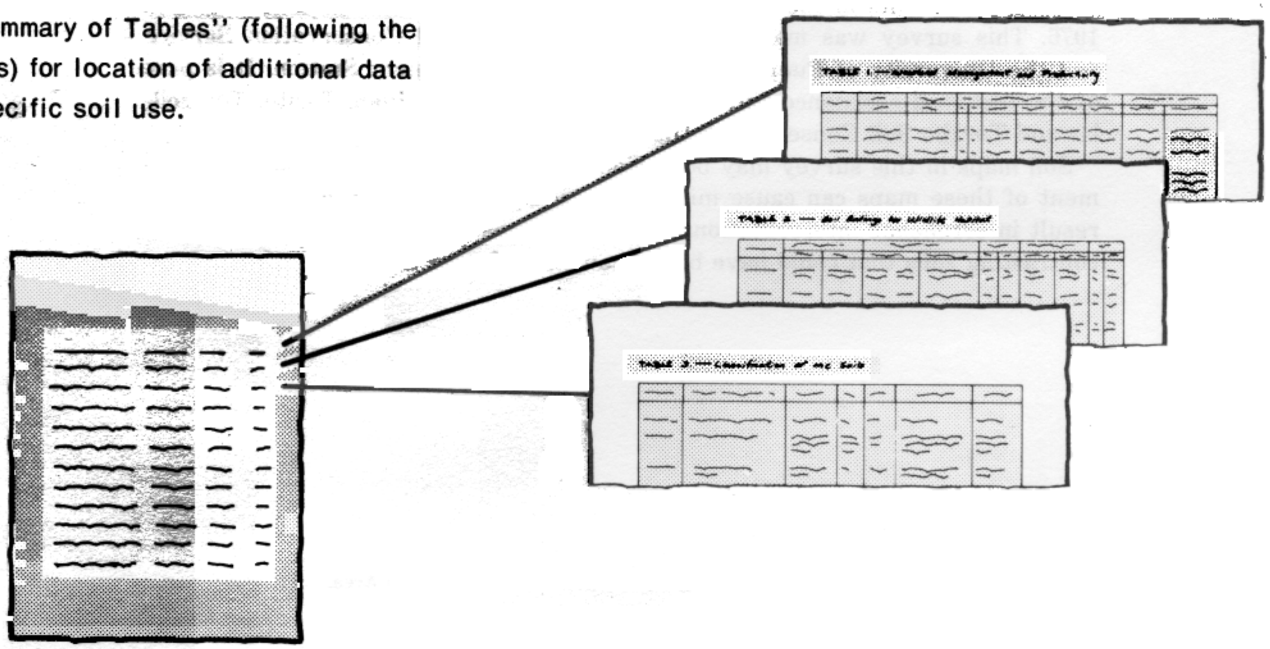


THIS SOIL SURVEY

Turn to "Index to Soil Mapping Units" which lists the name of each mapping unit and the page where that mapping unit is described.



6. See "Summary of Tables" (following the Contents) for location of additional data on a specific soil use.



Consult "Contents" for parts of the publication that will meet your specific needs. This survey contains useful information for farmers or ranchers, foresters or agronomists; for planners, community decision makers, engineers, developers, builders, or homebuyers; for conservationists, recreationists, teachers, or students; to specialists in wildlife management, waste disposal, or pollution control.

This is a publication of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and agencies of the States, usually the Agricultural Experiment Stations. In some surveys, other Federal and local agencies also contribute. The Soil Conservation Service has leadership for the Federal part of the National Cooperative Soil Survey. In line with Department of Agriculture policies, benefits of this program are available to all, regardless of race, color, national origin, sex, religion, marital status, or age.

Major fieldwork for this soil survey was completed in October 1972. Soil names and descriptions were approved in August 1973. Unless otherwise indicated, statements in the publication refer to conditions in the survey area in 1976. This survey was made cooperatively by the Soil Conservation Service and the University of Puerto Rico Agricultural Experiment Station. It is part of the technical assistance furnished to the Cibuco, San Juan, Torito, Torrecillas and Turabo Soil Conservation Districts.

Soil maps in this survey may be copied without permission, but any enlargement of these maps can cause misunderstanding of the detail of mapping and result in erroneous interpretations. Enlarged maps do not show small areas of contrasting soils that could have been shown at a larger mapping scale.

Cover: Contour plantings of bananas in the San Juan Area.

Contents

Contents—continued

Issued November 1978

Index to soil mapping units

Summary of Tables

Summary of Tables—Continued

Foreword

The Soil Survey of the San Juan Area contains much information useful in any land-planning program. Of prime importance are the predictions of soil behavior for selected land uses. Also highlighted are limitations or hazards to land uses that are inherent in the soil, improvements needed to overcome these limitations, and the impact that selected land uses will have on the environment.

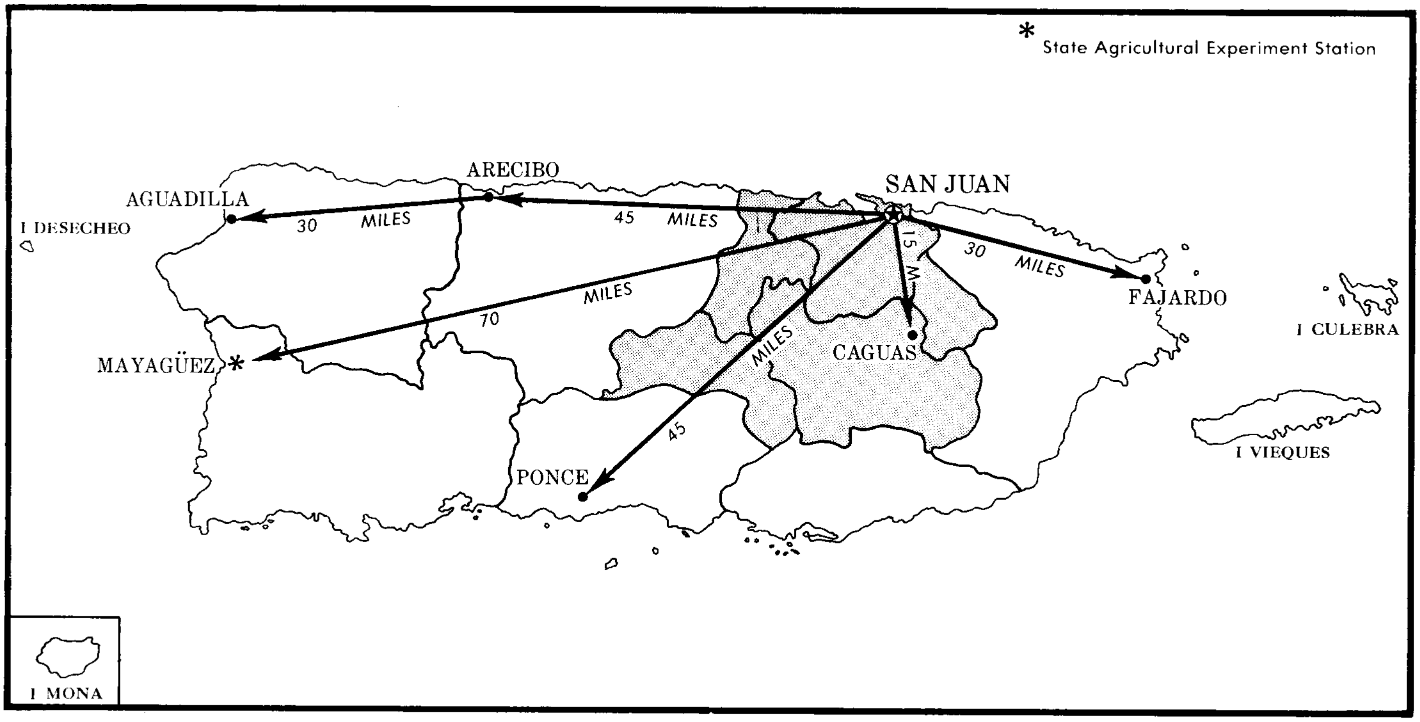
This soil survey has been prepared for many different users. Farmers, ranchers, foresters, and agronomists can use it to determine the potential of the soil and the management practices required for food and fiber production. Planners, community officials, engineers, developers, builders, and homebuyers can use it to plan land use, select sites for construction, develop soil resources, or identify any special practices that may be needed to insure proper performance. Conservationists, teachers, students, and specialists in recreation, wildlife management, waste disposal, and pollution control can use the soil survey to help them understand, protect, and enhance the environment.

Great differences in soil properties can occur even within short distances. Soils may be seasonally wet or subject to flooding. They may be shallow to bedrock. They may be too unstable to be used as a foundation for buildings or roads. Very clayey or wet soils are poorly suited to septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

These and many other soil properties that affect land use are described in this soil survey. Broad areas of soils are shown on the general soil map; the location of each kind of soil is shown on detailed soil maps. Each kind of soil in the survey area is described, and much information is given about each soil for specific uses. Additional information or assistance in using this publication can be obtained from the local office of the Soil Conservation Service or the Cooperative Extension Service.

This soil survey can be useful in the conservation, development, and productive use of soil, water, and other resources.

Angel Quintero
Director, Caribbean Area
Soil Conservation Service



Location of San Juan Area of Puerto Rico.

SOIL SURVEY OF SAN JUAN AREA OF PUERTO RICO

By Rafael A. Boccheciamp, Soil Conservation Service

Fieldwork by Rafael A. Boccheciamp, William Francia Rivera, Julio E. Trigo, G. Torres Ricci, Jose E. Brunet, and Luis H. Rivera, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service, in cooperation with the University of Puerto Rico, Agricultural Experiment Station

General nature of the area

The island of Puerto Rico is the smallest and farthest east of the four islands - Cuba, Jamaica, Hispaniola, and Puerto Rico - known as the Greater Antilles. It lies in the Torrid Zone. The north central coast of Puerto Rico is about 1,600 statute miles southeast of New York City, and the western part of the island is about 450 miles from the eastern point of Cuba. Ponce, on the south coast, is about 525 miles due north of Caracas, Venezuela.

The island was discovered by Christopher Columbus on his second voyage, November 19, 1493. The native inhabitants of the island, the friendly Taino Indians of the Arawak culture, lived in small villages, each ruled by a cacique, a chief. They grew food crops such as cassava and corn, and also tobacco and cotton. They also fished and hunted birds for their subsistence. They were clever at working stones, clay, and gold and adorned themselves with ornaments of these materials. The island was first settled in 1508 by Juan Ponce de Leon.

The San Juan Soil Survey Area is in northeast-central Puerto Rico (see facing page). It is bounded on the north by the Atlantic Ocean. San Juan, the capital of Puerto Rico, is in the northern part of the survey area. Mayaguez is 98 miles from San Juan. Ponce, the second largest city on the island, is 75 miles from the capital. The survey area covers an area of 447,279 acres. According to the census of 1970, the population totaled 1,172,609, of which 286,906 was rural and 885,703 urban. At that time there were 8,646 farms in the survey area.

The area consists of three major physiographic areas: the nearly level to sloping coastal plain, which is 10 percent of the area; the haystacks or limestone hills with their remarkable karst topography, which is about 4 percent; and the extensive igneous upland, which is 86 percent.

There are five soil conservation districts in the San Juan Soil Survey Area, namely: the Cibuco SCD, 80,101 acres, the municipalities of Corozal, Comerio, Naranjito, and Toa Alta; the San Juan SCD, 122,372 acres, the municipalities of Bayamon, Dorado, Toa Baja, Catano, Guaynabo, Rio Piedras, and Trujillo Alto; the Torito SCD, 74,533 acres, the municipalities of Cayey, Cidra, and Aguas Buenas; the Turabo SCD, 88,643 acres, the municipalities of Caguas, Gurabo, and San Lorenzo; and the Torrecillas SCD, 81,630 acres, the municipalities of Barranquitas, Aibonito, and Orocovis.

Farming is the principal enterprise of the area. Numerous industries, among which is the Consolidated Cigar Company, the largest cigar factory in the world, contribute to the welfare and economy of the island.

Improved pasture such as pangolagrass, stargrass, and Merker grass cover about 210,750 acres, or 47 percent of the area, according to the census of Agriculture of 1969. Most of the pastureland is used for raising beef and dairy cattle.

The principal cash and food crops of the area are plantains, taniers, yams, and tobacco. The total acreage is 89,353, or 20 percent of the area.

Woodland covers 72,239 acres, or 16 percent of the survey area.

Climate

In the San Juan Area of Puerto Rico the days are hot, except in January and February. The nights are warm all year. Winds from the Atlantic Ocean lower the afternoon temperatures on most days. Temperatures in the mountains of the interior are appreciably lower than elsewhere, but freezing temperatures are unknown anywhere in the area. Rainfall is abundant throughout the year in most of the area. The least falls in February and March. Except for the semiarid southernmost part, rainfall is heaviest in the mountains.

Tables 1 and 2 list data on temperature and precipitation for the survey area, as recorded at San Juan Airport for the period 1955 to 1974 and at Barranquitas, which is 2200 feet higher than San Juan, for the period 1963 to 1974.

In winter the average temperature at San Juan is 77 degrees F, and the average daily minimum temperature is 70. The lowest temperature on record, which occurred at

San Juan on March 3, 1957, is 60 degrees. In summer the average temperature is 82 degrees, and the average daily maximum temperature is 88. The highest recorded temperature, which occurred on June 21, 1972, is 96 degrees.

In winter the average temperature at Barranquitas is 69 degrees, and the average daily minimum temperature is 61. In summer the average temperature is 74 degrees, and the average daily maximum temperature is 82. The highest recorded temperature, which occurred on October 2, 1969, is 96 degrees.

Growing degree days, shown in tables 1 and 2, are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (60 degrees F).

Of the total annual precipitation at San Juan, 31 inches, or 56 percent, usually falls in April through September, which includes the growing season for most crops. In 2 years out of 10, the rainfall in April through September is less than 23 inches. The heaviest 1-day rainfall during the period of record was 5.01 inches at San Juan on August 6, 1955.

Of the total annual precipitation at Barranquitas, 28 inches, or 49 percent, usually falls in April through September. In 2 years out of 10, the rainfall during this period is less than 19 inches. The heaviest 1-day rainfall during the period of record at Barranquitas was 8.70 inches on October 9, 1970.

From June through November, an occasional tropical depression skirts or crosses the area and produces heavy rainfall that causes severe flooding. Thunderstorms number about 40 each year, 17 of which occur in summer. Every 10 to 20 years a hurricane causes wind damage and flooding.

The average relative humidity in midafternoon is about 65 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The percentage of possible sunshine is 60. The prevailing wind is from the northeast. Average windspeed is highest, 10 miles per hour, in March.

Climatic data in this section were specially prepared for the Soil Conservation Service by the National Climatic Center, Asheville, North Carolina.

How this survey was made

Soil scientists made this survey to learn what kinds of soil are in the survey area, where they are, and how they can be used. The soil scientists went into the area knowing they likely would locate many soils they already knew something about and perhaps identify some they had never seen before. They observed the steepness, length, and shape of slopes; the size of streams and the general pattern of drainage; the kinds of native plants or crops; the kinds of rock; and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material, which has been changed very little by leaching or by the action of plant roots.

The soil scientists recorded the characteristics of the profiles they studied, and they compared those profiles with others in areas nearby and in places more distant. Thus, through correlation, they classified and named the soils according to nationwide, uniform procedures.

After a guide for classifying and naming the soils was worked out, the soil scientists drew the boundaries of the individual soils on aerial photographs. These photographs show woodlands, buildings, field borders, roads, and other details that help in drawing boundaries accurately. The soil map at the back of this publication was prepared from aerial photographs.

The areas shown on a soil map are called soil map units. Some map units are made up of one kind of soil, others are made up of two or more kinds of soil, and a few have little or no soil material at all. Map units are discussed in the sections "General soil map for broad land use planning" and "Soil maps for detailed planning."

While a soil survey is in progress, samples of soils are taken as needed for laboratory measurements and for engineering tests. The soils are field tested, and interpretations of their behavior are modified as necessary during the course of the survey. New interpretations are added to meet local needs, mainly through field observations of different kinds of soil in different uses under different levels of management. Also, data are assembled from other sources, such as test results, records, field experience, and information available from state and local specialists. For example, data on crop yields under defined practices are assembled from farm records and from field or plot experiments on the same kinds of soil.

But only part of a soil survey is done when the soils have been named, described, interpreted, and delineated on aerial photographs and when the laboratory data and other data have been assembled. The mass of detailed information then needs to be organized so that it is readily available to different groups of users, among them farmers, managers of rangeland and woodland, engineers, planners, developers and builders, homebuyers, and those seeking recreation.

General soil map for broad land use planning

The general soil map at the back of this publication shows, in color, map units that have a distinct pattern of soils and of relief and drainage. Each map unit is a unique natural landscape. Typically, a map unit consists of one or more major soils and some minor soils. It is named for the major soils. The soils making up one unit can occur in other units but in a different pattern.

The general soil map provides a broad perspective of the soils and landscapes in the survey area. It provides a basis for comparing the potential of large areas for general kinds of land use. Areas that are, for the most part, suited to certain kinds of farming or to other land uses can be identified on the map. Likewise, areas of soils having properties that are distinctly unfavorable for certain land uses can be located.

Because of its small scale, the map does not show the kind of soil at a specific site. Thus, it is not suitable for planning the management of a farm or field or for selecting a site for a road or building or other structure. The kinds of soil in any one map unit differ from place to place in slope, depth, stoniness, drainage, or other characteristics that affect their management.

The soils in the survey area vary widely in their potential for major land uses. Table 3 shows the extent of the map units shown on the general soil map and gives general ratings of the potential of each, in relation to the other map units, for major land uses. Soil properties that pose limitations to the use are indicated. The ratings of soil potential are based on the assumption that practices in common use in the survey area are being used to overcome soil limitations. These ratings reflect the ease of overcoming the soil limitations and the probability of soil problems persisting after such practices are used.

Each map unit is rated for *cultivated farm crops, specialty crops, woodland, urban uses,* and *recreation areas.* Cultivated farm crops are those grown extensively by farmers in the survey area. Specialty crops include vegetables, fruits, and nursery crops grown on limited acreage and generally requiring intensive management. Woodland refers to land that is producing either trees native to the area or introduced species. Urban uses include residential, commercial, and industrial developments. Intensive recreation areas include campsites, picnic areas, ballfields, and other areas that are subject to heavy foot traffic. Extensive recreation areas include those used for nature study and as wilderness.

Map unit descriptions

Soils formed in residuum from basic volcanic rocks

These map units are in the central and southern parts of the soil survey area. The soils formed mainly in clayey material weathered from basic volcanic rocks. They are mostly steep to very steep. A few are gently sloping to sloping. V-shaped drainageways dissect the entire area. Many of the soils in the humid area are planted to clean cultivated crops regardless of the steepness of slope and hazard of erosion. The Descalabrado unit, in the southern part of the survey area, is mostly brushy pasture. The semiarid climate, steepness of slope, and shallow depth to bedrock make it unsuited to cultivated crops.

1. Maricao-Los Guineos

Deep, steep to very steep, well drained and moderately well drained soils of the humid mountainous areas

This unit is in the southeastern part of the survey area. The soils formed in residuum weathered from basic volcanic rocks. They are steep to very steep. They are used for food crops, pasture, and forest. They receive moisture throughout the year and are not deficient in moisture needed for the common crops.

This unit occupies 10 percent of the total acreage. The landscape is mountainous and is strongly dissected by intermittent streams. Steep to very steep side slopes and ridges are common.

The Maricao soils are deep to hard rock, well drained, and clayey. They are on strongly dissected uplands where slope gradients are 20 to 60 percent. They occupy about 55 percent of the unit.

The Los Guineos soils are deep to hard rock, moderately well drained, and clayey. They are on side slopes having gradients of 20 to 60 percent. They occupy about 40 percent of the unit.

The remaining 5 percent of the unit is made up of the deep, well drained, clayey Humatas soils.

This unit in general has severe limitations for farming because of the slope and the erosion hazard. Complex conservation practices and good management are needed in order to produce crops. These soils are best suited to grasses and trees. Steep slopes and the erosion hazard make fieldwork costly and difficult.

2. Humatas-Naranjito-Consumo

Deep to moderately deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, the second largest, makes up 29 percent of the total acreage. It is in the mountainous section of the survey area. The landscape is one of gently sloping foot slopes to very steep side slopes and ridges that are dissected by intermittent streams. These soils formed in the residuum of weathered basic volcanic rocks and siltstone. They are used for food crops and pasture. They receive adequate moisture throughout the year for the crops commonly grown.

The Humatas soils are deep, well drained, and clayey. They are on mountainsides where slope gradients are 20 to 60 percent. They make up about 36 percent of the unit.

The Naranjito soils are moderately deep, 20 to 40 inches to hard consolidated volcanic rocks, and are well drained and clayey. They are on strongly dissected uplands where slope gradients are 12 to 60 percent. They make up about 29 percent of the unit.

The Consumo soils are deep but have very highly weathered rock at a depth of 14 to 24 inches. They are well drained, clayey soils on the side slopes of naturally dissected uplands where slope gradients are 20 to 60 percent. They occupy about 17 percent of the unit.

The remaining 18 percent consists of the deep, well drained, clayey Daguey, Aceitunas, and Rio Piedras soils and the somewhat poorly drained Lares soils.

This unit in general has severe limitations for cultivated crops because of the slope and the erosion hazard.

The less steep slopes are suitable for cultivation if complex soil conservation practices are applied and the soils are well managed. Liming and fertilizing are necessary for better crop yields. The use of machinery is not feasible on most of this unit. The slope is a severe limitation for buildings or other developments.

3. Mucara-Caguabo

Moderately deep to shallow, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, the largest, makes up about 39 percent of the total survey area. The landscape is mountainous and is highly dissected by intermittent streams. Narrow ridges are common. This unit is in the humid mountainous region of the survey area extending from the vicinity of Orocovis to San Lorenzo.

The Mucara soils are moderately deep, 20 to 40 inches to semiconsolidated rock, and are well drained and clayey. They are on side slopes of strongly dissected uplands where slope gradients are 12 to 60 percent. They make up about 58 percent of the unit.

The Caguabo soils are shallow to hard rock, well drained, and loamy. They are on side slopes and ridgetops where slope gradients are 20 to 60 percent. They make up about 37 percent of the unit. In some areas the surface of these soils is covered with stones.

The remaining 5 percent consists of the well drained, loamy Morado and Sabana soils and the moderately well drained, clayey Juncos soils. The Morado and Sabana soils occupy similar positions on the landscape as the Mucara and Caguabo soils. The Juncos soils, which are more gently sloping, occupy the side slopes and foot slopes of strongly dissected uplands.

This unit in general is not suitable for cultivation because of the slope, erosion hazard, rapid runoff, and depth to rock. It is suitable for pasture and woodland. A large acreage is in brush and brushy native pasture. Some areas have been cleared and planted to pangolagrass. Small patches are in food crops. Steep slopes, the erosion hazard, and the depth to rock are permanent limitations that preclude the use of these soils for clean cultivation. Fieldwork is difficult and costly. The soils have severe limitations for nonfarm uses such as dwellings, roads, recreational facilities, and other intensive developments.

4. Descalabrado

Shallow, very steep, well drained soils of the semiarid mountainous areas

This unit is in the southern part of the survey area. The soils formed in the residuum of weathered basic volcanic rocks. They do not receive enough rainfall throughout the year and are deficient in moisture needed for growing common cultivated crops. The topography is rugged and very steep. This unit makes up 1 percent of the total survey area.

The Descalabrado soils are shallow to volcanic rock and well drained. They are on side slopes where slope gradients are 40 to 60 percent. They make up 91 percent of the unit. The remaining 9 percent consists of boulders and the shallow, well drained, acid Guayama soils.

Because of the low rainfall of the area, most of the soils are in native guineagrass and brush. Clean tilled crops are not suited because of the slopes, depth to rock, and moisture deficiency. Most of the plant cover dies during long periods of drought.

Soils formed in residuum from intrusive igneous rocks

This unit is in the southeastern part of the survey area near the town of San Lorenzo. The soils formed mainly in the residuum of granitic rocks. Most are steep and very steep. The landscape is mountainous, with V-shaped drainageways dissecting the entire area and with narrow, knife-like ridges, gullies, and slips. Some of the soils are planted to clean cultivated food crops, but many are in native and improved pasture. Most soils in this unit have low potential for crops because of the steep slopes and shallow depth to the granitic rock.

5. Pandura-Lirios

Shallow to deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, one of the smaller, makes up 7 percent of the total acreage of the soil survey area. It is in the vicinity of San Lorenzo. The soils formed in the residuum of granitic rock that is part of the San Lorenzo Batholith. The landscape is mountainous and is highly dissected by numerous intermittent streams. Narrow ridges, gullies, and slip areas are common.

The Pandura soils are shallow to weathered granitic rocks, well drained, loamy, moderately steep to steep. They are on side slopes of the granitic uplands where slope gradients are 12 to 60 percent. They make up about 62 percent of the unit.

The Lirios soils are deep, but highly weathered granitic rock is at a depth of 20 to 34 inches. These are well drained, steep to very steep soils with a clayey subsoil. They are on side slopes and narrow ridgetops where slope gradients are 20 to 60 percent. They make up 26 percent of the unit.

The remaining 12 percent of the unit is made up of the deep, well drained, clayey Limones and Jagueyes soils and the somewhat poorly drained, clayey Cayagua soils. The Limones and Jagueyes soils are on side slopes and narrow ridgetops where slope gradients are 20 to 60 percent.

This unit in general has severe limitations for farming because of the slope, erosion hazard, and low fertility of the soils. It has been intensively cultivated for food crops. Some areas are in improved pasture. Others are in brush and brushy pasture.

Steep slopes and the erosion hazard are permanent limitations that preclude the use of these soils for clean cultivated crops. The slope is a severe limitation for nonfarm uses such as dwellings, septic tanks, recreational areas, and other intensive developments.

Soils formed in residuum from limestone

This unit is in the northwestern part of the survey area. The soils formed mainly in clayey materials weathered from limestone. Many are steep and very steep. Some are nearly level to sloping. The landscape has a karst topography, which is characterized by haystack hills, locally known as "mogotes;" sinkholes; and underground drainage. Most of the soils are in brushy forest. Others are in native and improved pasture. The soils have low potential for clean cultivated crops.

6. Tanama-Colinas-Soller

Shallow to moderately deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit makes up 4 percent of the total acreage of the survey area. The landscape is one of karst topography characterized by the brush-covered "mogotes," or haystack hills. This unit is in the northwestern part of the survey area, between the northern coastal plains and the uplands. The soils of this unit are severely limited for farming because of the steep slopes and the shallow to moderate depth to limestone rock. Some have been cleared of brushy vegetation and planted to pangolagrass. A large part, however, is still in brush and brushy pasture.

The Tanama soils are shallow, are well drained, and have a clayey subsoil. They have slope gradients of 20 to 60 percent. They make up 39 percent of the unit.

The Colinas soils are moderately deep to mixed soft limestone, are well drained, and have a clayey subsoil. They have slope gradients of 12 to 60 percent. They make up 29 percent of the unit.

The Soller soils are shallow to hard fragmental limestone, are well drained, and have a thin clayey subsoil. They have slope gradients of 20 to 60 percent. They make up 28 percent of the unit.

The remaining 4 percent of the unit consists of the deep, well drained, clayey Juncal soils and areas of limestone rockland.

Soils formed in transported materials

Most of these units are in the northern part of the soil survey area. Some are in inner valleys in the central part. The soils formed mainly in clayey sediments of mixed origin and in organic materials. They are mainly nearly level to sloping. They are on the coastal plains, on flood plains, in inner valleys, and in low depressional and lagoonlike positions. Many are planted to clean cultivated crops to which they are well suited. Soils in the Martin Pena-Saladar-Hydraquents unit, however, are very poorly drained and are therefore limited for farming.

7. Almirante-Vega Alta-Matanzas

Deep, gently sloping to sloping, well drained soils on terraces and alluvial fans of the coastal plain

This unit occupies 3 percent of the total acreage. It consists of gently sloping to sloping soils on coastal plains, on terraces, and in valleys between the limestone hills. It is in the northern section of the survey area.

The Almirante soils are deep, well drained, and clayey. They are on coastal plains where slope gradients are 2 to 12 percent. They make up about 55 percent of the unit.

The Vega Alta soils are deep, well drained, and clayey. They are gently sloping to sloping. They are on coastal plains and terraces where slope gradients are 2 to 12 percent. They make up about 21 percent of the unit.

The Matanzas soils are deep, well drained, and clayey. They are on foot slopes and in small valleys between the limestone hills. They have slope gradients of 2 to 5 percent. They make up about 11 percent of the unit.

The remaining 13 percent of the unit is made up of the deep, gently sloping, well drained, clayey Bayamon and Torres soils. These soils are on coastal plain terraces and alluvial fans.

This unit is suited to farming. Most of it was used for sugarcane but is now in improved pasture such as pangolagrass and stargrass. The soils of this unit should be limed, fertilized, and worked at the proper moisture condition to prevent puddling. They receive adequate moisture throughout the year for the crops commonly grown. For nonfarm uses, they have only slight limitations.

8. Toa-Bajura-Coloso

Deep, nearly level, well drained to poorly drained soils on flood plains

This unit is in the northern part of the survey area. The soils formed in mixed sediments derived from miscellaneous volcanic rocks and deposited over nearly level river flood plains. They receive adequate moisture throughout the year for the cultivated crops commonly grown. Most of these soils were intensively cultivated for sugarcane. The trend now is toward improved pasture, such as pangolagrass and stargrass. This unit makes up 4 percent of the total acreage of the survey area.

The Toa soils are deep, are moderately well drained to well drained, are moderately permeable, and have a clayey subsoil. They make up 32 percent of the unit.

The Bajura soils are deep, are poorly drained, are slowly permeable, and have a clayey subsoil. They make up 27 percent of the unit.

The Coloso soils are deep, somewhat poorly drained, slowly permeable soils with a clayey subsoil. They make up 17 percent of the unit.

The remaining 24 percent of the unit consists of the nearly level, moderately deep, moderately permeable Estacion soils and the deep, well drained, sandy Reilly soils and areas of riverwash.

These soils have severe limitations for nonfarm uses such as dwellings, septic tanks, and roads because of poor drainage and the flood hazard.

9. Mabi-Rio Arriba

Deep, nearly level to sloping, moderately well drained to somewhat poorly drained soils on terraces, footslopes, and alluvial fans of inner valleys

This unit is in the east-central part of the survey area. The soils formed in fine textured sediments of mixed origin. They receive adequate moisture throughout the year for most crops.

This small unit makes up 2 percent of the total acreage of the survey area. Most of the soils were used for sugarcane production. The trend now is toward improved pasture, such as pangolagrass.

The mabi soils are deep, somewhat poorly drained, slowly permeable, clayey soils. They have slope gradients of 0 to 12 percent. They make up 54 percent of the unit.

The Rio Arriba soils are deep, moderately well drained, moderately slowly permeable soils with a clayey subsoil. They have slope gradients of 2 to 12 percent. They make up 41 percent of the unit.

The remaining 5 percent is the deep, poorly drained, clayey Montegrande soil.

The soils of this unit have severe limitations for nonfarm uses because of their clayey nature and high shrink-swell potential.

10. Martin Pena-Saladar-Hydraquents

Deep, nearly level, very poorly drained soils in low depressions and lagoons of the coastal plain

This unit occupies 1 percent of the total acreage of the survey area. The landscape consists of low-lying depressions filled with water most of the year. This unit is in the northwestern part of the coastal plain, in the vicinity of Dorado.

The Martin Pena soils are deep and very poorly drained. They have a thin surface layer of muck underlain by clayey material. They make up 51 percent of the unit.

The Saladar soils are deep, very poorly drained muck. They make up about 23 percent of the unit.

Hydraquents formed in variable materials in tidal marshes that are permanently saturated with brackish water. These soils have no sulfidic materials within 50 centimeters of the mineral surface. They make up 12 percent of the unit.

The remaining 14 percent of the unit is made up of the deep, excessively drained Catano and Durados soils. These soils occupy a nearly level area of the coastal plain in the northwestern part of the survey area.

These soils have severe limitations for farming because of very poor drainage. Complex drainage practices are needed if they are to be reclaimed. For nonfarm uses, they also have severe limitations because of very poor drainage and low bearing capacity. It is necessary to sink pilings and use other complex engineering practices.

The soils of this unit are in an area of intensive development, and most of this area is being reclaimed for dwellings.

Soil maps for detailed planning

The map units shown on the detailed soil maps at the back of this publication represent the kinds of soil in the survey area. They are described in this section. The descriptions together with the soil maps can be useful in determining the potential of a soil and in managing it for food and fiber production; in planning land use and developing soil resources; and in enhancing, protecting, and preserving the environment. More information for each map unit, or soil, is given in the section "Use and management of the soils."

Preceding the name of each map unit is the symbol that identifies the soil on the detailed soil maps. Each soil description includes general facts about the soil and a brief description of the soil profile. In each description, the principal hazards and limitations are indicated, and the management concerns and practices needed are discussed.

The map units on the detailed soil maps represent an area on the landscape made up mostly of the soil or soils for which the unit is named. Most of the delineations shown on the detailed soil map are phases of soil series.

Soils that have a profile that is almost alike make up a *soil series*. Except for allowable differences in texture of the surface layer or of the underlying substratum, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement in the profile. A soil series commonly is named for a town or geographic feature near the place where a soil of that series was first observed and mapped.

Soils of one series can differ in texture of the surface layer or in the underlying substratum and in slope, erosion, stoniness, salinity, wetness, or other characteristics that affect their use. On the basis of such differences, a soil series is divided into phases. The name of a *soil phase* commonly indicates a feature that affects use or management. For example, Colinas clay loam is one of several phases within the Colinas series.

Some map units are made up of two or more dominant kinds of soil. Such map units are called soil complexes, soil associations, and undifferentiated groups.

A *soil complex* consists of areas of two or more soils that are so intricately mixed or so small in size that they cannot be shown separately on the soil map. Each area includes some of each of the two or more dominant soils, and the pattern and proportion are somewhat similar in all areas. Urbanland-Mucara complex is an example.

A *soil association* is made up of soils that are geographically associated and are shown as one unit on the map because it is not practical to separate them. A soil association has considerable regularity in geographic pattern and in the kinds of soil that are a part of it. The extent of the soils can differ appreciably from one delineation to another; nevertheless, interpretations can be made for use and management of the soils.

An *undifferentiated group* is made up of two or more soils that could be mapped individually but are mapped as one unit because there is little value in separating them. The pattern and proportion of the soils are not uniform. An area shown on the map has at least one of the dominant (named) soils or may have all of them.

Most map units include small, scattered areas of soils other than those that appear in the name of the map unit. Some of these soils have properties that differ substantially from those of the dominant soil or soils and thus could significantly affect use and management of the map unit. These soils are described in the description of each map unit. Some of the more unusual or strongly contrasting soils that are included are identified by a special symbol on the soil map.

Most mapped areas include places that have little or no soil material and support little or no vegetation. Such places are called *miscellaneous areas*; they are delineated on the soil map and given descriptive names. Made land is an example. Some of these areas are too small to be delineated and are identified by a special symbol on the soil map.

The acreage and proportionate extent of each map unit are given in table 4, and additional information on properties, limitations, capabilities, and potentials for many soil uses is given for each kind of soil in other tables in this survey. (See "Summary of tables.") Many of the terms used in describing soils are defined in the Glossary.

Soil descriptions

AaB—Aceitunas clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on terraces and alluvial fans. Slopes are smooth and are 100 to 500 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is dark brown friable clay about 8 inches thick. The subsoil, to a depth of 60 inches, is yellowish red clay. It is firm to a depth of 30 inches and is friable from 30 inches to a depth of 60 inches.

Included with this soil in mapping are some small areas of Rio Arriba and Lares soils. The surface layer of the Rio Arriba soils is brown clay and that of the Lares soils is dark brown clay. These soils make up 10 to 20 percent of the acreage.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work because of the stickiness and plasticity of the clay. It should be tilled at the optimum moisture content to avoid puddling and the formation of large clods. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane, plantains, and taniers. It is best suited, however, to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately suited to most urban uses because of its clayey nature. If the soil is used as construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIe.

AaC—Aceitunas clay, 5 to 12 percent slopes. This is a sloping, well drained soil on terraces and alluvial fans. Slopes are smooth and are 100 to 800 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark brown friable clay about 8 inches thick. The subsoil, to a depth of 60 inches, is yellowish red clay. It is firm to a depth of 30 inches and is friable from 30 inches to a depth of 60 inches.

Included with this soil in mapping are some small areas of Rio Arriba, Lares, and Via soils. The surface layer of the Rio Arriba soils is brown clay and that of the Lares soils is dark brown clay. The surface layer of the Via soils is dark brown clay loam. These soils make up 15 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work because of the stickiness and plasticity of the clay. It should be tilled at the optimum moisture content to avoid puddling and the formation of large clods. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane, plantains, and taniers. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately suited to urban uses because of the slope and its clayey nature. If the soil is used as construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIIe.

AbD—Aibonito clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on ridgetops and side slopes of strongly dissected volcanic uplands. Slopes are 400 to 800 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is dark grayish brown, friable clay about 7 inches thick. The subsoil is about 36 inches thick; it is strong brown clay mottled with red and yellowish brown. The substratum, beginning at a depth of 43 inches, is red, strong brown, and white, friable clay saprolite to a depth of 65 inches and silty clay saprolite from 65 to 110 inches.

Included with this soil in mapping are small areas of Humatas, Consumo, and Los Guineos soils. The surface layer of the Humatas soils is dark brown clay, that of the Consumo soils is reddish brown clay, and that of the Los Guineos soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. The soil is medium in natural fertility and has a deep root zone. It is difficult to work because of slope and the stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for such crops as plantains, taniers, and yams. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, mahogany, kadam, mahoe, and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and a temporary plant cover established quickly in denuded areas. Capability subclass IVe.

AbE—Aibonito clay, 20 to 40 percent slopes. This is a steep, well drained soil on ridgetops and side slopes of strongly dissected uplands. Slopes are 400 to 1000 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark grayish brown, friable clay about 7 inches thick. The subsoil is about 36 inches thick; it is strong brown clay mottled with red and yellowish brown. The substratum, beginning at a depth of 43 inches, is red, strong brown, and white, friable clay saprolite to a depth of 65 inches and silty clay saprolite from 65 to 110 inches.

Included with this soil in mapping are small areas of Humatas, Consumo, and Los Guineos soils. The surface layer of the Humatas soils is dark brown clay; that of the Consumo soils is reddish brown clay; and that of the Los Guineos is dark yellowish brown clay. These soils make up 15 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. This soil is medium in natural fertility, and it has a deep root zone. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for such crops as plantains, taniers, and yams. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

AmB—Almirante clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on coastal plains and in valleys between the limestone hills. Slopes are smooth and are 800 to 1500 feet long. The areas range from 20 to 600 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is firm clay to a depth of 60 inches. From 7 to 34 inches, it is strong brown; from 34 to 46 inches, it is brownish yellow and dark red; and from 46 to 60 inches, it is variegated brownish yellow, dark red, and light gray.

Included with this soil in mapping are small areas of the Vega Alta, Matanzas, and Bayamon soils. The surface layer of the Vega Alta soils is dark yellowish brown clay loam, and that of the Matanzas and Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work due to the stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is a major concern of management.

This soil has been used for sugarcane. It is best suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because of its clayey nature. Capability subclass IIe.

AmC—Almirante clay, 5 to 12 percent slopes. This is a sloping, well drained soil on coastal plains and in valleys between the limestone hills. Slopes are smooth and are 400 to 1000 feet long. The areas range from 10 to 400 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is firm clay to a depth of 60 inches. From 7 to 34 inches, it is strong brown; from 34 to 46 inches, it is brownish yellow and dark red; and from 46 to 60 inches, it is variegated brownish yellow, dark red, and light gray.

Included with this soil in mapping are small areas of Vega Alta, Matanzas, and Bayamon soils. The surface layer of the Vega Alta soils is dark yellowish brown clay loam; that of the Matanzas and Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work due to stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is a major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because of its clayey nature. Capability subclass IIIe.

Ba—Bajura clay. This is a nearly level, poorly drained soil on river flood plains. Slopes are smooth and are 500 to 2000 feet long. The areas range from 20 to 1000 acres.

Typically the surface layer is dark brown, firm clay about 5 inches thick. The subsoil, about 7 inches thick, is dark gray, firm clay mottled with yellowish brown, very dark gray, and dark brown. The substratum, from a depth of 12 inches to 31 inches, is gray and yellowish brown, firm clay mottled with greenish gray. From 31 inches to 60 inches, the substratum is greenish gray, firm clay mottled with brownish yellow and bluish gray.

Included with this soil in mapping are small areas of the Coloso soils. The surface layer of the Coloso soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow and the available water capacity is high. This soil is difficult to work due to stickiness and plasticity of the clay and wetness. It is fertile and has a deep root zone. When properly drained and managed, it is suited to crops (fig. 1).

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and paragrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of drainage, flood hazard, and high shrink-swell potential. Capability subclass IIIw.

BmB—Bayamon clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on foot slopes and in small valleys between the limestone hills. Slopes are 500 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark reddish brown, friable clay about 8 inches thick. The subsoil, to a depth of 66 inches is weak red and red, firm to friable clay.

Included with this soil in mapping are small areas of Matanzas soils. The surface layer of the Matanzas soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is medium, and the hazard of erosion is slight to moderate. This soil is difficult to work because of the stickiness and plasticity of the clay. It is medium in natural fertility and has a deep root zone. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion and maintaining natural fertility are the major concerns of management.

This soil has been used for sugarcane and pineapples. It is suited to pangolagrass, stargrass, and Merker grass (fig. 2).

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has slight to moderate limitations for most urban uses. If the soil is used for construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIe.

CaE—Caguabo clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and tops of strongly dissected uplands. Slopes are 500 to 1000 feet long. The areas range from 20 to 800 acres.

Typically the surface layer is dark grayish brown, friable clay loam about 4 inches thick. The next layer is brown, friable very gravelly clay loam about 6 inches thick. The substratum, beginning at a depth of 10 inches, is a mixture of weathered and partially weathered volcanic rocks. Consolidated rock is at a depth of 16 inches.

Included with this soil in mapping are small areas of Mucara, Naranjito, and Consumo soils and a few rocky hilltops. The surface layer of the Mucara soils is very dark grayish brown clay; that of the Naranjito soils is dark brown silty clay loam; and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate in this soil, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and shallow. Hillside ditches and diversions are difficult to lay out, establish, and maintain. This soil is fertile but has a shallow root zone. Controlling erosion is the major concern of management.

This soil has been used for tobacco and food crops such as sweet potatoes, bananas, and coffee. It is best suited to pangolagrass and stargrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, eucalyptus, and mahogany trees. Production of Honduras pine is low, about 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep, shallow, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

CaF—Caguabo clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and mountaintops of strongly dissected uplands. Slopes are 400 to 800 feet long. The areas range from 20 to 2000 acres.

Typically the surface layer is dark grayish brown, friable clay loam about 4 inches thick. The next layer is about 5 inches thick; it is brown, friable very gravelly clay loam. The substratum, beginning at a depth of 10 inches, is a mixture of weathered and partially weathered volcanic rocks. Consolidated rock is at a depth of 16 inches.

Included with this soil in mapping are small areas of Mucara and Naranjito soils and a few spots that have many boulders and stones on the surface. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Naranjito soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and shallow. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The soil is fertile but has a shallow root zone. Controlling erosion is the major concern of management.

This soil has been used for tobacco and food crops such as sweet potatoes, bananas, and coffee. It is best suited, however, to pangolagrass and stargrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is low, about 700 to 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep, shallow, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

CbF—Caguabo-Rock outcrop complex, 40 to 60 percent slopes. This complex consists of very steep, well drained soils and Rock outcrop on side slopes and narrow ridges. The areas range from 10 to 500 acres. The complex is about 60 percent Caguabo clay loam and 40 percent Rock outcrop and other minor soils. Caguabo and Rock outcrop form such an intricate pattern that they were not separated in mapping.

In a representative profile of Caguabo clay loam the surface layer is about 3 inches thick. The next layer, about 5 inches thick, is brown, friable very gravelly clay loam. It is underlain by a mixture of weathered and partially weathered volcanic rocks. Volcanic bedrock is at a depth of 10 to 20 inches.

Included with this soil complex in mapping are spots of deeper soils that formed between the rock outcrops. Also included are some areas of severely eroded Caguabo soils that have a thin surface layer of brown to dark grayish brown clay loam. These soils are on ridgetops.

Permeability is moderate in the Caguabo soil, and the available water capacity is low. The root zone is shallow. Tilth is fair to poor. Surface runoff is very rapid. In unlimed areas the soil is slightly acid.

The vegetation is shrubs, brush, and grass. This complex is not suited to cultivated crops. The potential for pasture is low. The Caguabo soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is low, about 700 board feet per acre per year. The hazard of erosion and the limitations on the use of equipment are moderate. Logging roads, skid trails, and machine plantings should be on the contour to help control erosion. The use of equipment is restricted mainly by the very steep slopes and the many rock outcrops.

This complex is poorly suited to most urban uses, mainly because of the very steep slopes and shallow depth to the volcanic rock, which is at a depth of 10 to 20 inches. Most of the areas are subject to slides. Erosion is a severe hazard in areas not protected by vegetative cover. In areas that are used as construction sites, development should be on the contour. Removal of vegetative cover should be held to a minimum, and plant cover established quickly on denuded areas. Capability subclass VIIIs.

Ce—Candelero loam. This is a gently sloping, somewhat poorly drained soil on terraces, alluvial fans, and foot slopes. Slopes are undulating and are 100 to 800 feet long. The areas range from 30 to 100 acres.

Typically the surface layer is dark grayish brown loam about 6 inches thick. The subsoil from 6 inches to a depth of 35 is mainly dark brown, dark gray, and very dark gray, firm sandy clay loam mottled with yellowish brown, greenish gray, and brownish yellow. From 35 inches to a depth of 60 inches, the subsoil is brownish yellow and yellowish brown, firm sandy clay mottled with gray, greenish gray, and yellowish red.

Included with this soil in mapping are small areas of Cayagua soils. The surface layer of the Cayagua soils is dark grayish brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is medium. This soil is difficult to work due to wetness and the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, Merker grass, and paragrass.

This soil is limited for most urban uses because of wetness, flood hazard, and its clayey nature. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

ClC—Catalina clay, 4 to 12 percent slopes. This is a sloping, well drained soil on side slopes and hilltops of the humid uplands. Slopes are 300 to 400 feet long. The areas range from 10 to 150 acres.

Typically the surface layer is dark reddish brown, friable clay about 6 inches thick. The subsoil layers from 6 inches to a depth of 84 inches are reddish brown and dark reddish brown firm clay. From 84 to 99 inches, the subsoil is variegated dusky red, dark reddish brown, and strong brown clay.

Included with this soil in mapping are small areas of Humatas, Daguey, and Consumo soils. The surface layer of the Humatas and Daguey soils is dark brown clay, and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains, yams, taniers, and coffee. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses due to slope, its clayey nature, and seepage. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Cn—Catano loamy sand. This is a nearly level, excessively drained soil on narrow strips of the coastal plain. The areas range from 20 to 200 acres.

Typically the surface layer of this soil is very dark grayish brown loamy sand about 7 inches thick. The next layer is about 16 inches thick; it is dark brown, loose sand. The substratum, beginning at a depth of 23 inches, is dark grayish brown, loose sand.

Included with this soil in mapping are small areas of Durados soils. The surface layer of the Durados soils is very dark grayish brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very slow. This soil is easily worked. The root zone is deep, but natural fertility is low. The soil is very limited for farming.

This soil has been used for growing coconuts. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to most urban uses. Capability subclass VIs.

Co—Cayagua sandy loam. This is a sloping, poorly drained soil on alluvial fans. Slopes are 200 to 800 feet long. The areas range from 50 to 300 acres.

Typically the surface layer is dark grayish brown, friable sandy loam about 8 inches thick. The subsoil is about 24 inches thick; it is yellowish brown and light olive gray, firm clay mottled with red, yellowish red, strong brown, and gray. The substratum, beginning at a depth of 32 inches, is yellowish brown, white, and gray, friable, sandy clay loam saprolite.

Included with this soil in mapping are some areas of Candelero soils. The surface layer of the Candelero soils is dark grayish brown loam. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of wetness. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of wetness, seepage, and slope. If the soil is used as construction sites, development should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

CrD2—Colinas clay loam, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on ridgetops and side slopes of low rolling hills. Slopes are convex and are 200 to 500 feet long. The areas range from 10 to 300 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white, soft limestone.

Included with this soil in mapping are small areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam; that of the

Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the surface layer. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, mahoe, and teak trees. Production of Honduras mahogany is very low, about 450 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

CrE2—Colinas clay loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on ridgetops and side slopes of low hills. Slopes are convex and are 100 to 300 feet long. The areas range from 20 to 400 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white soft limestone.

Included with this soil in mapping are some areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam, and that of the Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the surface layer. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is very low, about 350 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

CrF2—Colinas clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on ridgetops and side slopes of hills. Slopes are convex and are 100 to 400 feet long. The areas range from 50 to 300 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white soft limestone.

Included with this soil in mapping are some areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam, and that of the Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the surface layer. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass.

Proper stocking rates and deferred grazing are chief management needs.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Cs—Coloso silty clay loam. This is a nearly level, somewhat poorly drained soil on river flood plains. Slopes are smooth and 200 to 1000 feet long. The areas range from 100 to 600 acres.

Typically the surface layer is dark brown, friable silty clay loam about 7 inches thick. The underlying material from 7 to 16 inches is dark brown and dark yellowish brown, friable silty clay loam, from 16 to 32 inches is dark grayish brown and light gray silty clay loam mottled with dark yellowish brown, and from 32 to 70 inches is greenish gray silty clay mottled with yellowish red and yellowish brown.

Included with this soil in mapping are small areas of Toa and Bajura soils. The surface layer of the Toa soils is dark brown silty clay loam, and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the wetness and the stickiness and plasticity of the surface layer. The root zone is deep. This soil is fertile. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane (fig. 3). It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because it is somewhat poorly drained, too clayey, and subject to overflow. Capability subclass IIw.

CuE—Consumo clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of maturely dissected humid uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 100 to 800 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is reddish brown friable clay about 10 inches thick. The subsoil is about 10 inches thick; it is yellowish red, friable clay. The substratum, beginning at a depth of 20 inches, is red, brownish yellow, and yellowish red, very friable, silty clay loam saprolite.

Included with this soil in mapping are spots of Humatas, Naranjito, and Mucara soils. The surface layer of the Humatas soils is dark brown clay, and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Mucara soils is very dark grayish brown clay. These included soils make up about 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management. This soil has been used for crops such as coffee. It is suited to pangolagrass and to molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

CuF—Consumo clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of maturely dissected humid uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 100 to 1000 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is reddish brown friable clay about 10 inches thick. The subsoil is about 10 inches thick; it is yellowish red, friable clay. The substratum, beginning at a depth of 20 inches, is red, brownish yellow, and yellowish red, very friable, silty clay loam saprolite.

Included with this soil in mapping are spots of Humatas, Naranjito, and Mucara soils. The surface layer of the Humatas soils is dark brown clay, and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Mucara soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as coffee. It is suited to pangolagrass and to molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

CzC—Corozal clay, 5 to 12 percent slopes. This is a sloping, somewhat poorly drained soil on interfluves of strongly dissected low volcanic hills. Slopes are 200 to 400 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is dark reddish brown, firm clay about 7 inches thick. The subsoil is about 33 inches thick; it is mostly red, firm clay. The substratum, beginning at a depth of 40 inches, is yellowish red, light gray, and strong brown, friable, clay loam saprolite.

Included with this soil in mapping are small areas of Consumo, Daguey, and Humatas soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey and Humatas soils is dark brown clay. These soils make up 10 to 20 percent of the area of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers and plantains. It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses due to its clayey nature and wetness. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DaC—Daguey clay, 2 to 12 percent slopes. This is a gently sloping to sloping soil on stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes are 200 to 800 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is dark brown firm clay about 10 inches thick. The subsoil is about 62 inches thick; it is yellowish red and red, firm clay. The substratum, beginning at a depth of 72 inches, is yellowish red, strong brown, and reddish yellow, friable, silty clay loam saprolite.

Included with this soil in mapping are small areas of Humatas and Catalina soils. The surface layer of the Humatas soils is dark brown clay; that of the Catalina soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains, yams, taniers, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, and mahoe trees. Production of Honduras pine is moderate about 1300 board feet per acre per year. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

Slope is a moderate limitation for most urban uses. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DaD—Daguey clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes are 100 to 500 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is brown, firm clay about 10 inches thick. The subsoil is about 62 inches thick; it is yellowish red and red, firm clay. The substratum, beginning at a depth of 72 inches, is yellowish red, friable silty clay loam saprolite mottled with strong brown and reddish yellow.

Included with this soil in mapping are small areas of Humatas and Catalina soils. The surface layer of the Humatas soils is dark brown clay. That of the Catalina soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is moderately steep (fig. 4) and because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains, yams, taniers, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DeF—Descalabrado clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and tops of strongly dissected uplands. Slopes are 200 to 1000 feet long. The areas range from 100 to 1000 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 6 inches thick; it is dark brown, firm gravelly clay. The substratum, beginning at a depth of 11 inches, is dark yellowish brown and olive, friable gravelly sandy clay loam. Hard rock is at a depth of 17 inches.

Included with this soil in mapping are a few spots of Descalabrado-Rock outcrop complex and Guayama soils. The surface layer of the Guayama soils is dark reddish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. This soil is fertile, but has a shallow root zone. It is not suited to cultivated crops because it is in areas of low rainfall. The vegetation is brush and brushy pasture.

This soil is suited to Honduras pine. Production is very low, less than 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

DgF—Descalabrado-Rock outcrop complex, 40 to 60 percent slopes. This complex consists of very steep, well drained soils and Rock outcrop on strongly dissected slopes. The areas range from 100 to 500 acres. The complex is 70 percent Descalabrado clay loam and 30 percent Rock outcrop and other minor soils.

In a representative profile of Descalabrado clay loam the surface layer is very dark grayish brown clay loam about 5 inches thick. The subsoil, about 6 inches thick, is dark brown, firm gravelly sandy clay loam. The substratum, beginning at a depth of 11 inches, is dark yellowish brown and olive, friable gravelly sandy clay loam. Hard consolidated volcanic rock is at a depth of 17 inches.

Rock outcrop consists of exposed bedrock occurring in such an intricate pattern with the Descalabrado soils that it was impractical to separate them in mapping.

Included with this soil complex in mapping are spots of Guayama and other miscellaneous soils with varying soil properties.

Permeability is moderate in the Descalabrado soil, and the available water capacity is low. Runoff is rapid. Natural fertility is high, and organic matter content is moderate. Reaction is neutral. The root zone is shallow.

The vegetation is brush and brushy pasture. This complex is not suited to cultivated crops. The best potential is for wildlife habitat. Potential for production of Honduras pine is very low, less than 800 board feet per acre per year.

The hazard of erosion and the limitations on the use of equipment are major concerns of management. Plant competition is severe for Honduras pine.

This complex has severe limitations for most urban uses because it is very steep. Capability subclass VIIs.

Dm—Dique loam. This is a nearly level, well drained soil on river flood plains. Slopes are smooth and are 50 to 300 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is dark brown, friable loam about 6 inches thick. The subsoil is about 30 inches thick; it is dark brown and dark yellowish brown, friable loam. The substratum, beginning at a depth of 36 inches, is dark yellowish brown, friable loam.

Included with this soil in mapping are small areas of Toa soils. The surface layer of the Toa soils is dark brown silty clay loam.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is easily worked. The root zone is deep. Natural fertility is high. Crops respond well to fertilizer.

This soil has been used for sugarcane (fig. 5). It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard. Capability class I.

Dr—Durados sandy loam. This is a nearly level, excessively drained soil on coastal plains. Slopes are smooth and are 50 to 100 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, very friable sandy loam about 14 inches thick. The layer from 14 to 23 inches is very dark grayish brown, loose loamy sand. Below a depth of 23 inches is loose sand of mixed colors and some thick layers of cemented sand.

Included with this soil in mapping are some areas of Catano soils and coastal beaches. The surface layer of Catano soils is very dark grayish brown loamy sand. Catano soils and coastal beaches make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very slow. This soil is easily worked. The root zone is deep. Natural fertility is low.

This soil has been used for coconuts. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

This soil is limited for most urban uses because of the flood hazard. Capability subclass VIs.

Es—Estacion silty clay loam. This is a nearly level, well drained soil on river flood plains. Slopes are smooth and are 100 to 400 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark brown, friable silty clay loam about 8 inches thick. The layer from 8 to 20 inches is very dark grayish brown, friable gravelly clay loam. Below 20 inches is dark brown, loose gravelly sand.

Included with this soil in mapping are small areas of Reilly, Dique, and Toa soils. The surface layer of the Reilly soils is dark brown sandy loam, that of the Toa soils is dark brown silty clay loam, and that of the Dique soils is dark brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is moderately deep. Natural fertility is high. Crops respond well to fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard. Capability subclass IIIs.

GuF—Guayama clay loam, 20 to 60 percent slopes. This is a steep to very steep, well drained soil on side slopes and narrow ridgetops of dissected volcanic uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 50 to 300 acres.

Typically the surface layer is dark reddish brown, friable clay loam about 4 inches thick. The subsoil is about 8 inches thick; it is red, friable gravelly clay. The substratum, beginning at a depth of 12 inches, is red, friable gravelly silty clay loam. Consolidated volcanic rock is at a depth of 20 inches.

Included with this soil in mapping are small areas of Rock outcrop and Descalabrado soils. The surface layer of the Descalabrado soils is very dark grayish brown clay loam. Rock outcrop consists of exposed bedrock and thin patches of soil over rock. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for pasture. It is suited to guineagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production is very low, less than 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

Hm—Humacao loam. This is a nearly level, well drained soil on terraces. Slopes are smooth and are about 50 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark brown, friable loam about 8 inches thick. The subsoil is about 7 inches thick; it is dark yellowish brown, friable sandy clay loam. The substratum, beginning at a depth of 15 inches, is brown and strong brown, friable clay loam and reddish yellow, very friable sandy clay loam.

Included with this soil in mapping are some spots of Candelero soils. The surface layer of the Candelero soils is dark grayish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is easily worked. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for crops such as sugarcane, taniers, and plantains. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to most urban uses. Capability subclass IIe.

HtE— Humatas clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and ridgetops of strongly dissected humid uplands (fig. 6). Slopes are convex and are 200 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite.

Included with this soil in mapping are some narrow foot slopes and soils that have less than 20 percent slopes. Also included are spots of Consumo soils and, on a few hilltops, small areas of Daguey soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, yams, tobacco, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

HtF—Humatas clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and ridgetops of strongly dissected humid uplands. Slopes are convex and are 200 to 1000 feet long. The areas range from 10 to 500 acres.

Typically the surface layer is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite.

Included with this soil in mapping are some spots of Consumo soils and, on a few hilltops, small areas of Daguey soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, yams, tobacco, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

HuF—Humatas-Rock outcrop complex, 20 to 60 percent slopes. This complex consists of steep and very steep, well drained Humatas soils and Rock outcrop on side slopes and narrow ridgetops of the volcanic humid uplands. Slopes are mostly convex and 200 to 800 feet long. The areas have rough surfaces that are covered with rock outcrops. The areas range from 20 to 100 acres. Humatas clay occurs in areas between the outcrops of rock in such an intricate pattern that it was not practical to separate them in mapping. The dark brown clay surface layer of the Humatas soils contrasts markedly with the outcrops and other included soils.

This complex is about 45 percent Humatas clay, 40 percent Rock outcrop, and 15 percent other soils.

Typically the surface layer of the Humatas soil in this complex is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red, friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite. The other component of this complex consists of boulders ranging from 5 to 15 feet in diameter and outcrops of rock.

Included with this complex in mapping, making up about 15 percent of the areas, are other soils with variable properties.

Most areas of this complex are in brush and brushy pasture. Runoff is rapid, and erosion is a hazard. Because of steep to very steep slopes and the large number of boulders and outcrops of rock on the surface, the potential for farming is very poor. This soil has very poor potential for most urban uses because it is steep to very steep. Potential is best for growing trees and developing habitat for woodland wildlife. The hazard of erosion is severe. Removal of vegetation should be held to a minimum.

This complex is suitable for Honduras pine and eucalyptus trees. Productivity is moderate, the hazard of erosion is high, and there are limitations to the use of equipment. Management practices such as removal of undesirable brush, trees, and grasses and erosion control measures are difficult to apply.

This complex is limited for most urban uses because the soils are steep to very steep and rocky. Capability subclass VIIs.

Hy—Hydraquents, saline. These are nearly level, very poorly drained soils in lagoonlike places and in depressions adjacent to the coast. The areas range from 20 to 200 acres. These soils are covered with brackish water most of the year and are frequently flooded.

Color and texture vary throughout the profile of the soil. The underlying material ranges from sand to clay.

Permeability is very slow, and the available water capacity is very high. Runoff is very slow. Reclamation is very difficult and costly.

These soils support mangrove trees and other halophytic vegetation most of the time. They have severe limitations for most urban uses because they are very poorly drained and are subject to frequent overflow. Capability subclass VIIIw.

JaE2—Jagueyes loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on side slopes and narrow ridgetops. Slopes are 100 to 500 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark yellowish brown, friable loam about 5 inches thick. The subsoil is about 49 inches thick; it is yellowish red and red, friable clay loam to a depth of 41 inches. From 41 to 54 inches, it is red, friable sandy clay loam mottled with brownish yellow and light gray. The substratum, beginning at a depth of 54 inches, is yellowish red, friable, sandy clay loam saprolite.

Included with this soil in mapping are small areas of Lirios and Limones soils. Also included on some hilltops are areas of Jagueyes soils where slopes are less than 20 percent. The surface layer of the Lirios soil is brown silty clay loam, and that of the Limones soil is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for taniers and plantains. It is suited to pangolagrass, improved bermudagrass, Merker grass, and molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

JnD2—Juncal clay, 5 to 20 percent slopes, eroded. This is a sloping to moderately steep, moderately well drained soil on foot slopes and low rounded hills. Slopes are concave and are 100 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark grayish brown, firm clay about 10 inches thick. The subsoil is about 38 inches thick; it is dark yellowish brown, yellowish brown, and brownish yellow, firm clay. The substratum, beginning at a depth of 48 inches, is brownish yellow, friable silty clay loam.

Included with this soil in mapping are small areas of Colinas soils. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because it is sloping to moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for yams, taniers, and pigeon peas. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and grazing of pasture, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Honduras mahogany. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion is the major concern of management. All logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is sloping to moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

JuC—Juncos clay, 5 to 12 percent slopes. This is a sloping, moderately well drained soil on side slopes and foot slopes of strongly dissected uplands. Slopes are 100 to 500 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is black, firm clay about 8 inches thick. The subsoil is about 10 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 18 inches, is olive brown, firm clay. Volcanic rock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is moderate in this soil. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of stickiness and plasticity of clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion is the major concern of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because of slope, its clayey nature, and a high shrink-swell potential. If the soil is used as construction sites, development should be on the contour. Removal of the vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

JuD—Juncos clay, 12 to 20 percent slopes. This is a moderately steep, moderately well drained soil on side slopes and foot slopes of strongly dissected uplands. Slopes are 100 to 300 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is black, firm clay about 8 inches thick. The subsoil is about 10 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 18 inches, is olive brown, firm clay. Volcanic rock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mabi and Mucara soils. The surface layer of the Mabi and Mucara soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of the slope and the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because of slope, its clayey nature, and a high shrink-swell potential. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

LaB—Lares clay, 2 to 5 percent slopes. This is a gently sloping, somewhat poorly drained soil on terraces. Slopes are smooth and are 200 to 800 feet long. The areas range from 50 to 500 acres.

Typically the surface layer is dark brown, firm clay about 6 inches thick. The subsoil is about 30 inches thick; it is red and yellowish red, firm clay. The substratum, beginning at a depth of 36 inches, is brownish yellow, red, very pale brown, and dark yellowish brown, firm clay.

Included with this soil in mapping are spots of Daguey soils. The surface layer of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane, plantains, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion is slight, and the limitations for the use of equipment is moderate.

This soil is limited for most urban uses because it is too clayey. Removal of vegetation should be held to a minimum, and a temporary plant cover established quickly in denuded areas. Capability subclass IIe.

LaC2—Lares clay, 5 to 12 percent slopes, eroded. This is a sloping, somewhat poorly drained soil on terraces. Slopes are smooth and are 200 to 800 feet long. The areas range from 50 to 500 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, firm clay about 6 inches thick. The subsoil is about 30 inches thick; it is red and yellowish red, firm clay. The substratum, beginning at a depth of 36 inches, is brownish yellow, red, very pale brown, and dark yellowish brown, firm clay.

Included with this soil in mapping are spots of Daguey soils. The surface layer of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is medium. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane, plantains, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing of pasture, as well as liming and fertilizing, are the chief management needs (fig. 7).

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion is slight, and the limitations on the use of equipment are moderate.

This soil is limited for most urban uses because it is too clayey. A temporary plant cover should be established quickly in denuded areas. Capability subclass IIIe.

LmE—Limones clay, 20 to 40 percent slopes. This is a steep, moderately well drained soil on side slopes and narrow ridgetops. Slopes are irregular and are 100 to 500 feet long. The areas are 10 to 200 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is about 41 inches thick; it is yellowish brown and red, firm clay. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite.

Included with this soil in mapping are narrow ridges that have less than 20 percent slopes and spots of Lirios and Pandura soils. The surface layer of the Lirios soils is brown silty clay loam, and that of the Pandura soil is dark brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. The soil is difficult to work because it is steep (fig. 8). Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, and yams. It is suited to pangolagrass, improved bermudagrass, Merker grass, and molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

LmF—Limones clay, 40 to 60 percent slopes. This is a very steep, moderately well drained soil on side slopes and narrow ridgetops. Slopes are irregular and are 100 to 500 feet long. The areas range from 20 to 100 acres. A few shallow to deep gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is about 41 inches thick; it is yellowish brown and red, firm clay. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite.

Included with this soil in mapping are some narrow ridgetops where slopes are less than 40 percent. Also included are spots of Lirios and Pandura soils. The surface layer of the Lirios soils is brown silty clay loam, and that of the Pandura soil is dark brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. The soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains, yams, and taniers. It is suited to pangolagrass and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LoF2—Lirios silty clay loam, 20 to 60 percent slopes, eroded. This is a steep to very steep, well drained soil on side slopes and narrow ridgetops of the granitic humid uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 500 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is brown, friable silty clay loam in the upper part and red, friable clay in the lower part. The substratum, beginning at a depth of 24 inches, is variegated red, yellowish red, yellowish brown, brown, very pale brown, and white, friable clay and silty clay loam saprolite.

Included with this soil in mapping are small areas of Pandura and Limones soils. The surface layer of the Pandura soils is dark brown sandy loam, and that of the Limones soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep to very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for taniers, plantains, tobacco, bananas, and sweet potatoes. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LsE—Los Guineos clay, 20 to 40 percent slopes. This steep, moderately well drained soil is on side slopes of strongly dissected uplands. Slopes are irregular and are 300 to 1000 feet long. The areas range from 200 to 1000 acres. A few shallow gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 4 inches thick. The subsoil is about 44 inches thick; it is yellowish brown, red, and brownish yellow, firm clay with some white mottles in the lower part. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite mottled with brownish yellow, yellow, and white.

Included with this soil in mapping are some rounded hilltops and narrow foot slopes where slopes are less than 20 percent Also included are spots of Humatas, Consumo, and Naranjito soils. The surface layer of the Humatas soils is dark brown clay and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee and bananas. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is moderate, about 1400 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LsF—Los Guineos clay, 40 to 60 percent slopes. This is a very steep, moderately well drained soil on side slopes of strongly dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 200 to 1000 acres. A few shallow gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 4 inches thick. The subsoil is about 44 inches thick; it is yellowish brown, red, and brownish yellow, firm clay with some white mottles in the lower part. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite mottled with brownish yellow, yellow, and white.

Included with this soil in mapping are some hilltops where slopes are less than 40 percent and some very steep ridges where they are more than 60 percent. Also included are spots of Consumo soils. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee and bananas.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

MaA—Mabi clay, 0 to 2 percent slopes. This is a nearly level, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are smooth and are 100 to 300 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential (fig. 9) and the flood hazard. Capability subclass IIw.

MaB—Mabi clay, 2 to 5 percent slopes. This is a gently sloping, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are gently undulating and are 100 to 300 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential and the flood hazard. Capability subclass IIw.

MaC—Mabi clay, 5 to 12 percent slopes. This is a sloping, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential and the flood hazard. Capability subclass IIIe.

Md—Made land. Made land consists of areas that have been covered with gravel, rock, concrete blocks, and other debris. It has been built up for industrial uses and is not suited to farming.

MlF—Malaya clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of strongly dissected volcanic uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 100 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable clay about 6 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm gravelly clay. The substratum, beginning at a depth of 13 inches, is dark yellowish brown, firm gravelly clay loam. Bedrock is at a depth of 18 inches.

Included with this soil in mapping are spots of Caguabo soils. The surface layer of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is fertile, but is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

MoF—Maricao clay, 20 to 60 percent slopes. This is a steep to very steep, well drained soil on side slopes and narrow hilltops of the strongly dissected uplands. Slopes are irregular and are 300 to 800 feet long. The areas range from 20 to 500 acres. A few shallow and deep gullies have formed.

Typically the surface layer is reddish brown, friable clay about 6 inches thick. The subsoil is about 16 inches thick; it is red, friable clay in the upper part and silty clay in the lower part. The substratum, beginning at a depth of 22 inches, is red, strong brown, and pale brown, friable silty clay loam saprolite.

Included with this soil in mapping are spots of Consumo soils. Also included are some very severely eroded ridgetops. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep to very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Mp—Martin Pena muck. This is a nearly level, very poorly drained soil in low depressional areas of the humid coastal plains and river flood plains. The areas range from 10 to 800 acres.

Typically the surface layer is black muck about 8 inches thick. The underlying material is mostly mottled very dark brown and greenish gray clay.

Included with this soil in mapping are spots of Saladar and Bajura soils. The surface layer of the Saladar soils is black muck, and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is very slow and the available water capacity is very high. Runoff is slow. This soil is very difficult to work because of wetness. A very complex and expensive drainage system is needed if it is to be reclaimed.

This soil has been in cattails, sedges, papyrus, and other hydrophytic vegetation most of the time. It is suited to paragrass.

This soil is limited for most urban uses because of wetness, slow permeability, and the flood hazard. Capability subclass VIIw.

MsB—Matanzas clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on foot slopes and in small valleys between the limestone hills. Slopes are gently undulating and are 200 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark reddish brown, firm clay about 7 inches thick. The subsoil is about 46 inches thick; it is dark reddish brown and red, friable clay. Limestone bedrock is at a depth of 53 inches.

Included with this soil in mapping are some spots of Bayamon soils. The surface layer of the Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is slow. This soil is difficult to work. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for crops such as plantains, yams, and taniers. It is suited to pangolagrass, Merker grass, and paragrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has limitations for most urban uses because of its clayey nature. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIe.

MtB—Montegrande clay, 2 to 5 percent slopes. This is a gently sloping, moderately well drained soil on alluvial fans and foot slopes of the volcanic uplands. Slopes are smooth and are 100 to 300 feet long. The areas range from 30 to 50 acres.

Typically the surface layer is very dark grayish brown, firm clay about 7 inches thick. The subsoil is about 14 inches thick; it is dark brown and grayish brown, firm clay mottled with yellowish brown, gray, and greenish gray. The substratum from a depth of 21 inches to 29 inches is mixed dark yellowish brown and yellowish brown, firm clay. From 29 inches to 48 inches it is brown and yellowish brown very gravelly clay.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown, very firm clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of its clayey nature, the high shrink-swell potential, and the flood hazard. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIw.

MtC—Montegrande clay, 5 to 12 percent slopes. This is a sloping, moderately well drained soil on alluvial fans and foot slopes of the volcanic uplands. Slopes are undulating and are 100 to 200 feet long. The areas range from 20 to 40 acres.

Typically the surface layer is very dark grayish brown, firm clay about 7 inches thick. The subsoil is about 14 inches thick; it is dark brown and grayish brown, firm clay mottled with yellowish brown, gray, and greenish gray. The substratum from a depth of 21 inches to 29 inches is mixed dark yellowish brown and yellowish brown, firm clay. From 29 inches to 48 inches it is brown and yellowish brown very gravelly clay.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown, very firm clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of slope, clayey nature, and high shrink-swell potential. Capability subclass IIIe.

MuF2—Morado clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on side slopes, foot slopes, and hilltops of strongly dissected humid uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 70 to 500 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is weak red, friable clay loam about 8 inches thick. The subsoil is about 18 inches thick; it is reddish gray, dark reddish gray, red, weak red, and strong brown, friable clay loam. The substratum, beginning at a depth of 26 inches is variegated gray, light gray, and dark reddish gray clay loam saprolite. Bedrock is at a depth of 34 inches.

Included with this soil in mapping are spots of Caguabo soils. The surface layer of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Fertility is high. Controlling erosion is the major concern of management.

This soil has been in brushy forest and brushy pasture most of the time. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

MxD—Mucara clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on foot slopes, side slopes, and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 300 to 800 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Juncos and Naranjito soils. The surface layer of the Juncos soils is black clay, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. This soil is fertile. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of the Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

MxE—Mucara clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 100 to 500 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Caguabo and Naranjito soils. Also included are some hilltops that have many rocks and boulders on the surface. The surface layer of the Caguabo soils is dark grayish brown clay loam, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. The soil is fertile. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs. This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and is shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

MxF—Mucara clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 100 to 1000 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Caguabo and Naranjito soils. Also included are some hilltops that have many rocks and boulders on the surface. The surface layer of the Caguabo soils is dark grayish brown clay loam, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. This soil is fertile. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and grazing of pasture, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is very steep and it is shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

NaD2—Naranjito silty clay loam, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on strongly dissected volcanic uplands. Slopes are irregular and are 100 to 500 feet long. The areas range from 20 to 200 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite. Bedrock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mucara and Consumo soils. The surface layer of the Mucara soils is very dark grayish brown clay and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains and bananas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

NaE2—Naranjito silty clay loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on strongly dissected uplands. Slopes are irregular and are 100 to 400 feet long. The areas range from 50 to 100 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red, firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite.

Included with this soil in mapping are spots of Mucara and Caguabo soils. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

NaF2—Naranjito silty clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on strongly dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 30 to 1000 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red, firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite.

Included with this soil in mapping are spots of Mucara and Caguabo soils. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

PaD—Pandura sandy loam, 12 to 20 percent slopes. This is a moderately steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. The surface layer of the Limones soils is dark yellowish brown clay, and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

PaE—Pandura sandy loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 400 feet long. The areas range from 50 to 500 acres.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. Also included are a few spots of rock land. The surface layer of the Limones soils is dark yellowish brown clay and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

PaF—Pandura sandy loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 50 to 1000 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. Also included are few spots of rock land. The surface layer of the Limones soils is dark yellowish brown clay, and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

PeF—Pellejas clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on short side slopes and narrow ridges of the strongly dissected humid uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 20 to 200 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable clay loam about 4 inches thick. The subsoil is about 12 inches thick; it is yellowish brown clay loam. The substratum, beginning at a depth of 16 inches, is pale brown, light yellowish brown, gray, pinkish gray, and dark greenish gray very friable sandy loam saprolite.

Included with this soil in mapping are spots of Lirios soils. Also included are small areas that have slopes less than 40 percent. The surface layer of the Lirios soils is brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour.

Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Re—Reilly sandy loam. This is a nearly level, excessively drained soil on river flood plains adjacent to streams. The areas range from 10 to 100 acres.

Typically the surface layer is dark brown, very friable sandy loam about 7 inches thick. The underlying material is dark grayish brown gravelly sand to a depth of 18 inches and is coarse clean sand and gravel below 18 inches.

Included with this soil in mapping are spots of riverwash consisting of large size gravel. The spots of riverwash make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is shallow. Natural fertility is low.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard and seepage. Capability subclass IVs.

RoB—Rio Arriba clay, 2 to 5 percent slopes. This is a gently sloping, moderately well drained soil on alluvial fans and terraces above the river flood plains. Slopes are gently undulating and are 100 to 500 feet long. The areas range from 15 to 400 acres.

Typically the surface layer is brown, firm clay about 8 inches thick. The subsoil from 8 to 28 inches is yellowish brown, firm clay and from 28 to 60 inches is reddish yellow, firm clay. Below a depth of 16 inches, the subsoil is mottled with yellowish red and red.

Included with this soil in mapping are small areas of Mabi soils. The surface area of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of its clayey nature, slow permeability, high shrink-swell potential, and the flood hazard. Capability subclass IIs.

RoC2—Rio Arriba clay, 5 to 12 percent slopes, eroded. This is a sloping, moderately well drained soil on alluvial fans and terraces above the river flood plains. Slopes are undulating and are 100 to 500 feet long. The areas range from 10 to 300 acres. This soil has lost much of the surface layer through erosion.

Typically the surface layer is brown, firm clay about 8 inches thick. The subsoil from 8 to 28 inches is yellowish brown, firm clay and from 28 to 60 inches is reddish yellow, firm clay. Below a depth of 16 inches, the subsoil is mottled with yellowish red and red.

Included with this soil in mapping are small areas of Juncos and Mabi soils. The surface area of the Juncos soils is black clay, and that of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is rapid, and erosion is a hazard. This soil is difficult to work. The root zone is deep. Natural fertility is medium. Crops respond well to lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of its clayey nature, slow permeability, high shrink-swell potential, and the flood hazard. Capability subclass IIIe.

RpD2—Rio Piedras clay, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on foot slopes and side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 300 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with yellowish brown, red, and brownish yellow mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles. Cemented shale bedrock is at a depth of 48 inches.

Included with this soil in mapping are spots of Yunes soils. The surface layer of the Yunes soils is dark reddish brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees.

Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil if soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

RpE2—Rio Piedras clay, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 200 feet long. The areas range from 20 to 200 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with yellowish brown, red, and brownish yellow mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles. Cemented shale bedrock is at a depth of 48 inches.

Included with this soil in mapping are spots of Yunes soils. The surface layer of the Yunes soils is dark reddish brown silty clay loam. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

RpF2—Rio Piedras clay, 40 to 60 percent slopes, eroded. This a very steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 50 to 400 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with red, brownish yellow, and yellowish brown mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles.

Included with this soil in mapping are a few spots of Yunes soils. Also included are severely eroded spots on tops of ridges and along drains where the substratum is exposed. The surface layer of the Yunes soils is dark reddish brown, silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

SaF—Sabana silty clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and tops of humid volcanic uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 20 to 300 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm silty clay loam about 3 inches thick. The subsoil is about 12 inches thick; it is dark brown, friable silty clay in the upper part and variegated light brownish gray and strong brown, firm clay in the lower part. Consolidated volcanic rock is at a depth of 15 inches.

Included with this soil in mapping are spots of Mucara and Caguabo soils. Also included are some ridges with boulders and stones on the surface. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

ScB—Sabana Seca clay, 2 to 8 percent slopes. This is a gently sloping, poorly drained soil on coastal plains. The areas range from 10 to 200 acres.

Typically the surface layer is very dark grayish brown, firm clay about 10 inches thick. The clay subsoil is highly mottled. The dominant color from 10 to 13 inches is dark grayish brown, from 13 to 36 inches is light gray, and from 36 to 70 inches is white. The mottles are yellowish brown, red, dark red, dusky red, and strong brown.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is very slow, and the available water capacity is high. Runoff is very slow. This soil is very difficult to work because of wetness and because of the stickiness and plasticity of the clay. The root zone is shallow. Natural fertility is low.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass, common bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because it is wet and clayey. Capability subclass IIIw.

Sm—Saladar muck. This is a level, very poorly drained soil in closed depressions and in coastal marshes with inadequate outlets. The areas range from 10 to 700 acres.

Typically the surface layer is black muck about 10 inches thick. The underlying layers to a depth of 51 inches or more are black muck.

Included with this soil are spots of Martin Pena soils. The surface layer of the Martin Pena soils is black muck about 8 inches thick that overlies clayey material. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because it is too wet. Reclamation projects of this soil would be difficult and costly.

This soil has been in cattails, sedges, and reeds most of the time.

This soil is limited for most urban uses because it is too wet and is subject to overflow. Capability subclass VIIIw.

SoE—Soller clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and hilltops of rounded limestone hills. Slopes are convex, and are 100 to 300 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is yellow, friable, weathered limestone. Hard limestone is at a depth of 24 inches.

Included with this soil in mapping are spots of Colinas soils. Also included are severely eroded small areas on hilltops and along drainageways where the hard fragmental limestone parent material is exposed. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is low, about 350 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and shallow to bedrock. If this soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

SoF—Soller clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and hilltops of rounded limestone hills. Slopes are convex and are 100 to 200 feet long. The areas range from 30 to 500 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is yellow, friable, weathered limestone. Hard limestone bedrock is at a depth of 24 inches.

Included with this soil in mapping are small areas of Colinas soils. Also included are some severely eroded spots on hilltops and along drainageways where the hard fragmental limestone parent material is exposed. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is very low, less than 250 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and shallow to bedrock. If this soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

TaF—Tanama-Rock outcrop complex, 20 to 60 percent slopes. This complex consists of steep to very steep, shallow, well drained Tanama soils and Rock outcrop. This complex has formed in karst topography characterized by pepino hills or haystack hills in the northern part of the survey area. The topography is very rugged, and slopes in many directions. This irregular topography is caused by the solutional destruction of the dense, thin bedded limestone. Most areas are asymmetrical in form and range from 25 to 300 feet in height. They are about 5 to 100 acres. This complex is about 45 percent Tanama soils, 40 percent Rock outcrop, and 15 percent minor soils.

Tanama soils and Rock outcrop form such an intricate pattern that it was not practical to separate them in mapping. In a representative profile of Tanama soils the surface layer is dark reddish brown, friable clay about 4 inches thick. The subsoil is about 10 inches thick; it is reddish brown, firm clay. Hard semiconsolidated limestone is at a depth of 14 inches.

Included with this complex in mapping are spots of Soller soils. Also included are small areas of miscellaneous soils that have formed between the limestone outcrops and in the crevices and holes formed in the limestone. The surface layer of the Soller soils is very dark grayish brown clay loam.

In the Tanama soils the permeability is moderate and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep to very steep, and because it is intermingled with Rock outcrop. The root zone is shallow. Natural fertility is low. Most of this complex is in brush.

This complex is limited for most urban uses mainly because of the slopes, rock outcrops, and shallow depth to rock. Capability subclass VIIs.

To—Toa silty clay loam. This is a nearly level, moderately well drained to well drained soil on flood plains (fig. 10). The areas range from 20 to 500 acres.

Typically the surface layer is dark brown, friable silty clay loam about 8 inches thick. The subsoil is about 8 inches thick; it is dark brown, friable silty clay loam with pale brown mottles. The substratum, beginning at a depth of 16 inches, is brown and dark brown, friable silty clay loam with dark reddish brown, light gray, and brown mottles.

Included with this soil in mapping are spots of Dique, Coloso, and Bajura soils. The surface layer of the Dique soils is dark brown loam; that of the Coloso soils is dark brown silty clay loam; and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. This soil is easy to work. The root zone is deep. Natural fertility is high. Crops respond well to applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard, its clayey nature, and low strength. Capability class I.

TrB—Torres loamy sand, 2 to 5 percent slopes. This is a gently sloping, excessively drained soil on coastal plains and in trapped valleys among the haystack hills. Slopes are gently undulating and are 50 to 200 feet long. The areas range from 5 to 200 acres.

Typically the surface layer is very dark grayish brown and dark brown, loose loamy sand about 28 inches thick. The subsoil, to a depth of 64 inches, is yellowish brown, firm clay with prominent red, dark red, and light gray mottles.

Included with this soil in mapping are spots of Matanzas and Almirante soils. The surface layer of the Matanzas soils is dark reddish brown clay, and that of the Almirante soils is strong brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid in the surface layer and moderate in the subsoil. The available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is deep. Natural fertility is low.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suitable for most urban uses. It has limitations for some uses because of the clayey subsoil. Capability subclass VIs.

Ts—Tropopsamments. Tropopsamments consist of nearly level, deep, excessively drained soils formed in a thick accumulation of finely ground sea shells and sand. The areas are narrow strips of land that parallel the coast.

Commonly the soils to a depth of 60 inches are pale yellow or yellow, loose sand containing many shells and shell fragments.

Most areas of these soils are devoid of vegetation or they are producing a few coconuts.

These soils are limited for most urban uses because they are subject to the wave action of the sea. Capability subclass VIIIs.

Ud—Urban land-Durados complex. This nearly level complex is about 70 percent Urban land, 20 percent Durados soils, and about 10 percent other soils. The areas range from 500 to 2000 acres. The composition of this unit is about the same from place to place.

In undisturbed areas the surface layer of the Durados soils is very dark grayish brown, very friable sandy loam about 14 inches thick. The underlying material from 14 to 23 inches is very dark grayish brown, loose loamy sand; from 23 to 38 inches is very pale brown and very dark grayish brown loose sand; and from 38 to 60 inches is mixed dark yellowish brown, black, brownish yellow, and yellowish brown, loose sand with thick layers of cemented sand. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany community development. The landscape has been altered in places by cutting, filling, or grading and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas in the vicinity of Levittown. Capability subclass not assigned.

Um—Urban land-Mucara complex. This complex is about 50 percent Urban land, 30 percent Mucara soils, and about 20 percent Rock outcrop and other soils. Slopes are irregular and are 100 to 300 feet long. The areas range from 500 to 1000 acres.

Typically the surface layer of the Mucara soils is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Hard volcanic rock is at a depth of 30 inches. Urban land consists of areas that have been altered to prepare building sites, create trafficways, or create a better environment for growing lawn grasses and landscape plants.

Included with this complex are Rock outcrop and other minor soils. These make up about 20 percent of this mapping unit. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas around cities. Capability subclass not assigned.

Us—Urban land-Sabana Seca complex. This complex is about 60 percent Urban land, 30 percent Sabana Seca soils, and 10 percent other soils. The areas are nearly level to gently sloping and are on coastal plains. They range from 1000 to 3000 acres. The composition of this complex is about the same from place to place.

In undisturbed areas the surface layer of the Sabana Seca soils is very dark grayish brown, firm clay about 10 inches thick. The clay subsoil is highly mottled. The dominant color from 10 to 13 inches is dark grayish brown; from 13 to 36 inches is light gray; and from 36 to 70 inches is white. The mottles are yellowish brown, red, dark red, dusky red, and strong brown. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany community development. The landscape has been altered in places by cutting, filling, and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated areas in the vicinity of Levittown. Capability subclass not assigned.

Uv—Urban land-Vega Alta complex. This complex is about 60 percent Urban land, 25 percent Vega Alta soils, and 15 percent Aceitunas and Humatas soils. The areas are gently undulating to moderately undulating. They range from 3000 to 5000 acres. The composition of the complex is about the same from place to place.

In undisturbed areas the Vega Alta soils have a surface layer of dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray, friable clay. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany development. The landscape has been altered in places by cutting, filling, or grading and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas in the vicinities of the San Juan metropolitan area, Bayamon, and other towns and communities. Capability subclass not assigned.

VaB—Vega Alta clay loam, 2 to 5 percent slopes. This is a gently sloping, well drained soil on coastal plains and terraces. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray, friable clay.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has moderate limitations for most urban uses because of its clayey nature and low strength. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIe.

VaC2—Vega Alta clay loam, 5 to 12 percent slopes, eroded. This is a sloping, well drained soil on coastal plains and terraces (fig. 11). Slopes are undulating and are 100 to 300 feet long. The areas range from 20 to 300 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray friable clay.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because it is sloping and clayey and has low strength. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Vg—Vega Baja silty clay. This is a nearly level, somewhat poorly drained soil on coastal plains and alluvial fans. The areas range from 50 to 100 acres.

Typically the surface layer is dark brown, dark grayish brown, and yellowish brown, firm silty clay to a depth of 12 inches. The subsoil from 12 to 17 inches is dark grayish brown and yellowish brown, firm silty clay; from 17 to 32 inches is mixed strong brown and gray clay; and from 32 to 50 inches is brownish yellow and gray silty clay loam. The substratum, beginning at a depth of 50 inches, is light gray and strong brown, firm clay.

Included with this soil in mapping are spots of Coloso soils. The surface layer of the Coloso soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. This soil is difficult to work because of wetness and because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of the flood hazard, wetness, slow permeability, and its clayey nature. Capability subclass IIw.

VkC2—Via clay loam, 5 to 12 percent slopes, eroded. This is a sloping, well drained soil on high stream terraces. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 100 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 9 inches thick. The subsoil is about 27 inches thick; it is strong brown and yellowish brown, firm clay loam. The substratum, beginning at a depth of 36 inches, is strong brown, firm very gravelly clay loam.

Included with this soil in mapping are spots of Rio Arriba and Mabi soils. The surface layer of the Mabi soils is very dark grayish brown clay, and that of the Rio Arriba soils is brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has moderate to severe limitations for most urban uses because of slope, seepage, and its clayey nature. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Vv—Vivi loam. This is a nearly level, somewhat excessively drained soil on river flood plains. The areas range from 10 to 100 acres.

Typically the surface layer of this soil is dark brown, very friable loam about 9 inches thick. The subsoil is about 13 inches thick; it is dark yellowish brown, friable loam. The substratum, beginning at a depth of 22 inches, is dark yellowish brown loam from 22 inches to 34 inches, yellowish brown, very friable very fine sandy loam from 34 to 47 inches, and yellowish brown loamy sand from 47 to 58 inches.

Included with this soil in mapping are spots of Reilly soils. The surface layer of the Reilly soils is dark brown sandy loam. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability is rapid, and the available water capacity is low. This soil is fertile and is easily worked. The root zone is deep. Crops respond well to heavy applications of lime and fertilizers and to irrigation.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of the flood hazard and seepage. Capability subclass IIs.

YeE—Yunes silty clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of strongly dissected uplands. The slopes are irregular and are 100 to 300 feet long. The areas range from 20 to 300 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark reddish brown, friable silty clay loam about 2 inches thick. The subsoil is about 14 inches thick; it is dark brown and brown, friable very shaly silty clay loam. Below a depth of 16 inches is bedded fragmental shale. The beds are 1 to 4 inches thick. The shale is light red, strong brown, and pink.

Included with this soil in mapping are spots of Rio Piedras soils. The surface layer of the Rio Piedras soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is not suited to cultivated crops because it is steep and shallow to bedded shale. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soils are slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

YeF—Yunes silty clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of strongly dissected uplands. The slopes are irregular and are 100 to 300 feet long. The areas range from 30 to 250 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark reddish brown, friable silty clay loam about 2 inches thick. The subsoil is about 14 inches thick; it is dark brown and brown, friable very shaly silty clay loam. Below a depth of 16 inches is bedded fragmental shale. The beds are 1 to 4 inches thick. The shale is light red, strong brown, and pink.

Included with this soil in mapping are spots of Yunes soils with less than 40 percent slopes. Also included are a few small areas on tops of hills and along drainageways where the bedded shale is exposed. These soils and areas of shale make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is not suited to cultivated crops because it is very steep and shallow to bedded shale. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of managment. Logging roads, skid trails, and planting should be on the contour to help control erosion.

The use of logging equipment is restricted at times because the soils are slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

Use and management of the soils

The soil survey is a detailed inventory and evaluation of the most basic resource of the survey area—the soil. It is useful in adjusting land use, including urbanization, to the limitations and potentials of natural resources and the environment. Also, it can help avoid soil-related failures in uses of the land.

While a soil survey is in progress, soil scientists, conservationists, engineers, and others keep extensive notes about the nature of the soils and about unique aspects of behavior of the soils. These notes include data on erosion, drought damage to specific crops, yield estimates, flooding, the functioning of septic tank disposal systems, and other factors affecting the productivity, potential, and limitations of the soils under various uses and management. In this way, field experience and measured data on soil properties and performance are used as a basis for predicting soil behavior.

Information in this section is useful in planning use and management of soils for crops, pasture, and woodland and as sites for buildings, highways and other transportation systems, sanitary facilities, and parks and other recreation facilities. From the data presented, the potential of each soil for specified land uses can be determined, soil limitations to these land uses can be identified, and costly failures in houses and other structures, caused by unfavorable soil properties, can be avoided. A site where soil properties are favorable can be selected, or practices that will overcome the soil limitations can be planned.

Planners and others using the soil survey can evaluate the impact of specific land uses on the overall productivity of the survey area or other broad planning area and on the environment. Productivity and the environment are closely related to the nature of the soil. Plans should maintain or create a land-use pattern in harmony with the natural soil.

Contractors can find information that is useful in locating sources of sand and gravel, roadfill, and topsoil. Other information indicates the presence of bedrock, wetness, or very firm soil horizons that cause difficulty in excavation.

Health officials, highway officials, engineers, and many other specialists also can find useful information in this soil survey. The safe disposal of wastes, for example, is closely related to properties of the soil. Pavements, sidewalks, campsites, playgrounds, lawns, and trees and shrubs are influenced by the nature of the soil.

Crops and pasture

The major management concerns in the use of the soils for crops and pasture are described in this section. In addition, the crops or pasture plants best suited to the soil, including some not commonly grown in the survey area, are discussed; the system of land capability classification used by the Soil Conservation Service is explained; and the estimated yields of the main crops and hay and pasture plants are presented for each soil.

This section provides information about the overall agricultural potential of the survey area and about the management practices that are needed. The information is useful to equipment dealers, land improvement contractors, fertilizer companies, processing companies, planners, conservationists, and others. For each kind of soil, information about management is presented in the section "Soil maps for detailed planning." Planners of management systems for individual fields or farms should also consider the detailed information given in the description of each soil.

More than 300,000 acres in the survey area was used for crops and pasture in 1967, according to the Conservation Needs Inventory. Of this total, more than 89,000 acres was in crops and almost 211,000 acres in pasture.

The potential of the soils of the San Juan Area for increased production of food is good. There is considerable reserve productive capacity that is not being used for crops or pasture at the present time. This potential productive capacity could be further increased by extending the latest crop production technology to all land suitable for cropland in the survey area. This soil survey can greatly facilitate the application of such technology.

Acreage in crops and pasture has gradually been decreasing as more land is used for urban development. This is especially true in the urban fringe areas near the San Juan metropolitan area. The use of this soil survey can help in making land use decisions that will influence the role of farming in prime land retention.

Soil erosion is the major soil problem of cropland and pastureland in the San Juan Area. Where the slope is more than 5 percent, erosion is a hazard. Aceitunas, Almirante, Rio Arriba, and Vega Alta soils, for example, have slopes of 5 to 12 percent.

The loss of the surface layer through erosion is damaging for two reasons. First, productivity is reduced as the surface layer is lost and part of the subsoil is incorporated into the plowed layer. Loss of the surface layer is especially damaging on soils with a clayey subsoil such as the Lares, Mabi, and Montegrande soils. Erosion also reduces productivity on soils that tend to be droughty such as the Catano, Durados, Estacion, and Reilly soils. Second, soil erosion on farmland results in sediment entering streams and lakes. Control of erosion minimizes the pollution of streams by sediment and improves quality of water for human use, for recreation, and for fish and wildlife.

In many sloping fields, preparing a good seedbed and tilling are difficult on clayey spots, because the original, friable surface layer has been eroded away. Such spots are common in moderately eroded areas of Almirante and Vega Alta soils.

Erosion control practices provide protective surface cover, reduce runoff, and increase infiltration. A cropping system that keeps vegetative cover on the soil for extended periods can hold soil erosion losses to amounts that will not reduce the productive capacity of the soils. On livestock farms, which require pasture and cut grasses, the legume and grass forage crops reduce erosion on sloping land and also provide nitrogen and improve tilth.

Contour tillage or terracing is practical on soils that have long and regular slopes. On soils with short and irregular slopes, cropping systems that provide substantial vegetative cover are required to control erosion unless minimum tillage is practiced. Minimizing tillage and leaving crop residue on the surface help to increase infiltration and reduce the hazards of runoff and erosion. These practices can be adapted to most soils in the survey area. No tillage for row crops is effective in reducing erosion on sloping land and can be adapted to many soils with loamy surface layers, but is more difficult to practice successfully on soils with a clayey surface layer.

Diversions, terraces, and hillside ditches (fig. 12) reduce the length of slope and reduce runoff and erosion. They are more practical on deep, well drained soils that have regular slopes.

Information for the design of erosion control practices for each kind of soil is contained in the Technical Guide, available in the local offices of the Soil Conservation Service.

Soil drainage is the major management practice in some soils of the San Juan Area which are used for crops and pastures. Some soils are naturally so wet that the production of crops common to the area is not generally possible. These are the very poorly drained Hydraquents, Martin Pena, and Saladar soils.

Unless artificially drained, some poorly drained and somewhat poorly drained soils are so wet that crops are damaged during most years when the seasonal water table is high. In this category are the Bajura, Sabana Seca, and Vega Baja soils.

Soils such as the Coloso, Mabi, and Montegrande require less intensive drainage systems for sustained production.

The design of drainage systems varies with the kind of soil. A combination of surface and subsurface drainage is needed for the poorly drained soils for intensive row cropping. Drains have to be more closely spaced in soils with slow permeability than in permeable soils. Finding adequate outlets for drainage systems is difficult in some areas of the Bajura, Sabana Seca, and Vega Baja soils. Information on drainage design for each kind of soil is contained in the Technical Guide, available in local offices of the Soil Conservation Service.

Soil fertility is naturally low in most soils of the coastal plains of the survey area. These soils are very strongly acid and leached. Unless limed and fertilized, Aceitunas, Almirante, Bayamon, Lares, Torres, and Vega Alta soils have low to moderate productivity. The soils on the flood plains, such as the Toa, Bajura, and Coloso, range from neutral to slightly acid and are naturally higher in plant nutrients.

Some soils of the uplands such as Aibonito, Consumo, Daguey, Humatas, Limones, and Los Guineos are steep and very strongly acid, and the fertility is naturally low. They require applications of lime and fertilizer.

Others, such as Juncos, Morado, and Mucara soils, are slightly acid and are naturally higher in plant nutrients.

On all soils, additions of lime and fertilizer should be based on the results of soil tests, on the need of the crop, and on the expected level of yields.

Soil tilth is an important factor in the germination of seeds and in the infiltration of water into the soil. Soils with good tilth are granular and porous.

Many of the soils of the survey area have moderate amounts of organic matter in the surface layer. Generally the structure is moderate granular, and physical condition is good. However, if the erosion is moderate or severe, the subsoil, which is clayey, is exposed. The subsoil reduces infiltration and increases runoff. Regular additions of crop residue, manure, and other organic material can help to improve soil structure and reduce erosion.

Crops suited to the soils and climate of the San Juan Area and grown commercially are plantains, bananas, taniers, yams, sweet potatoes, tobacco, and fruit orchards.

There is high potential for the production of sugarcane in the San Juan Area.

Special crops, such as tomatoes, green peppers, cabbage, oranges, grapefruits, limes, chironjas and West Indian cherries, have high potential in the area. There is also a high potential for ornamental plants and shrubs in the uplands and in the coastal plains of the area.

The best adapted species for pasture are stargrass and pangolagrass and, to some extent, guineagrass.

Commercial plantings of rice are feasible in the somewhat poorly drained and poorly drained soils of the flood plains such as the Coloso and Bajura soils.

Coffee, both sun and shade varieties, does very well in the cooler uplands of the San Juan Area.

Latest information and suggestions for growing these crops can be obtained from the local offices of the Soil Conservation Service.

Yields per acre

The average yields per acre that can be expected of the principal crops under a high level of management are shown in table 5. In any given year, yields may be higher or lower than those indicated in the table because of variations in rainfall and other climatic factors. Absence of an estimated yield indicates that the crop is not suited to or not commonly grown on the soil or that a given crop is not commonly irrigated.

The estimated yields were based mainly on the experience and records of farmers, conservationists, and extension agents. Results of field trials and demonstrations and available yield data from nearby areas were also considered.

The yields were estimated assuming that the latest soil and crop management practices were used. Hay and pasture yields were estimated for the most productive varieties of grasses and legumes suited to the climate and the soil. A few farmers may be obtaining average yields higher than those shown in table 5.

The management needed to achieve the indicated yields of the various crops depends on the kind of soil and the crop. Such management provides drainage, erosion control, and protection from flooding; the proper planting and seeding rates; suitable high-yielding crop varieties; appropriate tillage practices, including time of tillage and seedbed preparation and tilling when soil moisture is favorable; control of weeds, plant diseases, and harmful insects; favorable soil reaction and optimum levels of nitrogen, phosphorus, potassium, and trace elements for each crop; effective use of crop residue, barnyard manure, and green-manure crops; harvesting crops with the smallest possible loss; and timeliness of all fieldwork.

The estimated yields reflect the productive capacity of the soils for each of the principal crops. Yields are likely to increase as new production technology is developed. The productivity of a given soil compared with that of other soils, however, is not likely to change.

Crops other than those shown in table 5 are grown in the survey area, but estimated yields are not included because the acreage of these crops is small. The local offices of the Soil Conservation Service and the Cooperative Extension Service can provide information about the management concerns and productivity of the soils for these crops.

Capability classes and subclasses

Capability classes and subclasses show, in a general way, the suitability of soils for most kinds of field crops. The soils are classed according to their limitations when they are used for field crops, the risk of damage when they are used, and the way they respond to treatment. The grouping does not take into account major and generally expensive landforming that would change slope, depth, or other characteristics of the soils; does not take into consideration possible but unlikely major reclamation projects; and does not apply to rice, cranberries, horticultural crops, or other crops that require special management. Capability classification is not a substitute for interpretations designed to show suitability and limitations of groups of soils for rangeland, for forest trees, or for engineering purposes.

In the capability system, all kinds of soil are grouped at three levels: capability class, subclass, and unit. These levels are defined in the following paragraphs. A survey area may not have soils of all classes.

Capability classes, the broadest groups, are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use. The classes are defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.

Class III soils have severe limitations that reduce the choice of plants, or that require special conservation practices, or both.

Class IV soils have very severe limitations that reduce the choice of plants, or that require very careful management, or both.

Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use.

Class VI soils have severe limitations that make them generally unsuitable for cultivation.

Class VII soils have very severe limitations that make them unsuitable for cultivation.

Class VIII soils and landforms have limitations that nearly preclude their use for commercial crop production.

Capability subclasses are soil groups within one class; they are designated by adding a small letter, *e*, *w*, *s*, or *c*, to the class numeral, for example, IIe. The letter *e* shows that the main limitation is risk of erosion unless close-growing plant cover is maintained; *w* shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); *s* shows that the soil is limited mainly because it is shallow, droughty, or stony; and *c*, used in only some parts of the United States, shows that the chief limitation is climate that is too cold or too dry.

In class I there are no subclasses because the soils of this class have few limitations. Class V contains only the subclasses indicated by *w*, *s*, or *c* because the soils in class V are subject to little or no erosion, though they have other limitations that restrict their use to pasture, rangeland, woodland, wildlife habitat, or recreation.

The acreage of soils in each capability class and subclass is indicated in table 6. All soils in the survey area except those named at a level higher than the series are included. Some of the soils that are well suited to crops and pasture may be in low-intensity use, for example, soils in capability classes I and II. Data in this table can be used to determine the farming potential of such soils.

Woodland

When Puerto Rico was colonized in the early 1500's, the island was completely covered by forests, but land clearing for farms was soon begun. By 1880 most of the forests had been cut. Some areas were unsuitable for permanent cultivation and were abandoned when their fertility was lost. Later, some of these areas were again cleared, cultivated, and abandoned. Land thus abandoned generally was taken over by inferior volunteer trees.

According to the 1967 Conservation Needs Inventory, there was a total of 72,239 acres of woodland: 11,637 acres of commercial forests and 60,602 of noncommercial forests. The total forested acreage is about 16 percent of the San Juan Area.

Forest is an excellent use of the soils of the San Juan Area for the protection of soil and water resources. Forest cover can minimize floods, reduce the amount of soil material lost as sediment in rivers, and hold runoff into periods of dry weather. Some natural noncommercial forests should be converted to commercial. Others should be protected and left in their natural state. Trees should be planted in some nonforested areas.

Species having the best potential for the San Juan area are Honduras pine, Honduras mahogany, kadam, teak, and eucalyptus.

Woodland management and productivity

Table 7 contains information useful to woodland owners or forest managers planning use of soils for wood crops. Mapping unit symbols for soils suitable for wood crops are listed, and the ordination (woodland suitability) symbol for each soil is given. All soils bearing the same ordination symbol require the same general kinds of woodland management and have about the same potential productivity.

The first part of the *ordination symbol*, a number, indicates the potential productivity of the soils for important trees. The number 1 indicates very high productivity; 2, high; 3, moderately high; 4, moderate; and 5, low. The second part of the symbol, a letter, indicates the major kind of soil limitation. The letter *x* indicates stoniness or rockiness; *w*, excessive water in or on the soil; *t*, toxic substances in the soil; *d*, restricted root depth; *c*, clay in the upper part of the soil; *s*, sandy texture; *f*, high content of coarse fragments in the soil profile; and *r*, steep slopes. The letter *o* indicates insignificant limitations or restrictions. If a soil has more than one limitation, priority in placing the soil into a limitation class is in the following order: x, w, t, d, c, s, f, and r.

In table 7 the soils are also rated for a number of factors to be considered in management. *Slight*, *moderate*, and *severe* are used to indicate the degree of major soil limitations.

Ratings of the *erosion hazard* indicate the risk of loss of soil in well managed woodland. The risk is *slight* if the expected soil loss is small, *moderate* if some measures are needed to control erosion during logging and road construction, and *severe* if intensive management or special equipment and methods are needed to prevent excessive loss of soil.

Ratings of *equipment limitation* reflect the characteristics and conditions of the soil that restrict use of the equipment generally needed in woodland management or harvesting. A rating of *slight* indicates that use of equipment is not limited to a particular kind of equipment or time of year; *moderate* indicates a short seasonal limitation or a need for some modification in management or equipment; *severe* indicates a seasonal limitation, a need for special equipment or management, or a hazard in the use of equipment.

Seedling mortality ratings indicate the degree that the soil affects expected mortality of planted tree seedlings. Plant competition is not considered in the ratings. Seedlings from good planting stock that are properly planted during a period of sufficient rainfall are rated. A rating of *slight* indicates that the expected mortality of the planted seedlings is less than 25 percent; *moderate*, 25 to 50 percent; and *severe*, more than 50 percent.

The *potential productivity* of merchantable or *important trees* on a soil is expressed as the average yearly growth in board feet per acre. The trees listed are not native, but appear to be those best suited to the soil. The figures for average yearly growth are estimates. Important trees are those that woodland managers generally favor in intermediate or improvement cuttings. They are selected on the basis of growth rate, quality, value, and marketability.

Trees to plant are those that are suitable for commercial wood production and that are suited to the soils.

Engineering

This section provides information about the use of soils for building sites, sanitary facilities, construction material, and water management. Among those who can benefit from this information are engineers, landowners, community planners, town and city managers, land developers, builders, contractors, and farmers and ranchers.

The ratings in the engineering tables are based on test data and estimated data in the "Soil properties" section. The ratings were determined jointly by soil scientists and engineers of the Soil Conservation Service using known relationships between the soil properties and the behavior of soils in various engineering uses.

Among the soil properties and site conditions identified by a soil survey and used in determining the ratings in this section were grain-size distribution, liquid limit, plasticity index, soil reaction, depth to bedrock, hardness of bedrock that is within 5 or 6 feet of the surface, soil wetness, depth to a seasonal high water table, slope, likelihood of flooding, natural soil structure or aggregation, in-place soil density, and geologic origin of the soil material. Where pertinent, data about kinds of clay minerals, mineralogy of the sand and silt fractions, and the kind of absorbed cations were also considered.

On the basis of information assembled about soil properties, ranges of values can be estimated for erodibility, permeability, corrosivity, shrink-swell potential, available water capacity, shear strength, compressibility, slope stability, and other factors of expected soil behavior in engineering uses. As appropriate, these values can be applied to each major horizon of each soil or to the entire profile.

These factors of soil behavior affect construction and maintenance of roads, airport runways, pipelines, foundations for small buildings, ponds and small dams, irrigation projects, drainage systems, sewage and refuse disposal systems, and other engineering works. The ranges of values can be used to (1) select potential residential, commercial, industrial, and recreational uses; (2) make preliminary estimates pertinent to construction in a particular area; (3) evaluate alternative routes for roads, streets, highways, pipelines, and underground cables; (4) evaluate alternative sites for location of sanitary landfills, onsite sewage disposal systems, and other waste disposal facilities; (5) plan detailed onsite investigations of soils and geology; (6) find sources of gravel, sand, clay, and topsoil; (7) plan farm drainage systems, irrigation systems, ponds, terraces, and other structures for soil and water conservation; (8) relate performance of structures already built to the properties of the kinds of soil on which they are built so that performance of similar structures on the same or a similar soil in other locations can be predicted; and (9) predict the trafficability of soils for cross-country movement of vehicles and construction equipment.

Data presented in this section are useful for land-use planning and for choosing alternative practices or general designs that will overcome unfavorable soil properties and minimize soil-related failures. Limitations to the use of these data, however, should be well understood. First, the data are generally not presented for soil material below a depth of 5 or 6 feet. Also, because of the scale of the detailed map in this soil survey, small areas of soils that differ from the dominant soil may be included in mapping. Thus, these data do not eliminate the need for onsite investigations, testing, and analysis by personnel having expertise in the specific use contemplated.

The information is presented mainly in tables. Table 8 shows, for each kind of soil, the degree and kind of limitations for building site development; table 9, for sanitary facilities; and table 11, for water management. Table 10 shows the suitability of each kind of soil as a source of construction materials.

The information in the tables, along with the soil map, the soil descriptions, and other data provided in this survey, can be used to make additional interpretations and to construct interpretive maps for specific uses of land.

Some of the terms used in this soil survey have a special meaning in soil science. Many of these terms are defined in the Glossary.

Building site development

The degree and kind of soil limitations that affect shallow excavations, dwellings with and without basements, small commercial buildings, and local roads and streets are indicated in table 8. A *slight* limitation indicates that soil properties generally are favorable for the specified use; any limitation is minor and easily overcome. A *moderate* limitation indicates that soil properties and site features are unfavorable for the specified use, but the limitations can be overcome or minimized by special planning and design. A *severe* limitation indicates that one or more soil properties or site features are so unfavorable or difficult to overcome that a major increase in construction effort, special design, or intensive maintenance is required. For some soils rated severe, such costly measures may not be feasible.

Shallow excavations are made for pipelines, sewerlines, communications and power transmission lines, basements, and open ditches. Such digging or trenching is influenced by soil wetness caused by a seasonal high water table; the texture and consistence of soils; the tendency of soils to cave in or slough; and the presence of very firm, dense soil layers, bedrock, or large stones. In addition, excavations are affected by slope of the soil and the probability of flooding. Ratings do not apply to soil horizons below a depth of 6 feet unless otherwise noted.

In the soil series descriptions, the consistence of each soil horizon is given, and the presence of very firm or extremely firm horizons, usually difficult to excavate, is indicated.

Dwellings without basements and *small commercial buildings* referred to in table 8 are built on undisturbed soil and have foundation loads of a dwelling no more than three stories high. Separate ratings are made for small commercial buildings without basements and for dwellings without basements. For such structures, soils should be sufficiently stable that cracking or subsidence of the structure from settling or shear failure of the foundation does not occur. These ratings were determined from estimates of the shear strength, compressibility, and shrink-swell potential of the soil. Soil texture, plasticity and in-place density, potential frost action, soil wetness, and depth to a seasonal high water table were also considered. Soil wetness and depth to a seasonal high water table indicate potential difficulty in providing adequate drainage for basements, lawns, and gardens. Depth to bedrock, slope, and large stones in or on the soil are also important considerations in the choice of sites for these structures and were considered in determining the ratings. Susceptibility to flooding is a serious hazard.

Local roads and streets referred to in table 8 have an all-weather surface that can carry light to medium traffic all year. They consist of a subgrade of the underlying soil material; a base of gravel, crushed rock fragments, or soil material stabilized with lime or cement; and a flexible or rigid surface, commonly asphalt or concrete. The roads are graded with soil material at hand, and most cuts and fills are less than 6 feet deep.

The load supporting capacity and the stability of the soil as well as the quantity and workability of fill material available are important in design and construction of roads and streets. The classifications of the soil and the soil texture, density, shrink-swell potential, and potential frost action are indicators of the traffic supporting capacity used in making the ratings. Soil wetness, flooding, slope, depth to hard rock or very compact layers, and content of large stones affect stability and ease of excavation.

Sanitary facilities

Favorable soil properties and site features are needed for proper functioning of septic tank absorption fields, sewage lagoons, and sanitary landfills. The nature of the soil is important in selecting sites for these facilities and in identifying limiting soil properties and site features to be considered in design and installation. Also, those soil properties that affect ease of excavation or installation of these facilities will be of interest to contractors and local officials. Table 9 shows the degree and kind of limitations of each soil for such uses and for use of the soil as daily cover for landfills. It is important to observe local ordinances and regulations.

If the degree of soil limitation is expressed as *slight*, soils are generally favorable for the specified use and limitations are minor and easily overcome; if *moderate*, soil properties or site features are unfavorable for the specified use, but limitations can be overcome by special planning and design; and if *severe*, soil properties or site features are so unfavorable or difficult to overcome that major soil reclamation, special designs, or intensive maintenance is required. Soil suitability is rated by the terms *good*, *fair*, or *poor*, which, respectively, mean about the same as the terms *slight*, *moderate*, and *severe*.

Septic tank absorption fields are subsurface systems of tile or perforated pipe that distribute effluent from a septic tank into the natural soil. Only the soil horizons between depths of 18 and 72 inches are evaluated for this use. The soil properties and site features considered are those that affect the absorption of the effluent and those that affect the construction of the system.

Properties and features that affect absorption of the effluent are permeability, depth to seasonal high water table, depth to bedrock, and susceptibility to flooding. Stones, boulders, and shallowness to bedrock interfere with installation. Excessive slope can cause lateral seepage and surfacing of the effluent. Also, soil erosion and soil slippage are hazards if absorption fields are installed on sloping soils.

In some soils, loose sand and gravel or fractured bedrock is less than 4 feet below the tile lines. In these soils the absorption field does not adequately filter the effluent, and ground water in the area may be contaminated.

On many of the soils that have moderate or severe limitations for use as septic tank absorption fields, a system to lower the seasonal water table can be installed or the size of the absorption field can be increased so that performance is satisfactory.

Sewage lagoons are shallow ponds constructed to hold sewage while aerobic bacteria decompose the solid and liquid wastes. Lagoons have a nearly level floor and cut slopes or embankments of compacted soil material. Aerobic lagoons generally are designed to hold sewage within a depth of 2 to 5 feet. Nearly impervious soil material for the lagoon floor and sides is required to minimize seepage and contamination of ground water. Soils that are very high in content of organic matter and those that have cobbles, stones, or boulders are not suitable. Unless the soil has very slow permeability, contamination of ground water is a hazard where the seasonal high water table is above the level of the lagoon floor. In soils where the water table is seasonally high, seepage of ground water into the lagoon can seriously reduce the lagoon's capacity for liquid waste. Slope, depth to bedrock, and susceptibility to flooding also affect the suitability of sites for sewage lagoons or the cost of construction. Shear strength and permeability of compacted soil material affect the performance of embankments.

Sanitary landfill is a method of disposing of solid waste by placing refuse in successive layers either in excavated trenches or on the surface of the soil. The waste is spread, compacted, and covered daily with a thin layer of soil material. Landfill areas are subject to heavy vehicular traffic. Risk of polluting ground water and trafficability affect the suitability of a soil for this use. The best soils have a loamy or silty texture, have moderate to slow permeability, are deep to a seasonal water table, and are not subject to flooding. Clayey soils are likely to be sticky and difficult to spread. Sandy or gravelly soils generally have rapid permeability, which might allow noxious liquids to contaminate ground water. Soil wetness can be a limitation, because operating heavy equipment on a wet soil is difficult. Seepage into the refuse increases the risk of pollution of ground water.

Ease of excavation affects the suitability of a soil for the trench type of landfill. A suitable soil is deep to bedrock and free of large stones and boulders. If the seasonal water table is high, water will seep into trenches.

Unless otherwise stated, the limitations in table 9 apply only to the soil material within a depth of about 6 feet. If the trench is deeper, a limitation of slight or moderate may not be valid. Site investigation is needed before a site is selected.

Daily cover for landfill should be soil that is easy to excavate and spread over the compacted fill in wet and dry periods. Soils that are loamy or silty and free of stones or boulders are better than other soils. Clayey soils may be sticky and difficult to spread; sandy soils may be subject to soil blowing.

The soils selected for final cover of landfills should be suitable for growing plants. Of all the horizons, the A horizon in most soils has the best workability, more organic matter, and the best potential for growing plants. Thus, for either the area- or trench-type landfill, stockpiling material from the A horizon for use as the surface layer of the final cover is desirable.

Where it is necessary to bring in soil material for daily or final cover, thickness of suitable soil material available and depth to a seasonal high water table in soils surrounding the sites should be evaluated. Other factors to be evaluated are those that affect reclamation of the borrow areas. These factors include slope, erodibility, and potential for plant growth.

Construction materials

The suitability of each soil as a source of roadfill, sand, gravel, and topsoil is indicated in table 10 by ratings of good, fair, or poor. The texture, thickness, and organic-matter content of each soil horizon are important factors in rating soils for use as construction materials. Each soil is evaluated to the depth observed, generally about 6 feet.

Roadfill is soil material used in embankments for roads. Soils are evaluated as a source of roadfill for low embankments, which generally are less than 6 feet high and less exacting in design than high embankments. The ratings reflect the ease of excavating and working the material and the expected performance of the material where it has been compacted and adequately drained. The performance of soil after it is stabilized with lime or cement is not considered in the ratings, but information about some of the soil properties that influence such performance is given in the descriptions of the soil series.

The ratings apply to the soil material between the A horizon and a depth of 5 to 6 feet. It is assumed that soil horizons will be mixed during excavation and spreading. Many soils have horizons of contrasting suitability within their profile. The estimated engineering properties in table 13 provide specific information about the nature of each horizon. This information can help determine the suitability of each horizon for roadfill.

Soils rated *good* are coarse grained. They have low shrink-swell potential, low potential frost action, and few cobbles and stones. They are at least moderately well drained and have slopes of 15 percent or less. Soils rated *fair* have a plasticity index of less than 15 and have other limiting features, such as moderate shrink-swell potential, moderately steep slopes, wetness, or many stones. If the thickness of suitable material is less than 3 feet, the entire soil is rated *poor.*

Sand and *gravel* are used in great quantities in many kinds of construction. The ratings in table 10 provide guidance as to where to look for probable sources and are based on the probability that soils in a given area contain sizable quantities of sand or gravel. A soil rated *good* or *fair* has a layer of suitable material at least 3 feet thick, the top of which is within a depth of 6 feet. Coarse fragments of soft bedrock material, such as shale and siltstone, are not considered to be sand and gravel. Fine-grained soils are not suitable sources of sand and gravel.

The ratings do not take into account depth to the water table or other factors that affect excavation of the material. Descriptions of grain size, kinds of minerals, reaction, and stratification are given in the soil series descriptions and in table 13.

Topsoil is used in areas where vegetation is to be established and maintained. Suitability is affected mainly by the ease of working and spreading the soil material in preparing a seedbed and by the ability of the soil material to support plantlife. Also considered is the damage that can result at the area from which the topsoil is taken.

The ease of excavation is influenced by the thickness of suitable material, wetness, slope, and amount of stones. The ability of the soil to support plantlife is determined by texture, structure, and the amount of soluble salts or toxic substances. Organic matter in the A1 or Ap horizon greatly increases the absorption and retention of moisture and nutrients. Therefore, the soil material from these horizons should be carefully preserved for later use.

Soils rated *good* have at least 16 inches of friable loamy material at their surface. They are free of stones and cobbles, are low in content of gravel, and have gentle slopes. They are low in soluble salts that can limit or prevent plant growth. They are naturally fertile or respond well to fertilizer. They are not so wet that excavation is difficult during most of the year.

Soils rated *fair* are loose sandy soils or firm loamy or clayey soils in which the suitable material is only 8 to 16 inches thick or soils that have appreciable amounts of gravel, stones, or soluble salt.

Soils rated *poor* are very sandy soils and very firm clayey soils; soils with suitable layers less than 8 inches thick; soils having large amounts of gravel, stones, or soluble salt; steep soils; and poorly drained soils.

Although a rating of *good* is not based entirely on high content of organic matter, a surface horizon is generally preferred for topsoil because of its organic-matter content. This horizon is designated as A1 or Ap in the soil series descriptions. The absorption and retention of moisture and nutrients for plant growth are greatly increased by organic matter.

Water management

Many soil properties and site features that affect water management practices have been identified in this soil survey. In table 11 soil and site features that affect use are indicated for each kind of soil. This information is significant in planning, installing, and maintaining water control structures.

Pond reservoir areas hold water behind a dam or embankment. Soils best suited to this use have a low seepage potential, which is determined by permeability and the depth to fractured or permeable bedrock or other permeable material.

Embankments, dikes, and levees require soil material that is resistant to seepage, erosion, and piping and has favorable stability, shrink-swell potential, shear strength, and compaction characteristics. Large stones and organic matter in a soil downgrade the suitability of a soil for use in embankments, dikes, and levees.

Drainage of soil is affected by such soil properties as permeability; texture; depth to bedrock, hardpan, or other layers that affect the rate of water movement; depth to the water table; slope; stability of ditchbanks; susceptibility to flooding; salinity and alkalinity; and availability of outlets for drainage.

Terraces and diversions are embankments or a combination of channels and ridges constructed across a slope to intercept runoff. They allow water to soak into the soil or flow slowly to an outlet. Features that affect suitability of a soil for terraces are uniformity and steepness of slope; depth to bedrock, hardpan, or other unfavorable material; large stones; permeability; ease of establishing vegetation; and resistance to water erosion, soil blowing, soil slipping, and piping.

Grassed waterways are constructed to channel runoff to outlets at a nonerosive velocity. Features that affect the use of soils for waterways are slope, permeability, erodibility, wetness, and suitability for permanent vegetation.

Recreation

The soils of the survey area are rated in table 12 according to limitations that affect their suitability for recreation uses. The ratings are based on such restrictive soil features as flooding, wetness, slope, and texture of the surface layer. Not considered in these ratings, but important in evaluating a site, are location and accessibility of the area, size and shape of the area and its scenic quality, the ability of the soil to support vegetation, access to water, potential water impoundment sites available, and either access to public sewerlines or capacity of the soil to absorb septic tank effluent. Soils subject to flooding are limited, in varying degree, for recreation use by the duration and intensity of flooding and the season when flooding occurs. Onsite assessment of height, duration, intensity, and frequency of flooding is essential in planning recreation facilities.

The degree of the limitation of the soils is expressed as slight, moderate, or severe. *Slight* means that the soil properties are generally favorable and that the limitations are minor and easily overcome. *Moderate* means that the limitations can be overcome or alleviated by planning, design, or special maintenance. *Severe* means that soil properties are unfavorable and that limitations can be offset only by costly soil reclamation, special design, intensive maintenance, limited use, or by a combination of these measures.

The information in table 12 can be supplemented by information in other parts of this survey. Especially helpful are interpretations for septic tank absorption fields, given in table 9, and interpretations for dwellings without basements and for local roads and streets, given in table 8.

Camp areas require such site preparation as shaping and leveling for tent and parking areas, stabilizing roads and intensively used areas, and installing sanitary facilities and utility lines. Camp areas are subject to heavy foot traffic and some vehicular traffic. The best soils for this use have mild slopes and are not wet or subject to flooding during the period of use. The surface has few or no stones or boulders, absorbs rainfall readily but remains firm, and is not dusty when dry. Strong slopes and stones or boulders can greatly increase the cost of constructing camping sites.

Picnic areas are subject to heavy foot traffic. Most vehicular traffic is confined to access roads and parking areas. The best soils for use as picnic areas are firm when wet, are not dusty when dry, are not subject to flooding during the period of use, and do not have slopes or stones or boulders that will increase the cost of shaping sites or of building access roads and parking areas.

Playgrounds require soils that can withstand intensive foot traffic. The best soils are almost level and are not wet or subject to flooding during the season of use. The surface is free of stones or boulders, is firm after rains, and is not dusty when dry. If shaping is required to obtain a uniform grade, the depth of the soil over bedrock or hardpan should be enough to allow necessary grading.

Paths and trails for walking, horseback riding, bicycling, and other uses should require little or no cutting and filling. The best soils for this use are those that are not wet, are firm after rains, are not dusty when dry, and are not subject to flooding more than once during the annual period of use. They should have moderate slopes and have few or no stones or boulders on the surface.

Soil properties

Extensive data about soil properties are summarized on the following pages. The two main sources of these data are the many thousands of soil borings made during the course of the survey and the laboratory analyses of selected soil samples from typical profiles.

In making soil borings during field mapping, soil scientists can identify several important soil properties. They note the seasonal soil moisture condition or the presence of free water and its depth. For each horizon in the profile, they note the thickness and color of the soil material; the texture, or amount of clay, silt, sand, and gravel or other coarse fragments; the structure, or the natural pattern of cracks and pores in the undisturbed soil; and the consistence of the soil material in place under the existing soil moisture conditions. They record the depth of plant roots, determine the pH or reaction of the soil, and identify any free carbonates.

Samples of soil material are analyzed in the laboratory to verify the field estimates of soil properties and to determine all major properties of key soils, especially properties that cannot be estimated accurately by field observation. Laboratory analyses are not conducted for all soil series in the survey area, but laboratory data for many soil series not tested are available from nearby survey areas.

The available field and laboratory data are summarized in tables. The tables give the estimated range of engineering properties, the engineering classifications, and the physical and chemical properties of each major horizon of each soil in the survey area. They also present data about pertinent soil and water features.

Engineering properties

Table 13 gives estimates of engineering properties and classifications for the major horizons of each soil in the survey area.

Most soils have, within the upper 5 or 6 feet, horizons of contrasting properties. Table 13 gives information for each of these contrasting horizons in a typical profile. *Depth* to the upper and lower boundaries of each horizon is indicated. More information about the range in depth and about other properties in each horizon is given for each soil series in the section "Soil series and morphology."

Texture is described in table 13 in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in soil material that is less than 2 millimeters in diameter. "Loam," for example, is soil material that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If a soil contains gravel or other particles coarser than sand, an appropriate modifier is added, for example, "gravelly loam." Other texture terms are defined in the Glossary.

The two systems commonly used in classifying soils for engineering use are the Unified Soil Classification System (Unified) (*2*) and the system adopted by the American Association of State Highway and Transportation Officials (AASHTO) (*1*).

The *Unified* system classifies soils according to properties that affect their use as construction material. Soils are classified according to grain-size distribution of the fraction less than 3 inches in diameter, plasticity index, liquid limit, and organic-matter content. Soils are grouped into 15 classes—eight classes of coarse-grained soils, identified as GW, GP, GM, GC, SW, SP, SM, and SC; six classes of fine-grained soils, identified as ML, CL, OL, MH, CH, and OH; and one class of highly organic soils, identified as Pt. Soils on the borderline between two classes have a dual classification symbol, for example, CL-ML.

The *AASHTO* system classifies soils according to those properties that affect their use in highway construction and maintenance. In this system a mineral soil is classified in one of seven basic groups ranging from A-1 through A-7 on the basis of grain-size distribution, liquid limit, and plasticity index. Soils in group A-1 are coarse grained and low in content of fines. At the other extreme, in group A-7, are fine-grained soils. Highly organic soils are classified in group A-8 on the basis of visual inspection.

When laboratory data are available, the A-1, A-2, and A-7 groups are further classified as follows: A-1-a, A-1-b, A-2-4, A-2-5, A-2-6, A-2-7, A-7-5, and A-7-6. As an additional refinement, the desirability of soils as subgrade material can be indicated by a group index number. These numbers range from 0 for the best subgrade material to 20 or higher for the poorest. The estimated classification, without group index numbers, is given in table 13. Also in table 13 the percentage, by weight, of rock fragments more than 3 inches in diameter is estimated for each major horizon. These estimates are determined mainly by observing volume percentage in the field and then converting that, by formula, to weight percentage.

Percentage of the soil material less than 3 inches in diameter that passes each of four sieves (U.S. standard) is estimated for each major horizon. The estimates are based on tests of soils that were sampled in the survey area and in nearby areas and on field estimates from many borings made during the survey.

Liquid limit and *plasticity index* indicate the effect of water on the strength and consistence of soil. These indexes are used in both the Unified and AASHTO soil classification systems. They are also used as indicators in making general predictions of soil behavior. Range in liquid limit and plasticity index are estimated on the basis of test data from the survey area or from nearby areas and on observations of the many soil borings made during the survey.

The estimates are rounded to the nearest 5 percent. Thus, if the ranges of gradation and Atterburg limits extend a marginal amount across classification boundaries (1 or 2 percent), the classification in the marginal zone is omitted.

Physical and chemical properties

Table 14 shows estimated values for several soil characteristics and features that affect behavior of soils in engineering uses. These estimates are given for each major horizon, at the depths indicated, in the typical pedon of each soil. The estimates are based on field observations and on test data for these and similar soils.

Permeability is estimated on the basis of known relationships among the soil characteristics observed in the field—particularly soil structure, porosity, and gradation or texture—that influence the downward movement of water in the soil. The estimates are for vertical water movement when the soil is saturated. Not considered in the estimates is lateral seepage or such transient soil features as plowpans and surface crusts. Permeability of the soil is an important factor to be considered in planning and designing drainage systems, in evaluating the potential of soils for septic tank systems and other waste disposal systems, and in many other aspects of land use and management.

Available water capacity is rated on the basis of soil characteristics that influence the ability of the soil to hold water and make it available to plants. Important characteristics are content of organic matter, soil texture, and soil structure. Shallow-rooted plants are not likely to use the available water from the deeper soil horizons. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design of irrigation systems.

Soil reaction is expressed as a range in pH values. The range in pH of each major horizon is based on many field checks. For many soils, the values have been verified by laboratory analyses. Soil reaction is important in selecting the crops, ornamental plants, or other plants to be grown; in evaluating soil amendments for fertility and stabilization; and in evaluating the corrosivity of soils.

Shrink-swell potential depends mainly on the amount and kind of clay in the soil. Laboratory measurements of the swelling of undisturbed clods were made for many soils. For others the swelling was estimated on the basis of the kind and amount of clay in the soil and on measurements of similar soils. The size of the load and the magnitude of the change in soil moisture content also influence the swelling of soils. Shrinking and swelling of some soils can cause damage to building foundations, basement walls, roads, and other structures unless special designs are used. A high shrink-swell potential indicates that special design and added expense may be required if the planned use of the soil will not tolerate large volume changes.

Risk of corrosion pertains to potential soil-induced chemical action that dissolves or weakens uncoated steel or concrete. The rate of corrosion of uncoated steel is related to soil moisture, particle-size distribution, total acidity, and electrical conductivity of the soil material. The rate of corrosion of concrete is based mainly on the sulfate content, texture, and acidity of the soil. Protective measures for steel or more resistant concrete help to avoid or minimize damage resulting from the corrosion. Uncoated steel intersecting soil boundaries or soil horizons is more susceptible to corrosion than an installation that is entirely within one kind of soil or within one soil horizon.

Erosion factors are used to predict the erodibility of a soil and its tolerance to erosion in relation to specific kinds of land use and treatment. The soil erodibility factor (K) is a measure of the susceptibility of the soil to erosion by water. Soils having the highest K values are the most erodible. K values range from 0.10 to 0.64. To estimate annual soil loss per acre, the K value of a soil is modified by factors representing plant cover, grade and length of slope, management practices, and climate. The soil-loss tolerance factor (T) is the maximum rate of soil erosion, whether from rainfall or soil blowing, that can occur without reducing crop production or environmental quality. The rate is expressed in tons of soil loss per acre per year.

Soil and water features

Table 15 contains information helpful in planning land uses and engineering projects that are likely to be affected by soil and water features.

Hydrologic soil groups are used to estimate runoff from precipitation. Soils not protected by vegetation are placed in one of four groups on the basis of the intake of water after the soils have been wetted and have received precipitation from long-duration storms.

The four hydrologic soil groups are:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils that have a layer that impedes the downward movement of water or soils that have moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clay soils that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Flooding is the temporary covering of soil with water from overflowing streams, with runoff from adjacent slopes, and by tides. Water standing for short periods after rains or after snow melts is not considered flooding, nor is water in swamps and marshes. Flooding is rated in general terms that describe the frequency and duration of flooding and the time of year when flooding is most likely. The ratings are based on evidence in the soil profile of the effects of flooding, namely thin strata of gravel, sand, silt, or, in places, clay deposited by floodwater; irregular decrease in organic-matter content with increasing depth; and absence of distinctive soil horizons that form in soils of the area that are not subject to flooding. The ratings are also based on local information about floodwater levels in the area and the extent of flooding and on information that relates the position of each soil on the landscape to historic floods.

The generalized description of flood hazards is of value in land-use planning and provides a valid basis for land-use restrictions. The soil data are less specific, however, than those provided by detailed engineering surveys that delineate flood-prone areas at specific flood frequency levels.

High water table is the highest level of a saturated zone more than 6 inches thick for a continuous period of more than 2 weeks during most years. The depth to a seasonal high water table applies to undrained soils. Estimates are based mainly on the relationship between grayish colors or mottles in the soil and the depth to free water observed in many borings made during the course of the soil survey. Indicated in table 15 are the depth to the seasonal high water table; the kind of water table, that is, perched, artesian, or apparent; and the months of the year that the water table commonly is high. Only saturated zones above a depth of 5 or 6 feet are indicated.

Information about the seasonal high water table helps in assessing the need for specially designed foundations, the need for specific kinds of drainage systems, and the need for footing drains to insure dry basements. Such information is also needed to decide whether or not construction of basements is feasible and to determine how septic tank absorption fields and other underground installations will function. Also, a seasonal high water table affects ease of excavation.

Depth to bedrock is shown for all soils that are underlain by bedrock at a depth of 5 to 6 feet or less. For many soils, the limited depth to bedrock is a part of the definition of the soil series. The depths shown are based on measurements made in many soil borings and on other observations during the mapping of the soils. The kind of bedrock and its hardness as related to ease of excavation is also shown. Rippable bedrock can be excavated with a single-tooth ripping attachment on a 200-horsepower tractor, but hard bedrock generally requires blasting.

Subsidence is the settlement of organic soils or of soils containing semifluid layers. Initial subsidence generally results from drainage. Total subsidence is initial subsidence plus the slow sinking that occurs over a period of several years as a result of the oxidation or compression of organic material.

Classification of soils

This section describes the soil series of the survey area, defines the current system of classifying soils, and classifies the soils of the area according to that system.

Soil series and morphology

In this section, each soil series recognized in the survey area is described in detail. The descriptions are arranged in alphabetic order by series name.

Characteristics of the soil and the material in which it formed are discussed for each series. The soil is then compared to similar soils and to nearby soils of other series. Then a pedon, a small three-dimensional area of soil that is typical of the soil series in the survey area, is described. The detailed descriptions of each soil horizon follow standards in the Soil Survey Manual (*3*). Unless otherwise noted, colors described are for moist soil.

Following the pedon description is the range of important characteristics of the soil series in this survey area. Phases, or mapping units, of each soil series are described in the section "Soil maps for detailed planning."

Aceitunas series

The Aceitunas series consists of clayey, oxidic, isohyperthermic Typic Palehumults. These soils are deep, well drained, and have a B2 horizon of yellowish red clay. They formed in fine textured sediments washed from limestone. The Aceitunas soils are on alluvial fans and in valleys. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 66 inches, and the mean annual temperature is 77 degrees F.

The Aceitunas soils are associated with the Via, Rio Arriba, and Mabi soils, but the clayey subsoil is not so expansive as that of those soils.

Typical pedon of Aceitunas clay, 5 to 12 percent slopes, 0.8 kilometer south of intersection of Highway 250 and Highway 1, then 25 feet west in a pangolagrass field.

Ap—0 to 8 inches, dark brown (7.5YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; few fine dark concretions; few fine pores; few krotovinas; very strongly acid; clear smooth boundary.

B21t—8 to 15 inches, yellowish red (5YR 4/6) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; many fine roots; common dead dark roots; few krotovinas; few fine pores; very strongly acid; gradual smooth boundary.

B22t—15 to 30 inches, yellowish red (5YR 4/8) clay; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; common dead roots; common patchy clay films; few pores; few fine roots; few fine weathered rock fragments; very strongly acid; gradual smooth boundary.

B23t—30 to 43 inches, yellowish red (5YR 4/8) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few dead roots; few pores; few weathered rock fragments; few patchy clay films on ped surfaces; very strongly acid; gradual smooth boundary.

B24t—43 to 60 inches, yellowish red (5YR 4/8) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine dark stains; patchy clay films, very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR or 5YR, value of 3 or 4, and chroma of 3 or 4.

The B2t horizon has hue of 5YR and 2.5YR, value of 4 to 6, and chroma of 6 to 8. It has weak to moderate fine and medium subangular blocky structure.

Aibonito series

The Aibonito series consists of clayey, oxidic, isohyperthermic Orthoxic Tropohumults. These soils are deep, well drained, and have a B2 horizon of strong brown clay. They formed in residuum of volcanic rocks. The Aibonito soils are on side slopes and ridgetops of volcanic uplands. Slopes range from 12 to 40 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 75 degrees F.

The Aibonito soils are associated with the Catalina, Comerio, and Mucara soils. They have a thinner solum than the Catalina and Comerio soils and a thicker solum than the Mucara soils.

Typical pedon of Aibonito clay, 20 to 40 percent slopes, 5 feet east from kilometer 6.2 of Highway 162, Aibonito, P.R.

Ap—0 to 7 inches, dark grayish brown (10YR 4/2) clay; moderate fine subangular blocky structure; very hard, friable, slightly sticky, plastic; many fine roots; very strongly acid; abrupt irregular boundary.

B1—7 to 11 inches, strong brown (7.5YR 5/6) clay; common fine distinct yellowish red (5YR 4/6) mottles in ped interiors and brown (10YR 4/3) coatings on ped surfaces; extremely firm, sticky, plastic; few fine roots restricted to the ped surfaces; few sand size grains; extremely acid; gradual wavy boundary.

B21t—11 to 22 inches, strong brown (7.5YR 5/6) clay; common fine distinct yellowish red (5YR 4/6) mottles and brown (10YR 4/3) coatings on surfaces of peds; strong coarse prismatic parting to moderate medium subangular blocky structure; extremely firm, sticky, plastic; few fine roots restricted to surfaces of peds; few sand size grains; extremely acid; gradual wavy boundary.

B22t—22 to 32 inches, strong brown (7.5YR 5/6) clay; common fine distinct red (2.5YR 5/6) mottles; strong coarse prismatic structure parting to moderate medium subangular blocky; brown (10YR 4/3) coatings on ped surfaces; extremely firm, sticky, plastic; few fine roots; few sand size grains; extremely acid; gradual wavy boundary.

B3—32 to 43 inches, strong brown (7.5YR 5/6) clay; many medium prominent yellowish brown (10YR 5/6) and red (2.5YR 4/6) mottles, and few medium prominent white (10YR 8/1) mottles; weak medium subangular blocky structure; thin patchy clay films; friable, slightly sticky, plastic; very few fine roots; extremely acid; gradual wavy boundary; 30 percent of this horizon is saprolite.

C1—43 to 65 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6), and white (10YR 8/1) clay saprolite; massive; friable, slightly sticky, plastic; extremely acid; gradual wavy boundary.

C2—65 to 110 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6), and white (10YR 8/1) silty clay saprolite; massive; friable, slightly sticky, slightly plastic; extremely acid. Rock structure is visible. Material can be easily crushed with fingers.

The solum is 33 to 56 inches thick. Reaction throughout is very strongly acid or extremely acid.

The A horizon has hue of 10YR and 7.5YR, value of 4, and chroma of 2 to 4.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 6 to 8.

The C horizons are clay and silty clay.

Almirante series

The Almirante series consists of clayey, oxidic, isohyperthermic Plinthic Paleudults. These soils are deep, are well drained, and have a B2 horizon of strong brown and brownish yellow clay underlain by plinthite layers. They formed in fine textured sediments of mixed origin. The Almirante soils are on coastal plains and in valleys between the limestone hills. Slopes range from 2 to 12 percent, but are dominantly 2 to 5 percent. The mean annual precipitation is 65 inches, and the mean annual temperature is 78 degrees F.

The Almirante soils are associated with the Bayamon, Matanzas, Tanama, and Vega Alta soils. They have a thicker solum than the Matanzas and the Tanama soils. They have plinthite which the Bayamon soils lack. They are deeper over the plinthite than the Vega Alta soils.

Typical pedon of Almirante clay, 2 to 5 percent slopes, 1 kilometer from intersection of Highway 693 and 694, then 40 feet north, Dorado, P.R.

Ap—0 to 7 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; many quartz grains; many fine dark concretions; very strongly acid; clear smooth boundary.

B21t—7 to 34 inches, strong brown (7.5YR 5/6) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; few patchy clay films; many quartz grains; common black stains; common fine roots; few fine pores; very strongly acid; clear smooth boundary.

B22t—34 to 46 inches, brownish yellow (10YR 6/8) and dark red (10R 3/6) clay; weak medium subangular blocky structure; firm, sticky, plastic; dark concretions; purple stains; few fine rock fragments; about 8 percent by volume is plinthite; very strongly acid; gradual smooth boundary.

B23t—46 to 60 inches, variegated brownish yellow (10YR 6/8), dark red (10R 3/6), and light gray (5Y 7/1) clay; weak medium subangular blocky structure; firm, sticky, plastic; about 15 percent by volume is plinthite; very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR, 7.5YR, or 5YR; value of 3 or 4; and chroma of 2 to 4.

The B2t horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 to 6; and chroma of 4 to 8. It has a weak to moderate fine to medium subangular blocky structure.

Bajura series

The Bajura series consists of fine, mixed, nonacid isohyperthermic Vertic Tropaquepts. These soils are deep, are poorly drained, and have a B horizon of dark gray clay. They formed in fine textured sediments of mixed origin. The Bajura soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 84 inches, and the mean annual temperature is 78 degrees F.

The Bajura soils are associated with the Coloso, Toa, and Dique soils. They have more expansive clays than the Coloso soils. They are finer textured than the Toa and the Dique soils.

Typical pedon of Bajura clay, 0.2 miles east, 0.2 miles north, and 25 feet east from kilometer 18.4 of Highway 165.

Ap—0 to 5 inches, dark brown (10YR 3/3) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few dead roots; few krotovinas; few root channels; few fine pebbles; medium acid; gradual smooth boundary.

B—5 to 12 inches, dark gray (10YR 4/1) clay; mottles are common medium distinct yellowish brown (10YR 5/6), few medium distinct very dark gray (5Y 3/1), and few fine brown to dark brown (7.5YR 4/4); weak coarse subangular blocky structure; firm, slightly sticky, plastic; few pressure faces; few fine roots; few dead roots; few fine pebbles; medium acid; gradual smooth boundary.

C1g—12 to 31 inches, gray to light gray (5Y 6/1) and yellowish brown (10YR 5/6) clay; few fine greenish gray (5G 6/1) mottles; weak coarse subangular blocky structure; firm, sticky, plastic; few pebbles; few dead roots; slightly acid; gradual smooth boundary.

C2g—31 to 38 inches, greenish gray (5G 6/1) clay; many medium distinct brownish yellow (10YR 6/6) and few medium distinct bluish gray (5B 5/1) mottles; weak coarse subangular blocky structure; firm, sticky, plastic; neutral; gradual smooth boundary.

C3g—38 to 60 inches, greenish gray (5GY 6/1) clay; with common medium prominent bluish gray (5B 5/1) and common medium distinct olive brown (2.5Y 4/4) mottles; massive; firm, very sticky, very plastic; few dead roots; few soft black concretions; neutral.

The solum is 12 to 20 inches thick. Reaction is medium acid to slightly acid.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 3 or less. It has moderate medium subangular blocky structure.

Bayamon series

The Bayamon series consists of clayey, oxidic, isohyperthermic Typic Haplorthox. These soils are deep, are well drained, and have a B horizon of red clay. They formed in fine textured sediments of mixed origin. The Bayamon soils are on stable coastal plains and in valleys between limestone hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 65 inches, and the mean annual temperature is 78 degrees F.

The Bayamon soils are associated with the Almirante, Matanzas, and Vega Alta soils. They have a thicker solum than the Matanzas and Vega Alta soils. They lack the plinthic horizons of the Almirante and Vega Alta soils.

Typical pedon of Bayamon clay, 2 to 5 percent slopes, 80 feet east of shed and 50 feet north of junction of dirt roads, 0.4 miles west from farm entrance on dirt road. A.S.A. farm at Finca Monterrey, Bo. Higuillar, Dorado, P.R.

Ap—0 to 8 inches, dark reddish brown (2.5YR 3/4) clay; moderate fine granular structure; friable, slightly sticky, slightly plastic; common fine roots; few fine iron concretions; common fine sand size quartz grains; very strongly acid; clear smooth boundary.

B21—8 to 27 inches, weak red (10R 4/4) clay; weak coarse subangular blocky structure parting to moderate fine angular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine oxide concretions; common fine quartz grains; common fine pores; black coatings on old root channels; very strongly acid; gradual smooth boundary.

B22—27 to 42 inches, red (10R 4/6) clay; massive in place, parting to weak very fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine pores; few fine sand size quartz grains; few fine black specks; very strongly acid; gradual smooth boundary.

B23—42 to 66 inches, red (10R 4/6) clay; massive in place, parting to weak very fine subangular blocky structure; very friable, slightly sticky, slightly plastic; few sand size quartz grains; few very fine black specks; few fine pores; yellow waxy coatings on ped surfaces and root channels; very strongly acid.

The solum is more than 60 inches thick. Reaction is very strongly acid.

The A horizon has hue of 5YR, 2.5YR, or 10R; value of 3 or 4; and chroma of 3 or 4.

The B2 horizon has hue of 2.5YR or 10R, value of 4 to 6, and chroma of 3 to 8. It is massive or has weak coarse and medium subangular blocky structure which parts readily into weak and moderate fine and medium angular and subangular blocky structure.

Caguabo series

The Caguabo series consists of loamy-skeletal, mixed, isohyperthermic Lithic Eutropepts. These soils are shallow, are well drained, and have an AC horizon of brown very gravelly clay loam. They formed in residuum of volcanic rocks. The Caguabo soils are on side slopes and ridgetops of strongly dissected uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Caguabo soils are associated with the Mucara, Morado, and Sabana soils. They have a thinner solum than the Mucara and Morado soils. They are less acid than the Sabana soils.

Typical pedon of Caguabo clay loam, 20 to 40 percent slopes, 300 feet east and 400 feet south of the tobacco drying barn which is approximately 1000 feet west of station headquarters, Gurabo Experiment Station.

Ap—0 to 4 inches, dark grayish brown (10YR 4/2) clay loam; weak fine granular structure; slightly hard, friable, nonsticky, slightly plastic; common fine volcanic rock fragments, common fine roots; slightly acid; clear smooth boundary.

AC—4 to 10 inches, brown (10YR 4/3) very gravelly clay loam; massive in place, parting to weak fine granular structure; friable, slightly sticky, slightly plastic; more than 50 percent by volume fine volcanic fragments; few fine roots; slightly acid; clear smooth boundary.

C—10 to 16 inches, mixture of weathered and partially weathered volcanic rock fragments that can be penetrated by spade.

R—16 inches, consolidated rock.

The solum is 8 to 16 inches thick. Reaction throughout is slightly acid.

The A horizon has hue of 10YR or 2.5Y, value of 3 or 4, and chroma of 2 to 4.

The AC horizon has hue of 10YR or 7.5YR, value of 3 to 5, and chroma of 3 or 4.

Candelero series

The Candelero series consists of fine-loamy, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are somewhat poorly drained, and have a B2g horizon of dark gray or very dark gray sandy clay loam. They formed in moderately fine textured sediments high in quartz, feldspar, and hornblende minerals derived from granitic rocks.

The Candelero soils are on terraces, alluvial fans, and foot slopes. Slopes range from 2 to 5 percent. The mean annual precipitation is 87 inches, and the mean annual temperature is 77 degrees F.

The Candelero soils are associated with the Humacao and Cayagua soils. They have a thicker solum than the Humacao and Cayagua soils.

Typical pedon of Candelero loam, 0.1 mile northeast from kilometer 0.6 of Highway 183, then 450 feet northwest from a farm road, San Lorenzo, P.R.

Ap—0 to 6 inches, dark grayish brown (10YR 4/2) loam; few fine dark gray (10YR 4/1) mottles; weak fine subangular blocky structure parting to granular; friable; nonsticky, slightly plastic; common fine roots; common fine quartz grains; common fine black concretions; very strongly acid; clear smooth boundary.

B1—6 to 11 inches, dark brown (10YR 4/3) and dark gray (10YR 4/1), sandy clay loam; few fine yellowish red (5YR 4/6) and dark yellowish brown (10YR 4/4) mottles; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; many fine quartz crystals; common fine black concretions; very strongly acid; clear smooth boundary.

B21tg—11 to 20 inches, dark gray (10YR 4/1) sandy clay loam; many medium distinct yellowish brown (10YR 5/8) and few fine faint gray (N 5/0) mottles; weak medium and coarse subangular blocky structure; firm, slightly sticky, plastic; few fine roots; many quartz grains; common soft black concretions; strongly acid; gradual smooth boundary.

B22tg—20 to 35 inches, very dark gray (10YR 3/1) sandy clay loam; common medium distinct greenish gray (5GY 6/1) and brownish yellow (10YR 6/6) mottles; massive; firm, slightly sticky, plastic; few fine roots; many quartz grains; few fine dark minerals; common dark minerals; common dark stains due to dead roots; strongly acid; gradual smooth boundary.

B31g—35 to 49 inches, brownish yellow (10YR 6/8) sandy clay; mottles are common medium distinct dark gray (5Y 4/1) and few fine greenish gray (5G 5/1) and light brownish gray (10YR 6/2); massive; firm, slightly sticky, plastic; few fine quartz grains; few dark soft concretions; few dark stains; medium acid; gradual smooth boundary.

B32g—49 to 60 inches, yellowish brown (10YR 5/4) sandy clay; mottles are many fine distinct gray (5Y 6/1) and few fine yellowish red (5YR 4/6) and dark reddish brown (2.5YR 3/4); firm, slightly sticky, plastic; few fine quartz grains; few sand lenses; few soft black concretions; medium acid.

The solum is more than 60 inches thick. Reaction throughout is medium acid to very strongly acid.

The A horizon has hue of 10YR, value of 3 or 4, and chroma of 2 or 3.

The B2t horizon has hue of 10YR, value of 3 or 4, and chroma of 1 to 3. It has weak medium and coarse subangular blocky structure or is massive.

Catalina series

The Catalina series consists of clayey, oxidic, isohyperthermic Tropeptic Haplorthox. These soils are deep, are well drained, and have a B2 horizon of dark reddish brown and reddish brown clay. They formed in fine textured residuum of volcanic rocks. The Catalina soils are on side slopes and hilltops. Slopes range from 4 to 12 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 75 degrees F.

The Catalina soils are associated with the Humatas, Daguey, and Consumo soils. They have a thicker solum than the Daguey soils and have a thicker B2 horizon than the Humatas and Consumo soils.

Typical pedon of Catalina clay, 4 to 12 percent slopes, 45 feet east of field road and 470 feet south of house at kilometer 8.8 of Highway 152, Barranquitas, P.R.

Ap—0 to 6 inches, dark reddish brown (5YR 3/3) clay, few fine distinct reddish brown (2.5YR 4/4) pockets; weak fine granular structure; friable, slightly sticky, slightly plastic; many fine roots; many sand size particles; few fine pieces of charcoal; medium acid; abrupt smooth boundary.

B21—6 to 20 inches, dark reddish brown (2.5YR 3/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; common fine roots; common fine pores; many soft black sand size particles; very strongly acid; clear smooth boundary.

B22—20 to 34 inches, reddish brown (2.5YR 5/4) clay; few reddish brown (2.5YR 4/4) ped faces; weak fine subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few fine pores; few fine sand size particles; few pressure faces; very strongly acid; clear smooth boundary.

B23—34 to 84 inches, dark reddish brown (2.5YR 3/4) clay; weak fine angular blocky structure; firm, slightly sticky, plastic; few fine pores; common pressure faces; strongly acid; gradual wavy boundary.

B24—84 to 99 inches, variegated dusky red (10R 3/4), dark reddish brown (2.5YR 3/4), and strong brown (7.5YR 5/8) clay; few dark gray and white splotches; massive; firm, plastic; very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is medium acid to very strongly acid.

The A horizon has hue of 5YR or 2.5YR, value of 3 or 4, and chroma of 3 or 4.

The B2 horizon has hue of 2.5YR or 10R, value of 3 or 4, and chroma of 4 to 8. It has weak to moderate fine or medium subangular blocky structure or is massive.

Catano series

The Catano series consists of carbonatic, isohyperthermic Typic Tropopsamments. These soils are deep and excessively drained. They have A horizons of very dark brown sand and C horizons of dark brown and dark grayish brown sand. They formed in quartz sand, shell fragments, and miscellaneous volcanic rocks. The Catano soils are on coastal plains adjacent to the sea. Slopes range from 0 to 2 percent. The mean annual precipitation is 76 inches, and the mean annual temperature is 78 degrees F.

The Catano soils are associated with the Durados soils. They are coarser textured than the Durados soils.

Typical pedon of Catano loamy sand, 50 feet north of electrical transformers on east end of Punta Salinas, Catano, P.R.

A—0 to 7 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose, nonsticky, nonplastic; many fine roots; violent effervescence; clear smooth boundary.

AC—7 to 23 inches, dark brown (10YR 4/3) sand; single grain; loose; nonsticky, nonplastic; common fine roots; violent effervescence; clear smooth boundary.

C—23 to 58 inches; dark grayish brown (10YR 4/2) sand; single grain; loose, nonsticky, nonplastic; many fine shell fragments; violent effervescence.

Effervescence with dilute HCL ranges from slight to violent.

The A horizon has hue of 10YR and value and chroma of 2 or 3.

Cayagua series

The Cayagua series consists of fine, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are somewhat poorly drained, and have a B2tg horizon of light olive gray clay. They formed in residuum of coarse textured plutonic rocks. The Cayagua soils are on foot slopes and side slopes. Slopes range from 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Cayagua soils are associated with the Candelero and Humacao soils. They have a thinner solum than the Candelero soils and finer textured B horizons than the Humacao soils.

Typical pedon of Cayagua sandy loam, 70 feet north from kilometer 13.75 of Highway 183, San Lorenzo, P.R.

Ap—0 to 8 inches, dark grayish brown (10YR 4/2) sandy loam; few fine dark gray (5Y 4/1) mottles; weak fine subangular blocky structure; friable, nonsticky, nonplastic; common fine roots; common fine quartz grains; few fine black concretions; very strongly acid; abrupt smooth boundary.

B21t—8 to 16 inches, yellowish brown (10YR 5/4) clay; mottles are common fine prominent dark gray (5Y 4/1), yellowish red (5YR 5/8), and red (2.5YR 4/8); firm, slightly sticky, plastic; few fine roots; few patchy clay films; common fine quartz grains; common dark stains in root channels; few soft black concretions; very strongly acid; clear smooth boundary.

B22tg—16 to 22 inches, light olive gray (5Y 6/2) clay; common fine distinct yellowish brown (10YR 5/4) and strong brown (7.5YR 5/8) mottles; and few fine red (2.5YR 5/8) and greenish gray (5G 6/1) mottles; weak coarse subangular blocky structure; firm, slightly sticky, plastic; few fine roots; common fine quartz grains; few soft black concretions; very strongly acid; clear smooth boundary.

B3g—22 to 32 inches, light olive gray (5Y 6/2) sandy clay loam; common medium prominent yellowish brown (10YR 5/8) mottles, and few fine greenish gray (5BG 6/1) and light gray (2.5Y 7/2) mottles; massive; firm, slightly sticky, slightly plastic; common fine quartz grains; few soft black concretions; strongly acid; gradual smooth boundary.

C—32 to 43 inches, mixed yellowish brown (10YR 5/4 and 5/8), white (2.5Y 8/2), and gray (5Y 5/1) sandy clay loam saprolite; massive; friable, nonsticky, nonplastic; common fine quartz grains; common fine dark minerals; horizon consists of 80 percent saprolite; strongly acid.

The solum is 28 to 36 inches thick. Reaction throughout is very strongly acid to strongly acid.

The A horizon has hue of 10YR or 2.5Y, value of 3 or 4, and chroma of 2 or 3.

The B2 horizon has hue of 10YR to 5Y, value of 4 to 7, and chroma of 2 to 4. It has weak coarse angular blocky structure.

The C horizons are sandy clay loam and sandy loam.

Colinas series

The Colinas series consists of fine-loamy, carbonatic, isohyperthermic Eutropeptic Rendolls. These soils are moderately deep to soft limestone, are well drained, and have a B horizon of brownish yellow clay loam. They formed in moderately fine textured residuum of limestone. The Colinas soils are on ridgetops and side slopes. Slopes range from 12 to 60 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Colinas soils are associated with the Soller and Tanama soils. They are underlain by softer limestone than that of the Soller or Tanama soils. They are yellower than the Tanama soils.

Typical pedon of Colinas clay loam, 40 to 60 percent slopes, eroded, 500 feet southeast of junction of Highways 820 and 823, Bo. Quebrada Arenas, Toa Alta, P.R.

A1—0 to 11 inches, dark brown (10YR 3/3) clay loam; moderate medium granular structure; friable, nonsticky, plastic; many fine roots; few limestone fragments; mildly alkaline; clear smooth boundary.

B—11 to 26 inches, brownish yellow (10YR 6/6) clay loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; few limestone fragments; mildly alkaline; clear smooth boundary.

C1—26 to 48 inches, pale yellow (2.5Y 7/4) soft limestone crushing to silty clay loam; massive; very friable, nonsticky, slightly plastic; mildly alkaline.

C2—48 to 52 inches, mixture of yellow and white limestone containing common fine and medium limestone fragments.

The solum is 15 to 30 inches thick. Reaction throughout is mildly alkaline.

The A horizon has hue of 10YR, value of 3 to 6, and chroma of 2 or more.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 2 or more.

The C horizon is clay loam or silty clay loam.

Coloso series

The Coloso series consists of fine, mixed, nonacid, isohyperthermic Aeric Tropic Fluvaquents. These soils are deep, are somewhat poorly drained, and have a C horizon of dark grayish brown, dark brown, and dark gray silty clay. They formed in fine textured and moderately fine textured alluvial sediments of mixed origin. The Coloso soils are on flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Coloso soils are associated with the Bajura, Toa, and Dique soils. They are coarser textured and better drained than the Bajura soils, but finer textured and more poorly drained than the Toa and Dique soils.

Typical pedon of Coloso silty clay loam, 300 feet west of road and 400 feet north of the terrace break, which is approximately 2800 feet north of the Gurabo Experiment Station's headquarters.

Ap—0 to 7 inches, dark brown (10YR 3/3) silty clay loam; few fine distinct dark reddish brown (2.5YR 3/4) mottles; medium coarse granular structure; slightly hard, friable, nonsticky, slightly plastic; many roots; medium acid; clear smooth boundary.

C1—7 to 16 inches, mixed dark brown (10YR 4/3) and dark yellowish brown (10YR 4/4) silty clay loam; weak coarse subangular blocky structure; friable, nonsticky, slightly plastic; many roots; organic stains on ped surfaces; medium acid; clear smooth boundary.

C2g—16 to 32 inches, dark grayish brown (10YR 4/2) and light gray (10YR 6/1) silty clay loam; many medium distinct dark yellowish brown (10YR 4/4) mottles; weak coarse subangular blocky structure; firm, slightly sticky, plastic; black stains along fracture planes and in root channels, the light gray color is more concentrated in root channels and on fracture faces; many roots; medium acid; gradual smooth boundary.

C3g—32 to 55 inches, greenish gray (5G 5/1) silty clay; many medium distinct yellowish red (5YR 5/8) mottles; massive; firm, slightly sticky, plastic; common roots; medium acid; gradual smooth boundary.

C4g—55 to 70 inches, greenish gray (5G 5/1) silty clay; many medium distinct yellowish brown (10YR 5/6) mottles; massive; firm, slightly sticky, plastic; few roots; medium acid.

The A horizon has hue of 10YR, value of 3 or 4, and chroma of 2 to 4.

The Cg horizon has hue of 10YR, 2.5Y, or 5G; value of 3 to 6; and chroma of 2 or less.

Consumo series

The Consumo series consists of clayey, mixed, isohyperthermic Dystropeptic Tropudults. These soils are deep, are well drained, and have a B2t horizon of yellowish red clay. They formed in residuum of basic volcanic rocks. The Consumo soils are on side slopes and narrow ridges of strongly dissected, humid uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 76 degrees F.

The Consumo soils are associated with the Daguey, Humatas, Morado, and Mucara soils. They are shallower to saprolite than the Daguey and Humatas soils. They are redder, are more acid, and have finer texture than the Morado and Mucara soils.

Typical pedon of Consumo clay, 40 to 60 percent slopes, 0.7 mile south from kilometer 48.1 of Highway 1, along farm road of La Mina de Oro Restaurant, then 20 feet south.

Ap—0 to 10 inches, reddish brown (5YR 4/4) clay; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few small subrounded rock fragments; very strongly acid; clear smooth boundary.

B2t—10 to 14 inches, yellowish red (5YR 5/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; thin patchy clay films; few fine pores; few small subrounded rock fragments; very strongly acid; clear smooth boundary.

B3—14 to 20 inches; yellowish red (5YR 5/6) clay; many medium distinct red (2.5YR 4/6) and common fine distinct brownish yellow (10YR 6/6) mottles; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; about 50 percent saprolite; very strongly acid; clear smooth boundary.

C—20 to 46 inches, variegated red (2.5YR 4/6 and 5/6), brownish yellow (10YR 6/6), and yellowish red (5YR 5/6), silty clay loam saprolite; massive; very friable, slightly sticky, slightly plastic; original rock structure visible; can be crushed with fingers; very strongly acid.

The solum is 14 to 24 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 5YR or 2.5YR, value of 3 to 5, and chroma of 4 to 6.

The B2 horizon has hue of 5YR or 2.5YR, value of 4 or 5, and chroma of 6 or more.

Corozal series

The Corozal series consists of clayey, mixed, isohyperthermic Aquic Tropudults. These soils are deep, are somewhat poorly drained, and have a B2 horizon of red clay. They formed in residuum of volcanic rocks. The sloping Corozal soils are on interfluves of strongly dissected low volcanic hills. Slopes range from 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 75 degrees F.

The Corozal soils are associated with the Consumo and Humatas soils. They have a thicker solum and are more poorly drained than the Consumo and Humatas soils.

Typical pedon of Corozal clay, 5 to 12 percent slopes, 3 miles southwest of the town of Corozal on the Corozal Experiment Station farm, 60 feet east of cattle weighing pen.

Ap—0 to 7 inches, dark reddish brown (5YR 3/4) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; many fine roots; very strongly acid; clear wavy boundary.

B1—7 to 9 inches, mixed dark red (2.5YR 3/6) and grayish brown (10YR 5/2) clay; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thick continuous clay films; many fine roots; very strongly acid; clear wavy boundary.

B21t—9 to 13 inches, red (2.5YR 4/6) clay; reddish brown (5YR 4/4) on ped surfaces and root channels; moderate medium prismatic structure parting to moderate medium subangular blocky; firm, slightly sticky, plastic; thick continous clay films; many fine roots; very strongly acid; gradual wavy boundary.

B22t—13 to 24 inches, red (2.5YR 4/6) clay; yellowish brown (10YR 5/6) coatings on ped surfaces and in root channels; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films on ped faces and in root channels; common fine roots; very strongly acid; gradual wavy boundary.

B23t—24 to 32 inches, red (2.5YR 5/6) clay; yellowish brown (10YR 5/6) coatings on ped surfaces and in root channels; moderate medium subangular blocky structure parting to weak fine subangular blocky; friable, slightly sticky, slightly plastic; very few patchy clay films on vertical ped faces; few fine roots; very strongly acid; gradual wavy boundary.

B3—32 to 40 inches, yellowish red (5YR 5/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; very few patchy clay films on vertical ped faces; about 30 percent by volume is saprolite; pseudomorphs of feldspars easily crushed to shiny faces (kaolin books); very strongly acid; gradual irregular boundary.

C—40 to 60 inches; variegated yellowish red (5YR 5/6), light gray (5YR 7/1), and strong brown (7.5YR 5/6) clay loam saprolite; massive; friable, slightly sticky, slightly plastic; saprolite is easily crushed with fingers; rock structure visible; pseudomorphs of feldspars easily crushed to shiny faces (kaolin books); very strongly acid.

The solum is 40 to 50 inches thick. Reaction is very strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 or 4, and chroma of 4.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 or 5, and chroma of 6 to 8. It has strong to moderate subangular blocky structure or prismatic structure parting to subangular blocky.

Daguey series

The Daguey series consists of clayey, oxidic, isohyperthermic Orthoxic Tropohumults. These soils are deep, are well drained, and have a B horizon of reddish clay. They formed in the residuum of basic volcanic rocks. The Daguey soils are on the more stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes range from 2 to 20 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 78 degrees F.

The Daguey soils are associated with the Humatas and Consumo soils. The Daguey soils are more leached and have a thicker solum than the Humatas and Consumo soils.

Typical pedon of Daguey clay, 12 to 20 percent slopes, 40 feet west of Highway 813, then 80 feet south of road junction to house, Cibuco SCD, P.R.

Ap—0 to 10 inches, dark brown (7.5YR 4/4) clay; weak medium subangular blocky structure parting to moderate fine granular; firm, slightly sticky, slightly plastic; very strongly acid; abrupt wavy boundary.

B1—10 to 14 inches, reddish brown (5YR 5/4) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; clear smooth boundary.

B21t—14 to 23 inches, yellowish red (5YR 4/6) clay; few medium distinct yellowish brown (10YR 5/4) mottles; weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; clear smooth boundary.

B22t—23 to 31 inches, red (2.5YR 4/6) clay; strong medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin continuous clay films on ped faces; very strongly acid; gradual smooth boundary.

B23t—31 to 43 inches, red (2.5YR 4/6) clay; strong medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B24t—43 to 59 inches, red (2.5YR 4/6) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B3—59 to 72 inches, red (2.5YR 4/6) clay; weak medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; very thin patchy clay films; few small angular fragments of rock; very strongly acid; clear smooth boundary.

C1—72 to 86 inches, yellowish red (5YR 4/6) silty clay loam; common fine distinct strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) mottles; massive but with some evidence of original rock structure; friable, slightly sticky, slightly plastic; very strongly acid; gradual smooth boundary.

C2—86 to 90 inches, yellowish red (5YR 4/6) silty clay loam saprolite with well defined rock structure; common fine distinct strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) mottles; very strongly acid.

The solum is 50 to 80 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 7.5YR or 5YR, value of 3 to 5, and chroma of 2 to 4.

The B2 horizon has hue of 10R or 2.5YR, value of 4 or 5, and chroma of 6 to 8. It has moderate to strong medium and fine subangular blocky structure.

Descalabrado series

The Descalabrado series consists of clayey, mixed, isohyperthermic Lithic Vertic Ustropepts. These soils are shallow, are well drained, and have a B horizon of dark brown gravelly clay. They formed in residuum of basic volcanic rocks. The Descalabrado soils are on foot slopes, long and short side slopes, and ridgetops of semiarid volcanic uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 40 inches, and the mean annual temperature is 80 degrees F.

The Descalabrado soils are associated with the Guayama soils. The Descalabrado soils have colors with yellower hues and lack the argillic horizons of the Guayama soils.

Typical pedon of Descalabrado clay loam, 40 to 60 percent slopes, 1250 feet south from elementary school of Bo. Cercadillo, Cayey, P.R.

A1—0 to 5 inches, very dark grayish brown (10YR 3/2) clay loam; moderate fine granular structure; friable, nonsticky, slightly plastic, few fine roots; few fine pores; few rock fragments 2 millimeters to 25 millimeters in diameter; neutral; clear smooth boundary.

B—5 to 11 inches, dark brown (10YR 3/3) gravelly clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine pores; 20 percent rock fragments 2 millimeters to 25 millimeters in diameter; neutral; clear smooth boundary.

C—11 to 17 inches, mixed dark yellowish brown (10YR 3/4 and 10YR 4/4) and olive (5Y 5/3) gravelly sandy clay loam weathered rock; massive; friable, nonsticky, slightly plastic; 25 percent rock fragments 1 to 3 inches in diameter; neutral; clear abrupt boundary.

R—17 inches, hard semiconsolidated volcanic rock.

The solum is 8 to 14 inches thick. Reaction throughout is neutral.

The A horizon has hue of 10YR and 7.5YR, value of 2 or 3, and chroma of 2 or 3.

The B horizon has hue of 10YR or 7.5YR, value of 3 or 4, and chroma of 2 to 4.

Dique series

The Dique series consists of fine-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are well drained, and have a B2 horizon of dark yellowish brown loam. They formed in medium textured alluvial sediments of mixed origin. The Dique soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 72 inches, and the mean annual temperature is 77 degrees F.

The Dique soils are associated with the Toa, Bajura, Coloso, and Reilly soils. They are better drained and have coarser textures than the Bajura and Coloso soils. They are thicker and lack the gravelly layers of the Reilly soils. They are coarser textured and better drained than the Toa soils.

Typical pedon of Dique loam, 100 feet west from entrance of Gurabo Experiment Station, then 75 feet north of Highway 941.

Ap—0 to 6 inches, dark brown (10YR 4/3) loam; weak fine granular structure; friable, nonsticky, slightly plastic; many fine roots; medium acid; clear smooth boundary.

B1—6 to 16 inches, dark brown (10YR 4/3) loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few fine black concretions; medium acid; abrupt wavy boundary.

B2—16 to 20 inches, dark yellowish brown (10YR 4/4) loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; medium acid; gradual smooth boundary.

B3—20 to 36 inches, dark brown (10YR 4/3) loam; weak fine subangular blocky structure; friable; medium acid; abrupt smooth boundary.

C—36 to 54 inches, dark yellowish brown (10YR 4/4) loam; friable, nonsticky, nonplastic; medium acid.

The solum is 20 to 40 inches thick. Reaction throughout is medium acid.

The A and B horizons have hue of 10YR, value of 4 or 5, and chroma of 2 to 4.

Durados series

The Durados series consists of sandy, mixed, isohyperthermic Fluventic Hapludolls. These soils are deep, are excessively drained, and have dark grayish brown sandy loam Ap horizons over dark grayish brown loamy sand and sand C horizons. They formed in coarse textured materials which consist of sand size shell fragments and miscellaneous volcanic subrounded fragments. The Durados soils are on the coast at elevations close to sea level. Slope ranges from 0 to 2 percent. The mean annual precipitation is 70 inches, and the mean annual temperature is 80 degrees F.

The Durados soils are associated with the Coloso, Toa, and Catano soils. They are coarser textured and more permeable than the Coloso and Toa soils. They are finer textured than the Catano soils.

Typical pedon of Durados sandy loam, 0.2 mile northwest of kilometer 19.9, Highway 165, following a farm road, then 150 feet north.

Ap—0 to 14 inches, very dark grayish brown (10YR 3/2) sandy loam; massive; very friable, nonsticky, nonplastic; few fine roots; few medium coconut roots; few quartz grains; neutral; abrupt smooth boundary.

C1—14 to 23 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose; few fine cemented sandy concretions; neutral; abrupt smooth boundary.

C2—23 to 38 inches, very pale brown (10YR 7/3) and very dark grayish brown (10YR 3/2) sand; single grain; loose; about 25 percent of horizon is light gray (5Y 7/1) cemented sand that is strongly calcareous; moderately alkaline; abrupt smooth boundary.

C3—38 to 60 inches; sand that is mixed dark yellowish brown (10YR 4/4), black (10YR 2/1), brownish yellow (10YR 6/6), and yellowish brown (10YR 6/4); single grain; loose; this horizon has a thick layer of cemented sand that could be penetrated with an auger; few sea shells; common quartz grains; strongly alkaline, calcareous.

The mollic epipedon is 10 to 30 inches thick. Reaction throughout is neutral to strongly alkaline.

The A horizon has hue of 10YR or 7.5YR, value and chroma of 2 or 3.

Estacion series

The Estacion series consists of fine loamy over sandy or sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls. These soils are shallow, are well drained, and have an Ap horizon of dark brown silty clay loam and a C horizon of very dark grayish brown gravelly clay loam and sand. They formed in stratified moderately fine textured sediments over gravelly layers of mixed origin. The Estacion soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 70 inches, and the mean annual temperature is 80 degrees F.

The Estacion soils are associated with the Reilly, Toa, Coloso, Bajura, and Dique soils. They are finer textured in the upper horizons than the Reilly soils. They are coarser textured than the Bajura soils. They have gravelly subhorizons that the Toa, Coloso, and Dique soils lack.

Typical pedon of Estacion silty clay loam, 0.5 mile northwest from kilometer 32.8 of Highway 1, Caguas, P.R.

Ap—0 to 8 inches, dark brown (10YR 3/3) silty clay loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few subrounded gravel 1/2 to 2 inches in diameter; medium acid; clear smooth boundary.

C1—8 to 20 inches, very dark grayish brown (10YR 3/2) gravelly clay loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; many fine and coarse gravel-size subrounded fragments; medium acid; gradual smooth boundary.

C2—20 to 50 inches; dark brown (10YR 4/3) gravelly sand; single grain; loose, nonsticky, nonplastic; about 50 percent coarse gravel; many rounded cobbles 3 to 7 inches in diameter; slightly acid.

Reaction throughout is slightly acid to medium acid.

The A horizon has hue of 10YR or 7.5YR, value of 3, and chroma of 2 or 3.

The C horizons are gravelly clay loam and gravelly sand.

Guayama series

The Guayama series consists of clayey, mixed, isohyperthermic Lithic Haplustalfs. These soils are shallow, are well drained, and have a B horizon of red gravelly clay. They formed in residuum of volcanic rocks. The Guayama soils are on side slopes and narrow ridgetops of dissected uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 35 inches, and the mean annual temperature is 80 degrees F.

The Guayama soils are associated with the Descalabrado soils. The Guayama soils have a redder B horizon than the Descalabrado soils.

Typical pedon of Guayama clay loam, 20 to 60 percent slopes, 0.5 mile west from Jajome Bajo School, then 25 feet north from dirt road, Cayey, P.R.

A—0 to 4 inches, dark reddish brown (5YR 3/4) clay loam; weak fine granular structure; slightly hard, friable, slightly sticky, slightly plastic; common fine roots; common angular rock fragments 1/8 to 1 inch in diameter; neutral; clear smooth boundary.

B—4 to 12 inches, red (2.5YR 4/6) gravelly clay; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; about 25 percent angular rock fragments 1/4 to 2 inches in diameter; neutral; clear smooth boundary.

C—12 to 20 inches, red (2.5YR 5/8) gravelly silty clay loam; massive; friable, slightly sticky, slightly plastic; horizon consists of about 60 percent light yellowish brown (2.5Y 6/4) saprolite; about 25 percent weathered rock fragments; neutral; clear smooth boundary.

R—20 inches; greenish colored consolidated volcanic rock.

The solum is 10 to 14 inches thick. Depth to consolidated rock is 20 inches or less. Reaction throughout is neutral to mildly alkaline.

The A horizon has hue of 7.5YR or 5YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 5YR or 2.5YR, value of 3 or 4, and chroma of 4 to 6.

Humacao series

The Humacao series consists of fine-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are moderately well drained, and have a B horizon of dark yellowish brown sandy clay loam. They formed in medium and moderately fine textured sediments derived from plutonic rocks. The Humacao soils are on terraces above the river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 75 degrees F.

The Humacao soils are associated with the Candelero and Vivi soils. The Humacao soils have a thinner and coarser textured solum than the Candelero soils, but are finer textured throughout than the Vivi soils.

Typical pedon of Humacao loam, 0.4 mile west from kilometer 1.5 of Highway 912, then 18 feet north from rectangular cattle drinking tank, Bo. Cerro Gordo, San Lorenzo, P.R.

A—0 to 8 inches, dark brown (10YR 4/3) loam; weak fine granular structure; friable, nonsticky, nonplastic; many fine roots; common fine quartz grains; few dark minerals; strongly acid; clear smooth boundary.

B—8 to 15 inches, dark yellowish brown (10YR 4/4) sandy clay loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; common fine quartz grains; few dark concretions; strongly acid; clear smooth boundary.

C1—15 to 26 inches, brown (7.5YR 5/4) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; common fine quartz grains; common fine dark minerals; few dark concretions; strongly acid; clear smooth boundary.

C2—26 to 44 inches, strong brown (7.5YR 5/6) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; common fine quartz grains; common fine dark minerals; few dark concretions; strongly acid; clear smooth boundary.

C3—44 to 60 inches, redddish yellow (7.5YR 6/6) sandy clay loam; massive; very friable, nonsticky, nonplastic; many quartz grains; few dark minerals; strongly acid.

The solum is 13 to 24 inches thick. Reaction throughout is strongly acid to medium acid.

The A horizon has hue of 10YR or 7.5YR, value of 2 to 4, and chroma of 2 or 3.

The B horizon has hue of 10YR or 5YR, value of 4 to 6, and chroma of 3 to 8.

The C horizons are clay loam and sandy clay loam.

Humatas series

The Humatas series consists of clayey, kaolinitic, isohyperthermic Typic Tropohumults. These soils are deep, are well drained, and have a B2 horizon of red clay. They formed in residuum of basic volcanic rocks. The Humatas soils are on narrow ridgetops and side slopes. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 86 inches, and the mean annual temperature is 76 degrees F.

The Humatas soils are associated with the Catalina, Consumo, and Daguey soils. They have a thinner solum than the Catalina and Daguey soils and a thicker B2 horizon than the Consumo soils. They are also associated with the Naranjito soils, but are deeper than the Naranjito soils.

Typical pedon of Humatas clay, 40 to 60 percent slopes, 0.9 mile from kilometer 9.8 of Highway 765 and 200 feet northwest from dirt road, San Lorenzo, P.R.

Ap—0 to 5 inches, dark brown (7.5YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; few fine pores; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B21t—5 to 14 inches; red (2.5YR 4/6) clay; moderate medium subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few fine black concretions; common thin clay films on surfaces of peds and in pores; very strongly acid; clear smooth boundary.

B22t—14 to 24 inches, red (2.5YR 4/6) clay, few yellowish brown (10YR 5/4) mottles; moderate medium subangular blocky structure; friable, slightly sticky, plastic; few fine pores; common thin clay films on surfaces of peds and in pores; very strongly acid; gradual smooth boundary.

B3—24 to 34 inches, yellowish red (5YR 5/6) silty clay, few fine dark yellowish brown (10YR 4/4), red (10R 4/6), yellowish brown (10YR 5/6), and dusky red (2.5YR 3/4) mottles; weak fine and medium subangular blocky structure; friable, nonsticky, slightly plastic; few thin clay films; 2 percent weathered rock fragments; very strongly acid; clear smooth boundary.

C1—34 to 45 inches, red (10R 4/8), yellowish red (5YR 5/6), and strong brown (7.5YR 5/6) silty clay; massive; very friable, nonsticky, slightly plastic; few fine pores; 2 percent weathered rock fragments; 75 percent of horizon is saprolite; strongly acid; gradual smooth boundary.

C2—45 to 60 inches, dark red (10R 3/6), red (10R 4/6), reddish brown (5YR 5/4), olive yellow (2.5Y 6/8), and white (N 8/0) silty clay saprolite; massive; very friable, nonsticky, slightly plastic; few fine pores; 2 percent weathered rock fragments; strongly acid.

The solum is 23 to 41 inches thick. Reaction throughout is very strongly acid or strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 to 5, and chroma of 4 to 6.

The B2t horizon has hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 3 to 6. It has weak to moderate fine and medium subangular blocky structure.

The C horizon is silty clay, clay, or clay loam.

Jagueyes series

The Jagueyes series consists of fine-loamy, mixed, isohyperthermic Orthoxic Tropudults. These soils are deep, are well drained, and have a B2t horizon of red clay loam. They formed in residuum of plutonic rocks. The Jagueyes soils are on side slopes and narrow ridgetops of humid uplands. Slopes range from 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Jagueyes soils are associated with the Lirios, Limones, and Pandura soils. The Jagueyes have thicker and redder B2 horizons than the Pandura soils. They are coarser textured than Limones soils and have a thicker solum than Lirios soils.

Typical pedon of Jagueyes loam, 20 to 40 percent slopes, eroded, 2.8 miles southeast of kilometer 11.4 of Highway 181, then 350 feet southwest from dirt road, then 50 feet west, San Lorenzo, P.R.

Ap—0 to 5 inches, dark yellowish brown (10YR 4/4) loam; few fine grayish brown (2.5Y 5/2) mottles; weak fine subangular blocky structure parting to granular; friable, nonsticky, nonplastic; few fine roots; common fine quartz grains; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B21t—5 to 14 inches, yellowish red (5YR 4/6) and yellowish brown (10YR 5/6) clay loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; few fine pores; few patchy clay films; common quartz grains; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B22t—14 to 24 inches, red (2.5YR 4/6) clay loam; common medium distinct light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine pores; common patchy clay films; common fine quartz grains; few dark concretions; very strongly acid; gradual smooth boundary.

B23t—24 to 41 inches; red (2.5YR 4/6) clay loam; few medium distinct light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine pores; common patchy clay films, many fine quartz grains; few black concretions; very strongly acid; gradual smooth boundary.

B3—41 to 54 inches, red (2.5YR 4/8) sandy clay loam; common medium distinct brownish yellow (10YR 6/6) and few medium distinct light gray (10YR 7/2) mottles; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine pores; many fine quartz grains; few fine black minerals; very strongly acid; clear smooth boundary.

C—54 to 62 inches, yellowish red (5YR 5/8) sandy clay loam; mottles are many fine distinct pink (7.5YR 7/4), common fine distinct very pale brown (10YR 7/4), and few fine red (2.5YR 4/8); weak fine subangular blocky structure; friable, nonsticky, slightly plastic; many fine quartz grains; few fine black minerals; about 75 percent of horizon is saprolite; very strongly acid.

The solum is 48 to 60 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR or 7.5YR, value of 2 to 4, and chroma of 2 to 4.

The B2t horizon has hue of 5YR or 2.5YR, value of 4 to 7, and chroma of 6 to 8. It has weak to moderate fine to medium subangular blocky structure.

Juncal series

The Juncal series consists of fine, mixed, isohyperthermic Typic Tropudalfs. These soils are deep, are moderately well drained, and have B2t horizons of dark yellowish brown, brownish yellow, and yellowish brown clay. They formed in residuum of limestone. The Juncal soils are on foot slopes and low rounded hills. Slopes range from 5 to 20 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 77 degrees F.

The Juncal soils are associated with the Colinas soils. They are thicker and have yellower and lighter colors than the Colinas soils.

Typical pedon of Juncal clay, 5 to 20 percent slopes, eroded, 1.9 kilometers south of junction of Highways 2 and 677, 2.5 kilometers east of junction of Highways 823 and 677, 1700 feet northeast of a dairy barn, 800 feet northeast of a farm pond, Barrio Rio Lajas, Toa Alta, P.R.

Ap—0 to 10 inches, dark grayish brown (10YR 4/2) clay; weak coarse subangular blocky structure; firm, slightly sticky, plastic; many fine roots; medium acid; clear wavy boundary.

B21t—10 to 14 inches, dark yellowish brown (10YR 4/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; common fine roots; mildly alkaline; clear wavy boundary.

B22t—14 to 20 inches, yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin discontinuous patchy clay films; few fine roots; mildly alkaline; clear wavy boundary.

B23t—20 to 34 inches; brownish yellow (10YR 6/8) clay; common fine distinct yellowish red (5YR 5/8) mottles; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; mildly alkaline; clear wavy boundary.

B24t—34 to 40 inches; brownish yellow (10YR 6/6) clay; few fine prominent yellowish red (5YR 5/6) and few fine prominent light greenish gray (5BG 7/1) mottles; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films, few fine roots; few black concretions; neutral; clear wavy boundary.

B25t—40 to 48 inches; yellowish brown (10YR 5/6) clay; few fine prominent red (2.5YR 5/6) mottles; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; few roots; few black stains; neutral; clear wavy boundary.

C—48 to 60 inches, brownish yellow (10YR 6/8) silty clay loam; common fine faint light gray (10YR 7/2) mottles; friable, slightly sticky, plastic; there are lime splotches present in this horizon; about 40 percent of the horizon is soft limestone; mildly alkaline.

The solum is 36 to 58 inches thick. Reaction throughout ranges from medium acid to mildly alkaline.

The A horizon has hue of 7.5YR and 10YR, value of 4, and chroma of 2 or 3.

The B2t horizon has hue of 7.5YR and 10YR, value of 4 to 6, and chroma of 4 to 8. It has moderate fine to medium subangular blocky structure.

Juncos series

The Juncos series consists of fine, montmorillonitic, isohyperthermic Vertic Eutropepts. These soils are deep, are well drained, and have a B2 horizon of dark brown clay. They formed in residuum of basic volcanic rocks.

The Juncos soils are on side slopes and foot slopes of strongly dissected uplands. Slopes range from 5 to 20 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 66 inches, and the mean annual temperature is 77 degrees F.

The Juncos soils are associated with the Montegrande, Mabi, Mucara, and Caguabo soils. They have a thinner solum than the Montegrande and Mabi soils, but have a thicker sólum than the Mucara and Caguabo soils.

Typical pedon of Juncos clay, 12 to 20 percent slopes, 800 feet north of the southwestern corner of the Gurabo Experiment Substation.

Ap—0 to 8 inches, black (10YR 2/1) clay; common fine distinct yellow (10YR 7/6) mottles; weak fine and medium subangular blocky structure; very hard, firm, slightly sticky; plastic; many fine roots; few fine black concretions, slightly acid; clear smooth boundary.

B2—8 to 18 inches, dark brown (7.5YR 4/4) clay; small amount of Ap horizon mixed throughout; weak fine and medium subangular blocky structure; very hard, firm, slightly sticky, plastic; common fine roots; few pressure faces; common fine black concretions; few subrounded volcanic fragments 1/4 to 1 inch in diameter; black coatings along root channels; neutral; clear smooth boundary.

C1—18 to 31 inches, olive brown (2.5Y 4/4) clay; massive; firm, slightly sticky, plastic; common fine roots; pressure faces and slickensides; many fine black concretions; black coatings on root channels; few subrounded volcanic fragments 1/4 to 1 inch in diameter; neutral; gradual smooth boundary.

C2—31 to 40 inches; olive brown (2.5Y 4/4) clay; massive with thin clay stringers between cleavage planes; firm, slightly sticky, slightly plastic; few roots; 15 percent by volume consists of weathered volcanic rocks; neutral; gradual wavy boundary.

R—40 inches; semiconsolidated volcanic rock.

The solum is 12 to 24 inches thick. Reaction throughout ranges from slightly acid to neutral.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 1 or 2.

The B2 horizon has hue of 7.5YR, value of 4 or 5, and chroma of 4 to 6.

Lares series

The Lares series consists of clayey, mixed, isohyperthermic Aquic Tropohumults. These soils are deep, are moderately well drained, and have a B2t horizon of yellowish red clay. They formed in fine textured material derived from volcanic rocks. The Lares soils are on dissected terraces and foot slopes. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Lares soils are associated with the Daguey, Humatas, and Consumo soils. They are deeper to saprolite and are not so well drained as the Daguey, Humatas, and Consumo soils.

Typical pedon of Lares clay, 2 to 5 percent slopes, north of Urbanizacion Miraflores, 500 feet east of kilometer 3.0 of Highway 861, then 200 feet north along farm boundary.

Ap—0 to 6 inches, dark brown (10YR 4/3) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; common fine roots; few fine black concretions; few krotovinas; few fine pores; few fine quartz grains; very strongly acid; abrupt smooth boundary.

B1—6 to 15 inches, red (2.5YR 4/8) clay; reddish brown (5YR 5/4) ped faces; few fine brownish yellow (10YR 6/6) mottles; moderate, medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; common fine pores; few fine krotovinas; common patchy clay films on ped surfaces and in pores; few fine concretions; few quartz grains; very strongly acid; clear smooth boundary.

B2t—15 to 22 inches, yellowish red (5YR 5/6) clay; common fine distinct pale red (10R 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B3—22 to 36 inches, yellowish red (5YR 5/8) clay; common medium distinct pale yellow (5Y 7/4); few fine distinct strong brown (7.5YR 5/8) and red (2.5YR 4/8) mottles and common fine distinct light gray (10YR 7/2) mottles; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots, few quartz grains; few fine pores; few patchy clay films; very strongly acid; gradual smooth boundary.

C1—36 to 52 inches; variegated brownish yellow (10YR 6/8), red (2.5YR 4/8), very pale brown (10YR 7/4), and dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; firm, nonsticky, slightly plastic; few fine quartz grains; few fine dark minerals; few fine pores; very strongly acid; gradual smooth boundary.

C2—52 to 60 inches, variegated brownish yellow (10YR 6/6), dark red (2.5YR 3/6), light gray (7.5YR 7/2), and red (2.5YR 4/8) clay; weak fine subangular blocky structure; firm, nonsticky, nonplastic; many quartz grains; few dark minerals; few fine pores; very strongly acid.

The solum is 26 to 53 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 7.5YR or 10YR, value of 4, and chroma of 3 or 4.

The B2t horizon has hue of 7.5YR or 5YR, value of 4 to 6, and chroma of 4 or more.

Limones series

The Limones series consists of clayey, kaolinitic, isohyperthermic Epiaquic Orthoxic Tropohumults. These soils are deep, are moderately well drained, and have B2t horizons of yellowish brown and red clay. They formed in residuum of plutonic rocks. The Limones soils are on side slopes and narrow ridgetops of concordant remnants of highly dissected peneplains. Slopes range from 20 to 60 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Limones soils are associated with the Pandura, Jagueyes, and Lirios soils. They have a thicker solum than the Pandura and Lirios soils and are moderately well drained. They have a redder B2t horizon and are finer textured than the Jagueyes soils.

Typical pedon of Limones clay, 20 to 40 percent slopes, 1500 feet east from farm pond, 800 feet west from a dairy barn, 1700 feet west of the Quebrada Arenas school, 2100 feet east of the Cayaguas River and 1100 feet southwest of junction of Highway 912 and unnumbered road to the dairy barn.

Ap—0 to 7 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; few mottles caused by mixed A and B horizons during plowing; many quartz grains; few fine black concretions; very strongly acid; clear smooth boundary.

B1—7 to 18 inches, yellowish brown (10YR 5/4) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; few thin patchy clay films; few quartz grains; very strongly acid; clear smooth boundary.

B21t—18 to 30 inches, yellowish brown (10YR 5/8) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films; common fine quartz grains; few fine dark grains; very strongly acid; clear smooth boundary.

B22t—30 to 41 inches, red (2.5YR 4/6) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films; common fine quartz grains; few fine dark minerals; very strongly acid; gradual smooth boundary.

B3—41 to 48 inches, red (2.5YR 4/8) clay; common distinct reddish yellow (5YR 6/6); mottles; weak medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; thin patchy clay films; few fine quartz grains; very strongly acid; gradual smooth boundary.

C1—48 to 59 inches, red (2.5YR 4/6) clay; massive; friable; nonsticky, slightly plastic; few fine quartz grains; few dark minerals; about 30 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C2—59 to 79 inches, variegated red (2.5YR 5/8, 4/6, and 4/8) clay saprolite; massive; friable; nonsticky, nonplastic; many fine quartz grains; few dark minerals; very strongly acid.

The solum is 33 to 53 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 4, and chroma of 2 to 4.

The B2t horizon has hue of 10YR or 2.5YR, value of 4 or 5, and chroma of 4 to 8.

Lirios series

The Lirios series consists of clayey over loamy, mixed, isohyperthermic Typic Tropudults. These soils are deep, are well drained, and have a B2t horizon of brown silty clay loam and a B3 horizon of red clay. They formed in residuum of plutonic rocks. The Lirios soils are on side slopes of the strongly dissected humid uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 77 degrees F.

The Lirios soils are associated with the Limones, Jagueyes, and Pandura soils. They have a thinner solum and are better drained than the Limones and Jagueyes soils. They are redder and overlie more highly weathered plutonic rocks than those of the Pandura soils.

Typical pedon of Lirios silty clay loam, 20 to 60 percent slopes, eroded, 2.7 miles west from kilometer 11.4 Highway 181, and 300 feet east from dirt road.

Ap—0 to 4 inches, brown (7.5YR 4/4) silty clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; common fine quartz grains; few krotovinas; very strongly acid; clear smooth boundary.

B2t—4 to 12 inches, brown (7.5YR 4/4) silty clay loam; weak fine subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few patchy clay films on ped surfaces, common fine quartz grains; few fine dark minerals; very strongly acid; clear smooth boundary.

B3—12 to 24 inches, red (2.5YR 4/8) clay; common fine distinct light yellowish brown (2.5Y 6/4) and yellowish brown (10YR 5/4 and 5/6) mottles and few fine brownish yellow (10YR 6/6) mottles; weak medium subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few patchy clay films on ped surfaces; common fine quartz grains; few fine dark minerals; horizon is about 25 percent saprolite; very strongly acid; clear smooth boundary.

C1—24 to 34 inches, variegated red (2.5YR 4/8), yellowish brown (10YR 5/8), yellowish red (5YR 5/8), very pale brown (10YR 7/3), brown (7.5YR 5/4), white (2.5Y 8/2), and red (10R 4/8) clay; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine quartz grains; few fine dark minerals, few mica flakes; about 75 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C2—34 to 45 inches, variegated red (2.5YR 4/8), yellowish brown (10YR 5/8), yellowish red (5YR 5/8), very pale brown (10YR 7/3), brown (7.5YR 5/4), white (2.5Y 8/2), and red (10R 4/8) silty clay loam; massive; very friable, nonsticky, slightly plastic; many quartz grains; few dark minerals and mica flakes; very strongly acid; gradual smooth boundary.

C3—45 to 60 inches, variegated brownish yellow (10YR 6/8), yellow (10YR 7/8), red (10R 4/8), and very pale brown (10YR 7/4) silty clay loam; massive; very friable, nonsticky, slightly plastic; many fine dark minerals and quartz grains; structure of rock is more evident in this horizon; very strongly acid.

The solum is 20 to 24 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR or 10YR, value of 4 or 5, and chroma of 3 or 4.

The B2t horizon has hue of 7.5YR, 5YR, and 2.5YR; value of 4 to 6; and chroma of 4 to 8.

The C horizon is silty clay loam and clay.

Los Guineos series

The Los Guineos series consists of clayey, mixed, isothermic Epiaquic Tropohumults. These soils are deep, are moderately well drained, and have a B2t horizon of yellowish brown and red clay. They formed in residuum of basic volcanic rocks. The Los Guineos soils are on side slopes and hilltops of humid volcanic uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 95 inches, and the mean annual temperature is 70 degrees F.

The Los Guineos soils are associated with the Humatas, Consumo, Mucara, Naranjito, and Caguabo soils. They have a thicker solum and are less well drained than the Humatas, Consumo, Mucara, Naranjito, and Caguabo soils.

Typical pedon of Los Guineos clay, 20 to 40 percent slopes, 3.2 miles southeast of junction of Highway 1 and 184, along Highway 184 to Guavate and 40 feet north of highway.

Ap—0 to 4 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few fine black concretions; few krotovinas; very strongly acid; abrupt smooth boundary.

B21t—4 to 11 inches, yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm; slightly sticky, plastic; few fine pebbles; very strongly acid; clear smooth boundary.

B22t—11 to 19 inches, yellowish brown (10YR 5/6) clay with common fine prominent red (2.5YR 4/8) mottles; moderate medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few fine pores; common patchy clay films on ped surfaces and in pores; very strongly acid; clear smooth boundary.

B23t—19 to 34 inches, red (2.5YR 4/8) and brownish yellow (10YR 6/6) clay; moderate medium subangular blocky structure parting to moderate fine subangular blocky; firm, slightly sticky, plastic; few fine pores; common patchy clay films on ped surfaces and in pores; very strongly acid; gradual smooth boundary.

B3—34 to 48 inches, red (10R 4/8) clay; mottles are common medium distinct red (2.5YR 4/8), common medium prominent brownish yellow (10YR 6/8), few medium prominent yellow (10YR 7/6), and few fine prominent white (10YR 8/2); weak medium subangular blocky structure parting to weak fine subangular blocky; firm, slightly sticky, plastic; few fine pores; few patchy clay films on ped surfaces and in pores; about 25 percent of horizon consists of saprolite; very strongly acid; gradual smooth boundary.

C—48 to 60 inches, red (10R 4/8) clay; mottles are many medium prominent brownish yellow (10YR 6/8), few medium prominent yellow (10YR 7/6), and few fine prominent white (10YR 8/2); weak fine subangular blocky structure; friable, slightly sticky, plastic; horizon consists of about 75 percent saprolite; very strongly acid.

The solum is 41 to 54 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 4 or 5, and chroma of 3 to 5.

The B2t horizon has hue of 10YR and 7.5YR in the upper part and hue of 2.5YR and 10R in the lower part, value of 4 to 6, and chroma of 6 to 8.

Mabi series

The Mabi series consists of fine, montmorillonitic, isohyperthermic Vertic Eutropepts. These soils are deep, are somewhat poorly drained, and have a B2 horizon of yellowish brown clay. They formed in fine textured sediments derived from volcanic rocks. The Mabi soils are on alluvial fans and terraces above the river flood plains. Slopes range from 0 to 12 percent, but are dominantly 2 to 5 percent. The mean annual precipitation is 78 inches, and the mean annual temperature is 80 degrees F.

The Mabi soils are associated with the Montegrande, Rio Arriba, Juncos, and Mucara soils. They are clayey throughout and lack the gravelly subsurface layers of the Montegrande soils. They are darker colored than the Rio Arriba soils. They are not underlain by hard volcanic rocks as are the Juncos and Mucara soils.

Typical pedon of Mabi clay, 2 to 5 percent slopes, 800 feet north and 600 feet west of the Gurabo Experiment Substation Headquarters.

Ap—0 to 7 inches, very dark grayish brown (10YR 3/2) clay; few fine faint yellowish brown mottles; red (2.5YR 4/6) coatings along root channels; weak fine granular structure; hard, very firm, slightly sticky, plastic; common fine roots; common fine black nodules; few fine volcanic rock fragments; very strongly acid; clear smooth boundary.

B1—7 to 15 inches, dark yellowish brown (10YR 4/4) clay; few fine distinct gray (10YR 5/1) and common medium distinct yellowish brown (10YR 5/6) mottles; brown (10YR 4/3) when rubbed; weak fine and medium angular blocky structure with many pressure faces; very firm, slightly sticky, plastic; common fine roots; few fine black nodules; few fine volcanic rock fragments; strongly acid; clear wavy boundary.

B2—15 to 24 inches, yellowish brown (10YR 5/6) clay; many medium distinct gray (10YR 5/1) mottles; brown (10YR 4/3) when rubbed; weak fine and medium angular blocky structure with many pressure faces and slickensides that intersect; very firm, slightly sticky, plastic; few fine roots; few black nodules; few fine volcanic rock fragments; coatings along root channels; medium acid; clear wavy boundary.

C1—24 to 38 inches, yellowish brown (10YR 5/4) clay; few fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium and coarse angular blocky structure with many pressure faces and slickensides that intersect; very firm, slightly sticky, plastic; few fine black nodules; few fine volcanic rock fragments; few fine and medium carbonatic concretions; mildly alkaline; gradual smooth boundary.

C2—38 to 53 inches, yellowish brown (10YR 5/4) clay; common fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium angular blocky structure with common pressure faces and slickensides; very firm, slightly sticky, plastic; few fine black nodules; few fine volcanic rock fragments; few fine and medium carbonatic concretions; mildly alkaline; gradual smooth boundary.

C3—53 to 67 inches, yellowish brown (10YR 5/4) clay; common fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium angular blocky structure with few pressure faces and slickensides; very firm, slightly sticky, plastic; few fine black nodules; few fine and medium volcanic rock fragments; few fine carbonatic concretions; mildly alkaline; gradual wavy boundary.

The solum is 20 to 36 inches thick. Reaction throughout ranges from very strongly acid and medium acid in the upper horizons to mildly alkaline in the lower horizons.

The A horizon has hue of 10YR, value of 3 or less, and chroma of 2 or more.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 2 to 6.

Malaya series

The Malaya series consists of clayey, mixed, isohyperthermic Lithic Eutropepts. These soils are shallow, are well drained, and have a B horizon of dark brown gravelly clay. They formed in residuum of volcanic rocks. The Malaya soils are on side slopes of strongly dissected uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 77 degrees F.

The Malaya soils are associated with the Mucara and Caguabo soils. They have a thinner solum than the Mucara soils and are more alkaline than the Caguabo soils.

Typical pedon of Malaya clay loam, 40 to 60 percent slopes, 100 meters south from kilometer 61.6 of Highway 1.

A1—0 to 6 inches, dark brown (10YR 3/3) clay loam; weak medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few black concretions; about 10 percent by volume, fine and medium rock fragments; slightly acid; clear smooth boundary.

B—6 to 13 inches, dark brown (10YR 4/3) gravelly clay, weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; common fine black concretions; about 20 percent by volume, fine and medium rock fragments; mildly alkaline; clear smooth boundary.

C—13 to 18 inches, dark yellowish brown (10YR 4/4) gravelly clay loam; massive; firm, slightly sticky, slightly plastic; black coatings on faces and on partially weathered rock fragments; about 20 percent by volume is rock fragments; moderately alkaline; gradual wavy boundary.

R—18 inches, semiconsolidated tuffaceous rocks.

The solum is 10 to 20 inches thick. Reaction throughout is slightly acid to moderately alkaline.

The A horizon has hue of 5YR to 10YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 10YR, value of 4, and chroma of 3 or 4. It has weak medium to coarse subangular blocky structure.

The C horizon is gravelly clay loam. Depth to the consolidated volcanic rock is less than 20 inches.

Maricao series

The Maricao series consists of clayey, mixed, isothermic Dystropeptic Tropudults. These soils are deep, are well drained, and have a B2t horizon of red clay. They formed in residuum of basic volcanic rocks. The Maricao soils are on side slopes and narrow hilltops of strongly dissected humid uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 74 degrees F.

The Maricao soils are associated with the Los Guineos soils. They have a thinner B2t horizon than the Los Guineos soils.

Typical pedon of Maricao clay, 20 to 60 percent slopes, 300 feet east from kilometer 21.8 of Highway 157, then 50 feet south along farm boundary.

A—0 to 6 inches, reddish brown (5YR 5/4) clay; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; very strongly acid; clear smooth boundary.

B2t—6 to 14 inches, red (2.5YR 4/8) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; few patchy clay films; very strongly acid; clear smooth boundary.

B3—14 to 22 inches, red (2.5YR 5/6) silty clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; very strongly acid; clear smooth boundary.

C—22 to 60 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6 and 5/8), and pale brown (10YR 6/3) silty clay loam saprolite; massive; friable, slightly sticky, slightly plastic; very strongly acid.

The solum is 18 to 28 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 2.5YR and 5YR, value of 4 or 5, and chroma of 4 or more.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 or 5, and chroma of 6 or more.

Martin Pena series

The Martin Pena series consists of fine, mixed, nonacid, isohyperthermic Tropic Fluvaquents. These soils are deep, are very poorly drained, and have a black muck O horizon over silty clay loam and clay C horizons. They formed in organic materials from phanerogams such as reeds, sedges, and other water-loving grasses over fine textured sediments. The Martin Pena soils are in low depressional areas in the humid coastal plain and river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Martin Pena soils are associated with the Saladar, Bajura, and Coloso soils. They are underlain by mineral layers; whereas Saladar soils are organic throughout, and the Bajura and Coloso soils are mineral throughout.

Typical pedon of Martin Pena muck, 300 feet east of sentry box, entrance to the Sabana Seca Naval Communication Station, 30 feet north from center of paved unnumbered road.

Oa1—0 to 8 inches, black (10YR 2/1) muck; weak fine granular structure; slightly sticky, slightly plastic; many fine living and decayed roots; mildly alkaline; abrupt smooth boundary.

C1—8 to 18 inches, very dark brown (10YR 2/2) silty clay loam with thin lenses of brown to dark brown (10YR 4/3) organic materials; massive; slightly sticky, slightly plastic; few fine decayed roots; mildly alkaline; gradual smooth boundary.

C2—18 to 28 inches, very dark brown (10YR 2/2) clay; massive; slightly sticky, plastic; neutral; clear smooth boundary.

C3—28 to 55 inches, greenish gray (5G 5/1) clay; few fine faint very dark brown (10YR 2/2), dark greenish gray (5G 4/1), and greenish gray (5G 6/1) mottles; massive; slightly sticky, plastic; thin organic lenses; neutral; clear smooth boundary.

C4—55 to 63 inches, very dark brown (10YR 2/2) clay; few fine faint black (10YR 2/1) and greenish gray (5G 5/1) mottles; massive; slightly sticky, plastic; thin organic lenses; mildly alkaline.

The Oa1 horizon has hue of 10YR or 7.5YR, value of 2, and chroma of 2 or less.

The upper C horizon has hue of 10YR with value and chroma of 2 or 3. Thin organic lenses may occur in the lower C horizon. Reaction throughout the profile ranges from neutral to mildly alkaline.

Matanzas series

The Matanzas series consists of clayey, oxidic, isohyperthermic Tropeptic Eutrorthox. These soils are deep, are well drained, and have a B2 horizon of dark reddish brown and red clay. They formed in sediments derived from limestone. The Matanzas soils are on foot slopes and in small valleys between the limestone hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 64 inches, and the mean annual temperature is 77 degrees F.

The Matanzas soils are associated with the Bayamon and Tanama soils. They have a thinner solum and are shallower to hard limestone than the Bayamon soils. They are redder and deeper to the hard limestone than the Tanama soils.

Typical pedon of Matanzas clay, 2 to 5 percent slopes, 60 feet south and 100 feet west of Maguayo school, Bo. Maguayo, Toa Baja, P.R.

Ap—0 to 7 inches, dark reddish brown (5YR 3/4) clay; weak fine subangular blocky structure; slightly hard, firm, slightly sticky, slightly plastic; common fine roots; common fine quartz grains; common fine dark minerals; medium acid; clear smooth boundary.

B21—7 to 20 inches, dark reddish brown (2.5YR 3/4) clay; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; common fine pores; common fine quartz grains; medium acid; gradual smooth boundary.

B22—20 to 32 inches, red (2.5YR 4/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; common fine quartz grains; slightly acid; gradual smooth boundary.

B23—32 to 40 inches, red (2.5YR 4/8) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; common fine quartz grains; few fine pores; slightly acid; gradual smooth boundary.

B3—40 to 53 inches, red (2.5YR 4/6) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; common quartz grains; neutral; abrupt smooth boundary.

R—53 inches, limestone rock.

The solum thickness and depth to hard limestone is 40 to 60 inches. Reaction throughout ranges from medium acid to neutral.

The A horizon has hue of 5YR or 2.5YR, value of 2 or 3, and chroma of 2 to 4.

The B2 horizons have hue of 2.5YR, value of 3 or 4, and chroma of 3 to 8.

Montegrande series

The Montegrande series consists of fine, mixed, isohyperthermic Vertic Eutropepts. These soils are deep, are moderately well drained, and have B2 horizons of dark brown and grayish brown clay. They formed in fine textured sediments derived from volcanic rocks. The Montegrande soils are on foot slopes and alluvial fans. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Montegrande soils are associated with the Mabi, Rio Arriba, and Mucara soils. They have a thicker solum than the Mucara soils and are similar to the Mabi soils except for having very gravelly clay C horizons. They have a thinner solum and yellower color than the Rio Arriba soils.

Typical pedon of Montegrande clay, 2 to 5 percent slopes, 200 yards north from kilometer 5.65 of Highway 30, Gurabo Experiment Station, Gurabo, P.R.

Ap—0 to 7 inches, very dark grayish brown (10YR 3/2) clay; common fine faint reddish brown (5YR 4/4) mottles; weak fine granular structure; very hard, firm, slightly sticky, plastic; common fine black mineral grains; few fine rock fragments; common fine roots; strongly acid; clear smooth boundary.

B21—7 to 12 inches, dark brown (10YR 3/3) clay; mottles are common fine distinct yellowish brown (10YR 5/6), few fine faint gray (10YR 5/1), and common fine distinct greenish gray (5GY 5/1); weak medium angular blocky structure with few pressure faces; firm, slightly sticky, plastic; common fine black mineral grains; common fine roots; few fine rock fragments; slightly acid; clear wavy boundary.

B22—12 to 21 inches, grayish brown (10YR 5/2) clay; common medium distinct greenish gray (5GY 5/1) and common fine faint gray (10YR 5/1) mottles; weak coarse angular blocky structure with common pressure faces and slickensides; firm, slightly sticky, plastic; few fine black mineral grains; common fine roots; few fine rock fragments; slightly acid; gradual wavy boundary.

C1—21 to 29 inches, mixed dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/6) clay; weak medium and coarse angular blocky structure with common pressure faces and slickensides; firm, slightly sticky, plastic; few fine black mineral grains; few fine roots; neutral; clear wavy boundary.

IIC2—29 to 39 inches, brown (10YR 5/3) when rubbed very gravelly clay; massive with common pressure faces; firm, sticky, plastic; few fine black mineral grains; many sand size volcanic grains; about 55 percent of horizon is weathered and partially weathered volcanic rock fragments of mixed colors; neutral; gradual wavy boundary.

IIC3—39 to 48 inches, yellowish brown (10YR 5/4) when rubbed very gravelly clay; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; about 55 percent of horizon is weathered and partially weathered volcanic rock fragments of mixed colors; neutral; gradual wavy boundary.

The solum is 20 to 36 inches thick. Reaction throughout ranges from strongly acid in the A horizon to neutral in the lower horizons.

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 2 or 3.

The B2 horizon has hue of 7.5YR and 10YR, value of 3 to 5, and chroma of 2 to 4. It has weak medium to coarse angular to subangular blocky structure.

The C horizons are clay and very gravelly clay.

Morado series

The Morado series consists of fine-loamy, mixed, isohyperthermic Typic Eutropepts. These soils are moderately deep, are well drained, and have a mottled, reddish gray clay loam B2 horizon. They formed in residuum of volcanic rocks. The Morado soils are on side slopes, foot slopes, and hilltops of strongly dissected humid uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Morado soils are associated with the Mucara and Gaguabo series. They occupy similar positions in the landscape, but are deeper than the Caguabo soils. They have a thicker solum than the Mucara soils.

Typical pedon of Morado clay loam, 40 to 60 percent, eroded, 25 meters east from kilometer 2.9 of Highway 615, then 15 feet north.

Ap—0 to 8 inches, weak red (10R 4/2) clay loam; weak fine subangular blocky structure; friable, slightly sticky, plastic; common fine roots; neutral; clear smooth boundary.

B2—8 to 19 inches, reddish gray (5YR 5/2) clay loam; few fine faint red (2.5YR 4/6) mottles; weak fine subangular blocky structure; friable, slightly sticky, plastic; common fine roots; neutral; gradual wavy boundary.

B3—19 to 26 inches, variegated strong brown (7.5YR 5/6), dark reddish gray (5YR 4/2), weak red (2.5YR 4/2), and red (2.5YR 4/8) clay loam; massive; friable, slightly sticky, plastic; few fine roots; neutral; clear wavy boundary.

C—26 to 34 inches, variegated gray (5YR 5/1), light gray (7.5YR 7/0), and dark reddish gray (5YR 4/2) clay loam saprolite; massive; friable, slightly sticky, plastic; slightly acid; clear wavy boundary.

R—34 inches, reddish brown semiconsolidated rock.

The solum is 16 to 30 inches thick. Reaction throughout is neutral to slightly acid.

The A horizon has hue of 10R, 2.5YR, and 5YR; value of 4 or 5; and chroma of 1 to 3.

The B horizon has hue of 2.5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 8. It has weak fine subangular blocky structure.

Mucara series

The Mucara series consists of clayey, montmorillonitic, isohyperthermic, shallow Vertic Eutropepts. These soils are moderately deep, are well drained, and have a B horizon of dark brown clay. They formed in residuum of basic volcanic rocks. The Mucara soils are on foot slopes, side slopes, and rounded hilltops of strongly dissected humid uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Mucara soils are associated with the Caguabo, Morado, and Naranjito soils. They are deeper than the Caguabo soils, have a thinner solum than the Morado and Naranjito soils, and are yellower than the Naranjito soils.

Typical pedon of Mucara clay, 40 to 60 percent slopes, 0.6 mile from kilometer 67.2 of Highway 1, then 25 feet northwest along farm road.

Ap—0 to 5 inches, very dark grayish brown (10YR 3/2) clay; weak medium granular structure; firm, slightly sticky, plastic; many fine roots; slightly acid; clear smooth boundary.
B—5 to 12 inches, dark brown (10YR 3/3) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films along root channels and on faces of peds; few fine roots; common pressure faces; few fine dark concretions; few fine subrounded rock fragments; slightly acid; abrupt wavy boundary.
C—12 to 30 inches, highly weathered volcanic rocks, neutral.
R—30 inches, semiconsolidated volcanic rocks.

The solum is 10 to 20 inches thick. Reaction throughout is slightly acid to neutral. Depth to semiconsolidated volcanic rock ranges from 20 to 40 inches.

The A horizon has hue of 10YR and 2.5Y, value of 3 to 5, and chroma of 2 or 3.

The B horizon has hue of 7.5YR, 10YR, and 2.5Y; value of 3 to 5; and chroma of 2 to 4.

Naranjito series

The Naranjito series consists of clayey, mixed, isohyperthermic Typic Tropohumults. These soils are moderately deep, are well drained, and have a B horizon of reddish brown and yellowish red clay. They formed in residuum of volcanic rocks. The Naranjito soils occur on side slopes and hilltops of strongly dissected humid uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 76 degrees F.

The Naranjito soils are associated with the Mucara, Caguabo, Sabana, and Consumo soils. They have a thicker solum than the Mucara, Sabana, and Caguabo soils. They are on less weathered volcanic rock than the Consumo soils.

Typical pedon of Naranjito silty clay loam, 20 to 40 percent slopes, eroded, 100 feet east of intersection of Highway 833 with old trail to Fondo del Saco, Bo. Achiote, Naranjito, P.R.

Ap—0 to 4 inches, brown to dark brown (10YR 4/3) silty clay loam; moderate fine granular structure; friable, slightly sticky, slightly plastic; many fine roots; common fine rounded and subrounded rock fragments; very strongly acid; clear smooth boundary.
B2t—4 to 12 inches, reddish brown (5YR 4/4) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; thin patchy clay films; common fine dark concretions; very strongly acid; clear smooth boundary.
B3—12 to 24 inches, yellowish red (5YR 4/6) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; common fine dark concretions; thin patchy clay films; very strongly acid; clear smooth boundary.
C—24 to 40 inches, variegated yellowish red (5YR 4/6), red (2.5YR 4/6), and light yellowish brown (10YR 6/4) clay loam saprolite; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; strongly acid; abrupt smooth boundary.
R—40 inches, consolidated volcanic rock.

The solum is 15 to 30 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 to 5, and chroma of 3 to 4.

The B horizon has hue of 5YR, 10YR, and 2.5YR; value of 4 or 5; and chroma of 3 to 6.

Pandura series

The Pandura series consists of loamy, mixed, isohyperthermic, shallow Typic Eutropepts. These soils are shallow, are well drained, and have a B horizon of dark, yellowish brown sandy loam. They formed in residuum of plutonic rocks. The Pandura soils are on side slopes and hilltops of dissected uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Pandura soils are associated with the Lirios, Jagueyes, Candelero, and Cayagua soils. They have a thinner solum and are coarser textured than the Lirios and Jagueyes soils. They are better drained, shallower, and coarser textured than the Candelero and Cayagua soils.

Typical pedon of Pandura sandy loam, 20 to 40 percent slopes, 90 feet southwest from kilometer 3.85 of Highway 181, San Lorenzo, P.R.

Ap—0 to 7 inches, dark brown (10YR 4/3) sandy loam; weak fine subangular blocky structure parting to granular; friable, nonsticky, nonplastic; common fine roots; few fine quartz grains; strongly acid; clear smooth boundary.
B—7 to 12 inches, dark yellowish brown (10YR 4/4) sandy loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; common fine quartz grains; few dark minerals; few krotovinas; strongly acid; clear smooth boundary.
C1—12 to 26 inches, mixed very pale brown (10YR 7/4), pale brown (10YR 6/3), dark yellowish brown (10YR 4/4), and white (10YR 8/2) sandy loam saprolite; massive, but rock structure is evident; few fine roots; silty clay material with a dark grayish brown color (10YR 4/2) is deposited between rock cleavage; medium acid; gradual smooth boundary.
C2—26 inches, weathered granitic rock that can be penetrated with a spade.

The solum is 6 to 14 inches thick. Reaction throughout is medium acid to strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 10YR, value of 4 or 5, and chroma of 4 to 6.

Pellejas series

The Pellejas series consists of fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Typic Dystropepts. These soils are deep, are somewhat excessively drained, and have a B2 horizon of dark yellowish brown clay loam. They formed in residuum of plutonic rocks. The Pellejas soils are on side slopes and narrow ridges of strongly dissected humid uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Pellejas soils are associated with the Mucara, Caguabo, Consumo, and Naranjito soils. They have a thicker solum than the Mucara and Caguabo soils. They have yellower hue and lack the argillic horizons of the Consumo and Naranjito soils.

Typical pedon of Pellejas clay loam, 40 to 60 percent slopes, 200 feet northwest from kilometer 17.0 of Highway 152, Bo. Cedro Abajo, Naranjito, P.R.

Ap—0 to 4 inches, dark brown (10YR 4/3) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few krotovinas; common quartz grains; few fine pores; subsurface material is mixed with surface horizon; very strongly acid; clear smooth boundary.

B2—4 to 12 inches, yellowish brown (10YR 5/4) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine and medium roots; common quartz grains; few krotovinas that have white mottles from the parent material; few dark minerals; very strongly acid; gradual smooth boundary.

B3—12 to 16 inches, yellowish brown (10YR 5/4) clay loam; weak fine subangular blocky structure; very friable, nonsticky, slightly plastic; few fine roots; some dead roots; few dark minerals; few krotovinas; common quartz grains; about 25 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C1—16 to 42 inches, pale brown (10YR 6/3) and light yellowish brown (10YR 6/4) sandy loam; massive; very friable, nonsticky, nonplastic; this horizon consists mostly of saprolite; strongly acid; gradual smooth boundary.

C2—42 to 60 inches, variegated gray (10YR 6/1), white (10YR 8/1), pinkish gray (5Y 6/2), and dark greenish gray (5GY 4/1), loamy sand saprolite; massive; very friable, loose; strongly acid.

The solum is 11 to 20 inches thick. Reaction throughout ranges from strongly acid to very strongly acid.

The A horizon has hue of 10YR, value of 2 or 4, and chroma of 2 or 3.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 3 or 4.

Reilly series

The Reilly series consists of sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls. These soils are shallow to gravel, are excessively drained, and have a dark brown sandy loam Ap horizon over dark brown gravelly sand and clean sand and gravel C horizons. They formed in sediments of mixed origin. The Reilly soils are on river flood plains adjacent to streams. Slopes range from 0 to 2 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Reilly soils are associated with the Toa, Coloso, Bajura, and Dique soils. They are better drained and are shallower and coarser textured than the Bajura and Coloso soils. They have gravelly subsurface layers that the Dique soils lack. They are coarser textured than the Toa soils.

Typical pedon of Reilly sandy loam, 400 feet northwest of the entrance to the Gurabo Experiment Station, north of Highway 941.

Ap—0 to 7 inches, dark brown (10YR 3/3) sandy loam; very weak fine granular structure; very friable, slightly sticky, nonplastic; many roots; medium acid; gradual smooth boundary.

C1—7 to 18 inches, dark brown (10YR 3/3) gravelly sand; massive; very friable; many roots; medium acid; gradual smooth boundary.

C2—18 to 55 inches, coarse clean sand and gravel; about 60 percent coarse gravel; slightly acid.

The A horizon is 7 to 15 inches thick. Reaction throughout is medium acid to slightly acid.

The A horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

Rio Arriba series

The Rio Arriba series consists of fine, mixed, isohyperthermic Vertic Paleudalfs. These soils are deep, are moderately well drained, and have a B22t horizon of yellowish brown clay. They formed in sediments of mixed origin. The Rio Arriba soils are on alluvial fans and terraces above the river flood plains. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Rio Arriba soils are associated with the Mabi, Montegrande, Mucara, and Caguabo soils. They have a thicker solum than the Mucara and Caguabo soils and are better drained than the Mabi soils. They lack the gravelly clay C horizon of the Montegrande soils.

Typical pedon of Rio Arriba clay, 5 to 12 percent slopes, eroded, 0.4 kilometers west of the town of Gurabo, P.R., then 800 feet east of the western boundary of the Gurabo Experiment Station farm, and 600 feet north of the railroad tracks.

Ap—0 to 8 inches, brown (10YR 4/3) clay; weak coarse granular structure; hard, firm, slightly sticky, plastic; many fine roots; neutral; clear smooth boundary.

B21t—8 to 16 inches, yellowish brown (10YR 5/8) clay; moderate coarse prismatic structure parting to weak medium subangular blocky; yellowish brown (10YR 5/4) thin continuous coatings on vertical ped surfaces, and patchy coatings on horizontal ped surfaces; hard, firm, slightly sticky, plastic; common fine roots; common fine black nodules; medium acid; clear smooth boundary.

B22t—16 to 28 inches, yellowish brown (10YR 5/6) clay; common medium distinct yellowish red (5YR 4/6) mottles; weak coarse angular blocky structure with few slickensides and pressure faces; firm, slightly sticky, plastic; many fine black nodules; few fine roots; neutral; clear wavy boundary.

B23t—28 to 60 inches, reddish yellow (7.5YR 6/6) clay; many medium distinct red (2.5YR 5/6) mottles; weak coarse angular blocky structure; pressure faces with discontinuous clay coatings on ped surfaces; firm, slightly sticky, plastic; many fine black nodules; mildly alkaline.

The solum is more than 60 inches thick. Reaction throughout ranges from medium acid to mildly alkaline.

The A horizon has hue of 10YR and 7.5YR, value of 3 and 4, and chroma of 2 to 4.

The B2t horizon has hue of 10YR, 7.5YR, and 2.5YR; value of 4 to 6; and chroma of 4 to 8.

Rio Piedras series

The Rio Piedras series consists of clayey kaolinitic isohyperthermic Typic Tropohumults. These soils are moderately deep, well drained, and have a B2t horizon of red clay. They formed in residuum of siltstone. The Rio Piedras soils are on side slopes of dissected uplands. Slopes range from 12 to 60 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Rio Piedras soils are associated with the Yunes soils. They are deeper and have thick argillic horizons which the Yunes soils lack.

Typical pedon of Rio Piedras clay, 12 to 20 percent slopes, eroded, 300 feet southwest from kilometer 1.1 of Guadalcanal road in an orchard at the Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 8 inches, dark brown (7.5YR 4/4) clay; moderate medium granular structure; hard, firm, slightly sticky, slightly plastic; very strongly acid; abrupt smooth boundary.

B2t—8 to 18 inches, red (10R 4/6) clay; few fine distinct yellowish brown (10YR 5/6) mottles; moderate coarse prismatic structure parting to moderate medium subangular blocky; continuous dark reddish brown (2.5YR 3/4) clay films on most peds and in root channels; clay films thicker on vertical ped faces; very hard, very firm, slightly sticky, slightly plastic; few small soft black concretions; common small shale fragments; roots mainly along cleavage planes; very strongly acid; gradual wavy boundary.

B3—18 to 28 inches, red (10R 4/6) clay; common fine and medium distinct red (2.5YR 4/6) and brownish yellow (10YR 6/6) mottles; weak medium subangular blocky structure; patchy reddish brown (5YR 4/4) clay films on peds and in root channels; very hard, very firm, slightly sticky, slightly plastic; many partially weathered shale fragments; original shale structure visible; very strongly acid; gradual wavy boundary.

C1—28 to 34 inches, mixed red (2.5YR 4/6) and brownish yellow (10YR 6/6) clay; common fine distinct light gray (10YR 7/1) and strong brown (7.5YR 5/6) mottles; massive; original structure of shale visible; many small shale fragments easily broken by fingers; very strongly acid; gradual wavy boundary.

C2—34 to 48 inches, bedded partially weathered clay shale that can be penetrated with soil auger; shale has mixed colors with light red (2.5YR 6/8), strong brown (7.5YR 5/8), and pink (7.5YR 7/4) predominating; very strongly acid.

R—48 inches, bedded cemented shale; beds range from 1 to 4 inches thick.

The solum is 20 to 34 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR and 5YR, value of 3 to 5, and chroma of 3 or 4.

The B2t horizon has hue of 5YR, 2.5YR, and 10R; value of 4 or 5; and chroma of 6 to 8.

Sabana series

The Sabana series consists of clayey, mixed, isohyperthermic Lithic Dystropepts. These soils are shallow, are well drained, and have a B2 horizon of dark brown silty clay. They formed in residuum of volcanic rocks. The Sabana soils are on side slopes and narrow ridgetops of humid volcanic uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 80 degrees F.

The Sabana soils are associated with the Mucara and Caguabo soils. They have a thinner solum than the Mucara soils. They are more acid than the Caguabo soils.

Typical pedon of Sabana silty clay loam, 40 to 60 percent slopes, 500 feet southeast from kilometer 53.5 of Highway 1, Cayey, P.R.

Ap—0 to 3 inches, very dark grayish brown (10YR 3/1) silty clay loam; weak fine granular structure; firm, slightly sticky, slightly plastic; about 5 percent volcanic rock fragments; common fine roots; strongly acid; clear wavy boundary.

B2—3 to 8 inches, dark brown (10YR 4/3) silty clay; moderate fine subangular blocky structure; friable, slightly sticky, slightly plastic; about 5 percent volcanic rock fragments; few fine pores; few fine patchy clay films; few fine roots; strongly acid; clear smooth boundary.

B3—8 to 15 inches, variegated light brownish gray (10YR 6/2) and strong brown (7.5YR 5/6) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic, about 10 percent volcanic rock fragments; few fine roots; few fine patchy clay films; strongly acid; abrupt wavy boundary.

R—15 inches, semiconsolidated volcanic rock.

The solum thickness and depth to the rock is 10 to 20 inches. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 or 4, and chroma of 1 to 3.

The B2 horizon has hue of 10YR, 7.5YR, and 5YR; value of 4 to 6; and chroma of 3 to 8.

Sabana Seca series

The Sabana Seca series consists of clayey, mixed, isohyperthermic Oxic Plinthaquults. These soils are deep, are poorly drained, and have a B22g horizon of light gray clay. They formed in sediments of mixed origin. The Sabana Seca series are on humid coastal plains. Slopes range from 2 to 8 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Sabana Seca soils are associated with the Almirante and Bajura soils. They have more plinthite than the Almirante soils and are poorly drained. They occupy higher positions and have thicker B horizons than the Bajura soils.

Typical pedon of Sabana Seca clay, 2 to 8 percent slopes, 400 meters east from kilometer 8.5 of Highway 866, Toa Baja, P.R.

Ap—0 to 10 inches, very dark grayish brown (10YR 3/2) clay; weak fine subangular blocky structure parting to weak fine granular; firm, slightly sticky, plastic; many fine roots; extremely acid; abrupt smooth boundary.

B1—10 to 13 inches, dark grayish brown (2.5Y 4/2) clay; many medium and coarse prominent yellowish brown (10YR 5/6) mottles; moderate fine subangular and angular blocky structure; firm, slightly sticky, plastic; common fine roots; thin patchy clay films on ped faces; dark gray (10YR 4/1) coloration on old root channels and in cracks; extremely acid; clear wavy boundary.

B21tg—13 to 28 inches, light gray (5Y 6/1) clay; many coarse prominent yellowish brown (10YR 5/6) and few fine prominent red (10R 4/6) mottles; very weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, plastic; common fine roots; thin patchy clay films on ped faces; dark gray (10YR 4/1) coloration on old root channels and on ped faces; extremely acid; gradual smooth boundary.

B22tg—23 to 36 inches, light gray (5Y 6/1) and (5Y 7/1) clay; many fine to coarse strong brown (7.5YR 5/6) and common medium and coarse prominent dark red (10R 3/6) mottles, and a few specks of red (2.5YR 4/6); very weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, plastic; few fine roots; common fine concretions; thin patchy clay films on ped faces; extremely acid; gradual smooth boundary.

B23tg—36 to 48 inches, white (5Y 8/1) and (5Y 8/2) clay; many fine, medium, and coarse prominent dusky red (10R 3/4) and strong brown (7.5YR 5/6) mottles and concretions; weak coarse prismatic structure parting to weak medium subangular and angular blocky; firm, slightly sticky, plastic; thin patchy clay films on vertical and horizontal ped faces; extremely acid; clear smooth boundary.

B24tg—48 to 56 inches, white (5Y 8/1) clay; many coarse prominent dusky red (10R 3/4) and common fine to coarse prominent strong brown (7.5YR 5/8) mottles and concretions; weak coarse prismatic structure; firm, slightly sticky, plastic; thin patchy clay films on vertical ped faces; extremely acid; clear smooth boundary.

B25g—56 to 70 inches, white (5Y 8/1) clay; many coarse prominent dusky red (10R 3/4) and dark red (10R 3/6), and few fine prominent red (10R 4/8) and strong brown (7.5YR 5/8) mottles and concretions; weak coarse prismatic structure; firm, slightly sticky, plastic; very few patchy clay films on vertical faces; extremely acid.

The solum is more than 60 inches thick. Reaction throughout is very strongly acid to extremely acid.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 1 to 3.

The B2tg horizon has hue of 2.5Y and 5Y, value of 6 to 8, and chroma of 2 or less.

Saladar series

The Saladar series consists of euic, isohyperthermic Fluvaquentic Troposaprists. These soils are deep, are poorly drained, and have thick black muck O horizons. They formed in highly decomposed organic materials. The Saladar soils are in closed depressions and coastal marshes with restricted outlets. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Saladar soils are associated with the Martin Pena and Bajura soils. They lack mineral horizons and are slightly lower than the Martin Pena and Bajura soils.

Typical pedon of Saladar muck, 530 feet west of the corner of Dr. Joaquin Bosch Street and Dr. Colly Toste Street, Levittown Urbanization, Catano, P.R.

Oa1—0 to 10 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 30 percent fiber, about 10 percent when rubbed; weak fine granular structure; nonsticky; mildly alkaline; gradual smooth boundary.

Oa2—10 to 35 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 25 percent fiber, about 10 percent when rubbed; weak medium granular structure; nonsticky; neutral; gradual smooth boundary.

Oa3—35 to 51 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 25 percent fiber, 10 percent when rubbed; massive; nonsticky; neutral.

The organic portion of the control section has colors in hue of 10YR, value of 2, and chroma of 0 or 1. Reaction throughout ranges from mildly alkaline to neutral.

Soller series

The Soller series consists of clayey, mixed, isohyperthermic, shallow Eutropeptic Rendolls. These soils are shallow, are well drained, and have a B horizon of dark brown clay. They formed in residuum of limestone. The Soller soils are on side slopes and hilltops of low rounded hills. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 75 degrees F.

The Soller soils are associated with the Colinas and the Tanama soils. They have a thinner solum than the Colinas soils and are underlain by hard limestone. They are yellower and not as acid as the Tanama soils.

Typical pedon of Soller clay loam, 40 to 60 percent slopes, 400 feet south of Riverside Urbanization, then 250 feet southwest of water pump, Bayamon, P.R.

A1—0 to 5 inches, very dark grayish brown (10YR 3/2) clay loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; common fine roots; few quartz grains; common limestone rock fragments; mildly alkaline; clear smooth boundary.

B—5 to 12 inches, dark brown (10YR 3/3) clay; moderate coarse subangular blocky structure; firm, slightly sticky, plastic; common limestone rock fragments; common fine roots; moderately alkaline; gradual smooth boundary.

C—12 to 24 inches, yellow (10YR 7/6) weathered limestone; massive; friable, slightly sticky, slightly plastic; strongly alkaline; gradual smooth boundary.

R—24 inches, hard fragmental limestone.

The solum is 10 to 20 inches thick. Reaction throughout ranges from neutral to moderately alkaline.

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 1 or 2.

The B horizon has hue of 10YR, value of 3 or 4, and chroma of 2 to 4. It has weak to moderate medium to coarse subangular blocky structure.

Tanama series

The Tanama series consists of clayey, mixed, isohyperthermic, Lithic Tropudalfs. These soils are shallow, are well drained, and have a B2t horizon of reddish brown clay. They formed in residuum of limestone. The Tanama soils are on side slopes and foot slopes of limestone hills. Slopes range from 20 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Tanama soils are associated with the Juncal and Soller soils. They have a thinner solum and are shallower than the Juncal soils. They are redder and more acid than the Soller soils.

Typical pedon of Tanama clay in an area of Tanama-Rock outcrop complex, 20 to 60 percent slopes, 0.8 mile southwest from kilometer 0.95 of Highway 659, Bo. Santa Rosa, Dorado, P.R.

A1—0 to 4 inches, dark reddish brown (5YR 3/2) clay; weak fine subangular blocky structure; friable, slightly sticky, plastic; many fine roots; common fine and medium limestone fragments; few quartz grains; neutral; clear smooth boundary.

B2t—4 to 14 inches, reddish brown (5YR 4/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; common fine and medium roots; thin patchy clay films; common fine and medium limestone fragments; mildly alkaline; abrupt wavy boundary.

R—14 inches, hard semiconsolidated limestone.

The solum thickness and depth to rock is 12 to 20 inches. Reaction throughout ranges from slightly acid to mildly alkaline.

The A horizon has hue of 7.5YR and 5YR, value of 3 or 4, and chroma of 2 to 4.

The B2t horizon has hue of 5YR and 2.5YR, value of 4 or 5, and chroma of 4 to 8.

Toa series

The Toa series consists of fine, mixed, isohyperthermic Fluventic Hapludolls. These soils are deep, are moderately well drained to well drained, and have a B horizon of dark brown silty clay loam. They formed in sediments of mixed origin. The Toa soils are on river flood plains in the humid portion of the island. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Toa soils are associated with the Dique, Reilly, Coloso, and Bajura soils. They are better drained and coarser textured than the Bajura and Coloso soils. They are finer textured and have slower permeability than the Dique and Reilly soils.

Typical pedon of Toa silty clay loam, 250 feet southwest along fence next to old bridge and 100 feet southeast, which is west of the entrance to the Rio Piedras Experiment Station.

Ap—0 to 8 inches, dark brown (10YR 3/3) silty clay loam; moderate medium granular structure; slightly hard, friable, nonsticky, slightly plastic; many roots; slightly acid; clear smooth boundary.

B—8 to 16 inches, dark brown (10YR 3/3) silty clay loam; few fine faint pale brown (10YR 6/3) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many roots; slightly acid; gradual smooth boundary.

C1—16 to 56 inches, brown (10YR 5/3) silty clay loam, dark brown (10YR 4/3) when crushed; many fine distinct dark reddish brown (5YR 3/4) and few fine faint light gray mottles; weak medium and coarse subangular blocky structure; ped surfaces and root channels have a grayish brown (2.5YR 5/2) coating at lower depths; slightly hard, friable, slightly sticky, slightly plastic; common roots; common black concretions; thin lenses of sand; slightly acid; gradual smooth boundary.

C2—56 to 60 inches, dark brown (7.5YR 4/4) silty clay loam; many fine distinct gray and brown mottles; massive; friable, nonsticky, slightly plastic; common fine sand grains; slightly acid.

The mollic epipedon is 12 to 20 inches thick. Reaction throughout is slightly acid to neutral.

The A horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

The B horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

Torres series

The Torres series consists of clayey, oxidic, isohyperthermic Plinthic Palehumults. These soils are deep, are excessively drained, and have a B2t horizon of yellowish brown clay. They formed in sediments of mixed origin. The Torres soils are on coastal plains and in trapped valleys between the haystack hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Torres soils are associated with the Almirante, Bayamon, and Matanzas soils. They have a loamy sand A horizon that the Almirante, Bayamon, and Matanzas soils lack. They also lack the uniform red profiles of the Bayamon and Matanzas soils.

Typical pedon of Torres loamy sand, 2 to 5 percent slopes, 0.15 mile along a dirt road south from kilometer 25.5 of Highway 2, then 60 feet west of dirt road.

Ap—0 to 10 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose, nonsticky, nonplastic; common fine roots; few fine black concretions; strongly acid; gradual smooth boundary.

A11—10 to 21 inches, dark brown (10YR 3/3) loamy sand; weak coarse subangular blocky structure; very friable, nonsticky, nonplastic; few fine roots; few fine black concretions; strongly acid; gradual smooth boundary.

A12—21 to 28 inches, dark brown (10YR 3/3) sandy loam; weak coarse subangular blocky structure; very friable, nonsticky, nonplastic; common fine black concretions; strongly acid; abrupt smooth boundary.

B21t—28 to 36 inches, yellowish brown (10YR 5/8) clay; few fine prominent red (10R 4/8) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin clay films on ped faces; few sand sized quartz grains; strongly acid; gradual smooth boundary.

B22t—36 to 43 inches, yellowish brown (10YR 5/8) clay; common medium prominent red (10R 4/6) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin clay films on ped faces; few sand sized quartz grains; strongly acid; gradual smooth boundary.

B23t—43 to 64 inches, yellowish brown (10YR 5/8) clay; common medium prominent dark red (10R 3/6) and few medium prominent light gray (5Y 7/1) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin continuous clay films on ped faces; few fine quartz grains; strongly acid.

The solum is more than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3, and chroma of 2 to 4.

The B2t horizon has hue of 7.5YR and 10YR, value of 4 to 6, and chroma of 6 to 8.

Vega Alta series

The Vega Alta series consists of clayey, mixed, isohyperthermic Plinthic Tropudults. These soils are deep, are well drained, and have a B22t horizon of red and brownish yellow clay that contains plinthite. They formed in sediments of mixed origin. The Vega Alta soils are on coastal plains and terraces. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 76 inches, and the mean annual temperature is 77 degrees F.

The Vega Alta soils are associated with the Almirante, Vega Baja, Bajura, and Coloso soils. They are on higher geomorphic positions and are better drained than the Bajura, Coloso, and Vega Baja soils. They have a thinner solum and are shallower to plinthite than the Almirante soils.

Typical pedon of Vega Alta clay loam, 2 to 5 percent slopes, 150 feet north of radio station, 50 feet south of trail east of Rum Pilot Plant; section of experimental farm north of Highway 1 to Caguas, Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 8 inches, dark yellowish brown (10YR 3/4) clay loam; moderate fine granular structure; friable, slightly sticky, slightly plastic; many fine black concretions; common fine roots; strongly acid; abrupt wavy boundary.

B1—8 to 14 inches, reddish yellow (7.5YR 6/8) and yellowish red (5YR 4/6) clay; weak medium and coarse subangular blocky structure parting to moderate fine granular structure; firm, slightly sticky, slightly plastic; thin patchy clay films on ped faces and in root channels; many fine black concretions; few fine roots; strongly acid; clear wavy boundary.

B21t—14 to 25 inches, red (2.5YR 4/8) and strong brown (7.5YR 5/8) clay; moderate medium and coarse subangular blocky structure parting to weak medium angular blocky; firm, slightly sticky, slightly plastic; thick patchy clay films on ped faces; few fine black concretions; few fine roots; strongly acid; gradual wavy boundary.

B22t—25 to 36 inches, red (2.5YR 4/8) and brownish yellow (10YR 6/8) clay; weak medium and coarse subangular blocky structure; firm, nonsticky, slightly plastic; brownish yellow clay films in root channels; nodules of plinthite; few fine quartz grains; very strongly acid; gradual wavy boundary.

B23t—36 to 52 inches, dark red (10R 3/6), strong brown (7.5YR 5/8), and light gray (5Y 7/1) clay; weak coarse subangular blocky structure; friable, nonsticky, slightly plastic; thin patchy clay films; lenses of plinthite; very strongly acid; gradual wavy boundary.

BC—52 to 84 inches, dark red (10R 3/6), brownish yellow (10YR 6/8), and light gray (5Y 7/1) clay; massive; friable, nonsticky, slightly plastic; very strongly acid.

The solum is less than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR and 10YR, value of 3 or 4, and chroma of 2 or 3.

The B2t horizon has hue of 10R, 2.5YR, 7.5YR, and 10YR; value of 3 to 6; and chroma of 6 to 8.

Vega Baja series

The Vega Baja series consists of fine, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are poorly drained, and have a B22t horizon of strong brown and gray silty clay. They formed in sediments of mixed origin. The Vega Baja soils are on coastal plains and alluvial fans. Slopes range from 0 to 2 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Vega Baja soils are associated with the Coloso, Bajura, Toa, and Vega Alta soils. They are at slightly higher elevations above the flood plain than the Bajura and Coloso soils and are underlain by mottled coastal plains clays. They are more poorly drained than the Vega Alta and Toa soils. They lack the plinthite layers of the Vega Alta soils.

Typical pedon of Vega Baja silty clay, 200 feet north on road to Food Technology Laboratory and 200 feet to the right of the road (section of farm north of Highway 1 to Caguas, P.R.), Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 7 inches, dark brown (10YR 4/3) silty clay; weak fine granular structure; firm, slightly sticky, slightly plastic; few fine black concretions; many fine roots; very strongly acid; gradual wavy boundary.

A12—7 to 12 inches, mixed dark grayish brown (10YR 4/2) and yellowish brown (10YR 5/8) silty clay; weak coarse subangular blocky structure; firm, sticky, plastic; few fine black concretions; many fine roots; strongly acid; abrupt wavy boundary.

B21t—12 to 17 inches, dark grayish brown (10YR 4/2) and yellowish brown (10YR 5/8) silty clay; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few fine black concretions; black coatings on ped faces and in root channels; few fine roots; very strongly acid; abrupt wavy boundary.

B22t—17 to 32 inches, mixed strong brown (7.5YR 5/8) and gray (5Y 6/1) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; seams between peds and root channels filled with gray clay; few fine black concretions; very strongly acid; gradual wavy boundary.

B3—32 to 50 inches, brownish yellow (10YR 6/8) and gray (N 7/0) silty clay loam with pockets of yellowish brown (10YR 5/4) clay loam; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few peds and fracture planes coated with black; root channels and worm burrows filled with gray clay; strongly acid; abrupt wavy boundary.

C1—50 to 55 inches, light gray (N 7/0) silty clay; many fine distinct strong brown (7.5YR 5/8) mottles; massive; firm, sticky, plastic; medium acid; abrupt wavy boundary.

C2—55 to 60 inches, light gray (N 7/0) and strong brown (7.5YR 5/8) silty clay; massive; firm, sticky, plastic; medium acid.

The solum is 30 to 60 inches thick. Reaction throughout is medium acid to very strongly acid, and acidity decreases with depth.

The Ap horizon has hue of 7.5YR or 10YR, value of 3 or 4, and chroma of 3 or 4.

The B2t horizon has matrix colors in hue of 7.5YR to 2.5Y, value of 4 to 6, and chroma of 1 to 8.

Via series

The Via series consists of fine-loamy, mixed, isohyperthermic Typic Tropudalfs. These soils are deep, are well drained, and have a B22t horizon of yellowish brown clay loam. They formed in sediments of mixed origin. The Via soils are on high bottom terraces. Slopes range from 5 to 12 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 78 degrees F.

The Via soils are associated with the Rio Arriba, Mabi, and Mucara soils. They occupy similar terrace positions to the Rio Arriba soils, but are coarser textured and lack their Vertic properties. They are coarser textured and better drained than the Mabi soils and do not have their expansive clays. They are deeper than the Mucara soils and are not underlain by volcanic rocks.

Typical pedon of Via clay loam, 5 to 12 percent slopes, eroded, 0.6 mile northwest of kilometer 32.8 from Highway 1 along farm road, then 600 feet north to a pangolagrass field, Bo. Bairoa, Caguas, P.R.

Ap—0 to 9 inches, dark brown (10YR 4/3) clay loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; common fine pores; about 5 percent rock fragments and rounded pebbles; few coated quartz grains; few fine black concretions; strongly acid; abrupt smooth boundary.

B21t—9 to 17 inches, strong brown (7.5YR 5/8) clay loam; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; about 10 percent rock fragments and rounded pebbles; thin patchy clay films on vertical ped faces; common dark minerals; medium acid; clear smooth boundary.

B22t—17 to 26 inches, yellowish brown (10YR 5/6) clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 10 percent weathered rock fragments; few fine dark minerals; few fine pebbles; thin patchy clay films; medium acid; clear smooth boundary.

B23t—26 to 36 inches, strong brown (7.5YR 5/8) clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 10 percent weathered rock fragments; few fine dark minerals; few fine rounded pebbles; medium acid; clear smooth boundary.

IIC—36 to 60 inches, strong brown (7.5YR 5/8) very gravelly clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 60 percent weathered and unweathered rock fragments; many dark minerals; medium acid.

The solum is 30 to 60 inches thick. Reaction throughout ranges from medium acid to strongly acid.

The A horizon has hue of 10YR to 5YR, value of 4 or 5, and chroma of 2 to 4.

The B2t horizon has hue of 10YR and 7.5YR, value of 4 to 6, and chroma of 4 to 8.

Vivi series

The Vivi series consists of coarse-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are well drained, and have a B horizon of dark yellowish brown loam. They formed in sediments derived from plutonic rocks. The Vivi soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 80 degrees F.

The Vivi soils are associated with the Pandura soils. They have a thicker solum and are not underlain by plutonic rocks as the Pandura soils are.

Typical pedon of Vivi loam, 90 feet east from kilometer 2.1 from highway 745, Bo. Espino, San Lorenzo, P.R.

Ap—0 to 9 inches, dark brown (10YR 3/3) loam; weak fine granular structure; very friable, nonsticky, nonplastic; common fine roots; few fine black minerals; fine quartz grains; few fine black concretions; strongly acid; clear smooth boundary.

B—9 to 22 inches, dark yellowish brown (10YR 3/4) loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine black minerals; common fine quartz grains; strongly acid; clear smooth boundary.

C1—22 to 34 inches, dark yellowish brown (10YR 4/4) loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; few fine black minerals; common fine quartz grains; very strongly acid; clear smooth boundary.

C2—34 to 47 inches, yellowish brown (10YR 5/4) very fine sandy loam; massive; very friable, nonsticky, nonplastic; few fine black minerals; common fine quartz grains; very strongly acid; clear smooth boundary.

C3—47 to 58 inches, yellowish brown (10YR 5/4) loamy sand; massive; very friable, nonsticky, nonplastic; many fine black minerals; very strongly acid.

The solum is 10 to 22 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR to 2.5Y, value of 2 and 3, and chroma of 2 and 3.

The B horizon has hue of 10YR and 2.5Y, value of 3 to 6, and chroma of 2 to 4.

The C horizons are stratified loam, sandy loam, very fine sandy loam, and loamy sand.

Yunes series

The Yunes series consists of loamy-skeletal, mixed, isohyperthermic, shallow Typic Dystropepts. These soils are shallow, are well drained, and have B horizons of dark brown and brown very shaly silty clay loam. They formed in residuum of thin bedded shale. The Yunes soils are on side slopes and tops of strongly dissected uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is about 80 degrees F.

The Yunes soils are associated with the Rio Piedras soils. They have a thinner solum and lack the well developed argillic horizons of the Rio Piedras soils.

Typical pedon of Yunes silty clay loam, 20 to 40 percent slopes, 50 feet south of kilometer 2.3 from highway 847, Rio Piedras Experiment station, Rio Piedras, P.R.

A1—0 to 2 inches, dark reddish brown (5YR 3/2) silty clay loam, reddish gray (5YR 5/2) when dry; moderate medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; about 10 percent fine shale fragments; strongly acid; abrupt smooth boundary.

B2—2 to 11 inches, dark brown (7.5YR 3/2) very shaly silty clay loam; weak medium subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; about 60 percent shale fragments; strongly acid; abrupt smooth boundary.

B3—11 to 16 inches, brown (7.5YR 4/4) very shaly silty clay loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; about 80 percent shale fragments; strongly acid; abrupt smooth boundary.

R—16 inches, mixed light red (2.5YR 6/8), strong brown (7.5YR 5/8), and pink (7.5YR 7/4) bedded fragmental shale with thickness of beds from 1 to 4 inches; when moist, shale can be penetrated with difficulty by a spade.

The solum thickness and depth to rock is 10 to 20 inches. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 to 5, and chroma of 2 or 3.

The B horizon has hue of 2.5YR to 7.5YR, value of 3 to 6, and chroma of 3 to 6. It has weak medium to coarse subangular blocky structure. Shale fragments in the B horizons range from 50 to 80 percent.

Classification

The system of soil classification currently used was adopted by the National Cooperative Soil Survey in 1965. Readers interested in further details about the system should refer to “Soil taxonomy” (*4*).

The system of classification has six categories. Beginning with the broadest, these categories are the order, suborder, great group, subgroup, family, and series. In this system the classification is based on the different soil properties that can be observed in the field or those that can be inferred either from other properties that are observable in the field or from the combined data of soil science and other disciplines. The properties selected for the higher categories are the result of soil genesis or of factors that affect soil genesis. In table 16, the soils of the survey area are classified according to the system. Categories of the system are discussed in the following paragraphs.

ORDER. Ten soil orders are recognized as classes in the system. The properties used to differentiate among orders are those that reflect the kind and degree of dominant soil-forming processes that have taken place. Each order is identified by a word ending in *sol*. An example is Ultisol.

SUBORDER. Each order is divided into suborders based primarily on properties that influence soil genesis and are important to plant growth or that are selected to reflect the most important variables within the orders. The last syllable in the name of a suborder indicates the order. An example is Humult (*Hum*, meaning humus, plus *ult*, from Ultisol).

GREAT GROUP. Each suborder is divided into great groups on the basis of close similarities in kind, arrangement, and degree of expression of pedogenic horizons; soil moisture and temperature regimes; and base status. Each great group is identified by the name of a suborder and a prefix that suggests something about the properties of the soil. An example is Tropohumults (*Tropo*, meaning tropical, plus *humults*, the suborder of Ultisols that have high humus content).

SUBGROUP. Each great group may be divided into three subgroups: the central (typic) concept of the great groups, which is not necessarily the most extensive subgroup; the intergrades, or transitional forms to other orders, suborders, or great groups; and the extragrades, which have some properties that are representative of the great groups but do not indicate transitions to any other known kind of soil. Each subgroup is identified by one or more adjectives preceding the name of the great group. The adjective *Typic* identifies the subgroup that is thought to typify the great group. An example is Typic Tropohumults.

FAMILY. Families are established within a subgroup on the basis of similar physical and chemical properties that affect management. Among the properties considered in horizons of major biological activity below plow depth are particle-size distribution, mineral content, temperature regime, thickness of the soil penetrable by roots, consistence, moisture equivalent, soil slope, and permanent cracks. A family name consists of the name of a subgroup and a series of adjectives. The adjectives are the class names for the soil properties used as family differentiae. An example is clayey, kaolinitic, isohyperthermic Typic Tropohumults.

SERIES. The series consists of soils that formed in a particular kind of material and have horizons that, except for texture of the surface soil or of the underlying substratum, are similar in differentiating characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineral and chemical composition.

Formation of the soils

This section describes the five major factors of soil formation and tells how these factors have affected the soils of the San Juan Area.

Factors of soil formation

Soils are formed by the action of soils forming processes on material deposited or accumulated by geologic forces. The characteristics of the soil at any given point are determined by 1) the physical and mineralogical composition of the parent material; 2) the climate under which the material has accumulated and has existed since accumulation; 3) the plant and animal life on and in the soil; 4) the relief, or lay of the land; and 5) the length of time the forces of soil formation have acted on the soil material.

Climate and plant and animal life are active factors of soil genesis. They act on the parent material that has accumulated through the weathering of rocks and slowly change it to a natural body that has genetically related horizons. The effects of the climate and plant and animal life are conditioned by relief. The parent material also affects the kind of profile that can be formed and, in extreme cases, determines it almost entirely. Finally, time is needed for the changing of the parent material into a mature soil. The amount of time can be short or long, but some time is always required for soil horizons to develop.

The factors of soil formation are so closely interrelated in their effects on the soil that few generalizations can be made about the effect of any one unless conditions are specified for the other four.

Parent material

Parent material is the unconsolidated mass from which the soil forms. It largely determines the chemical and mineralogical composition of the soil. To a large extent, the minerals in the parent material determine the kinds and amounts of clay in the soil. Many of the soils in the San Juan Area formed in place material derived from plutonic rocks, mainly granodiorite and quartz diorite, and from extrusive volcanic rocks such as lava, tuff, breccia, and dune deposits, swamp and marsh deposits, and blanket pre-weathered deposits.

Climate

A soil forms rapidly in the San Juan Area because of the warm tropical climate. This warm climate is favorable throughout the year for rapid chemical and physical reactions, for the decomposition of organic material from plants and animals, and for other soil-forming processes.

The variations in temperature are relatively small within the area, but rainfall varies from place to place and this accounts for some differences in the soils.

Temperature and rainfall govern the rate of weathering of the rocks and the decomposition of minerals. They also influence leaching, eluviation, and illuviation. For example, soils in areas of lower rainfall are not so leached as soils in other parts of the area that originated from the same parent material, but have lost bases and nutrients because of the amount of rainfall.

For more specific information about climate of the San Juan Area, refer to the climate section.

Plants and animals

Plants, animals, fungi, and bacteria are important to soil formation. The changes they bring about depend mainly on the kinds of life processes peculiar to each.

Originally, the San Juan Area was covered by fairly dense tropical forest. A large part was cleared for cultivation. When it was later left idle, low brush and native pasture became dominant. Most of the original native vegetation has been destroyed or seriously disturbed, but its effect on soil formation is visible.

The vegetation is generally responsible for the amount of organic matter in the soil, the color of the surface layer, and the amount of nutrients. Growing plants provide a cover that helps to reduce erosion and stabilize the surface so that the soil-forming processes can continue. Leaves, twigs, and entire plants accumulate on the surface of forest soils and then decompose as a result of percolating water and of microorganisms, earthworms, and other forms of animal life acting on the soil. The roots of plants widen cracks on the rocks and thus permit more water to enter the soil. Also, the uprooting of trees influences soil formation by mixing the soil layers and loosening the underlying material.

Earthworms, ants, and many other burrowing animals are extremely active in the San Juan Area and help to keep the soil open and porous. They mix the layers of the soil, mix organic matter into the soil, and help break down the remains of plants. Earthworms and other small invertebrates feed on organic matter in the upper few inches of the soil. They slowly but continually mix the soil material and in places alter it chemically.

Bacteria, fungi, and other microorganisms hasten the weathering of rock minerals and the decay of organic matter.

Relief

The shape of the land surface, the slope, and the depth of the water table have had great influence on the formation of the soils in the survey area. Strongly sloping to steep soils, where runoff is moderate to rapid, generally are well drained, have bright colored, unmottled subsoil and are leached to a greater depth than wet soils in the same general area. About 73 percent of the soils of the San Juan Area are steep to very steep.

In level areas or slight depressions, where the water table is at or near the surface for long periods of time, the soils show marked evidence of wetness, as is the case of the Bajura and Martin Pena soils.

Time

In the formation of soils, time is needed for changes to take place in the parent material, and this is usually a long time when measured in years.

The soils of the San Juan Area range from those that show little or no development to older soils that show pronounced development.

Vivi and Dique soils are examples of young soils that formed from sediment that washed from the hills and was deposited on river flood plains. Bayamon, Matanzas, and Vega Alta are three of the older soils of the stable coastal plains, where the parent material has weathered in place for a long time.

References

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(3) United States Department of Agriculture. 1951. Soil survey manual. U.S. Dep. Agric. Handb. 18, 503 pp., illus. (Supplements replacing pp. 173-188 issued May 1962)

(4) United States Department of Agriculture. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. U.S. Dep. Agric. Handb. 436, 754 pp., illus.

Glossary

ABC soil. A soil having an A, a B, and a C horizon.

AC soil. A soil having only an A and a C horizon. Commonly such soil formed in recent alluvium or on steep rocky slopes.

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.

Alluvial fan. A fan-shaped deposit of sand, gravel, and fine material dropped by a stream where its gradient lessens abruptly.

Alluvium. Material, such as sand, silt, or clay, deposited on land by streams.

Area reclaim. An area difficult to reclaim after the removal of soil for construction and other uses. Revegetation and erosion control are extremely difficult.

Association, soil. A group of soils geographically associated in a characteristic repeating pattern and defined and delineated as a single mapping unit.

Available water capacity (available moisture capacity). The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field moisture capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. The capacity, in inches, in a 60-inch profile or to a limiting layer is expressed as—

	Inches
Very low	0 to 3
Low	3 to 6
Moderate	6 to 9
High	More than 9

Badland. Steep or very steep, commonly nonstony barren land dissected by many intermittent drainage channels. Badland is most common in semiarid and arid regions where streams are entrenched in soft geologic material. Local relief generally ranges from 25 to 500 feet. Runoff potential is very high, and geologic erosion is active.

Base saturation. The degree to which material having base exchange properties is saturated with exchangeable bases (sum of Ca, Mg, Na, K), expressed as a percentage of the exchange capacity.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Bottom land. The normal flood plain of a stream, subject to frequent flooding.

Boulders. Rock fragments larger than 2 feet (60 centimeters) in diameter.

Calcareous soil. A soil containing enough calcium carbonate (commonly with magnesium carbonate) to effervesce (fizz) visibly when treated with cold, dilute hydrochloric acid. A soil having measurable amounts of calcium carbonate or magnesium carbonate.

Cation. An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation-exchange capacity. The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. The term, as applied to soils, is synonymous with base-exchange capacity, but is more precise in meaning.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Clay film. A thin coating of oriented clay on the surface of a soil aggregate or lining pores or root channels. Synonyms: clay coat, clay skin.

Coarse fragments. Mineral or rock particles up to 3 inches (2 millimeters to 7.5 centimeters) in diameter.

Coarse textured (light textured) soil. Sand or loamy sand.

Cobblestone (or cobble). A rounded or partly rounded fragment of rock 3 to 10 inches (7.5 to 25 centimeters) in diameter.

Colluvium. Soil material, rock fragments, or both moved by creep, slide, or local wash and deposited at the bases of steep slopes.

Complex, soil. A mapping unit of two or more kinds of soil occurring in such an intricate pattern that they cannot be shown separately on a soil map at the selected scale of mapping and publication.

Concretions. Grains, pellets, or nodules of various sizes, shapes, and colors consisting of concentrated compounds or cemented soil grains. The composition of most concretions is unlike that of the surrounding soil. Calcium carbonate and iron oxide are common compounds in concretions.

Consistence, soil. The feel of the soil and the ease with which a lump can be crushed by the fingers. Terms commonly used to describe consistence are—

Loose.—Noncoherent when dry or moist; does not hold together in a mass.

Friable.—When moist, crushes easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.

Firm.—When moist, crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

Plastic.—When wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.

Sticky.—When wet, adheres to other material and tends to stretch somewhat and pull apart rather than to pull free from other material.

Hard.—When dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.

Soft.—When dry, breaks into powder or individual grains under very slight pressure.

Cemented.—Hard; little affected by moistening.

Contour stripcropping (or contour farming). Growing crops in strips that follow the contour. Strips of grass or close-growing crops are alternated with strips of clean-tilled crops or summer fallow.

Control section. The part of the soil on which classification is based. The thickness varies among different kinds of soil, but for many it is 40 or 80 inches (1 or 2 meters).

Corrosive. High risk of corrosion to uncoated steel or deterioration of concrete.

Cutbanks cave. Unstable walls of cuts made by earthmoving equipment. The soil sloughs easily.

Deferred grazing. A delay in grazing until range plants have reached a specified stage of growth. Grazing is deferred in order to increase the vigor of forage and to allow desirable plants to produce seed. Contrasts with continuous grazing and rotation grazing.

Depth to rock. Bedrock at a depth that adversely affects the specified use.

Diversion (or diversion terrace). A ridge of earth, generally a terrace, built to protect downslope areas by diverting runoff from its natural course.

Drainage class (natural). Refers to the frequency and duration of periods of saturation or partial saturation during soil formation, as opposed to altered drainage, which is commonly the result of artificial drainage or irrigation but may be caused by the sudden deepening of channels or the blocking of drainage outlets. Seven classes of natural soil drainage are recognized:

Excessively drained.—Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of the mottling related to wetness.

Somewhat excessively drained.—Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep that much of the water they receive is lost as runoff. All are free of the mottling related to wetness.

Well drained.—Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured. They are mainly free of mottling.

Moderately well drained.—Water is removed from the soil somewhat slowly during some periods. Moderately well drained soils are wet for only a short time during the growing season, but periodically for long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the solum, or periodically receive high rainfall, or both.

Somewhat poorly drained.—Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a high water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly drained.—Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated in layers directly below plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

Very poorly drained.—Water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. Unless the soil is artificially drained, most mesophytic crops cannot be grown. Very poorly drained soils are commonly level or depressed and are frequently ponded. Yet, where rainfall is high and nearly continuous, they can have moderate or high slope gradients, as for example in "hillpeats" and "climatic moors."

Drainage, surface. Runoff, or surface flow of water, from an area.

Eluviation. The movement of material in true solution or colloidal suspension from one place to another within the soil. Soil horizons that have lost material through eluviation are eluvial; those that have received material are illuvial.

Erosion. The wearing away of the land surface by running water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (geologic). Erosion caused by geologic processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of such landscape features as flood plains and coastal plains. Synonym: natural erosion.

Erosion (accelerated). Erosion much more rapid than geologic erosion, mainly as a result of the activities of man or other animals or of a catastrophe in nature, for example, fire, that exposes a bare surface.

Excess fines. Excess silt and clay. The soil does not provide a source of gravel or sand for construction purposes.

Fast intake. The rapid movement of water into the soil.

Favorable. Favorable soil features for the specified use.

Fertility, soil. The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable.

Field moisture capacity. The moisture content of a soil, expressed as a percentage of the ovendry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called *normal field capacity, normal moisture capacity,* or *capillary capacity.*

Fibric soil material (peat). The least decomposed of all organic soil material. Peat contains a large amount of well preserved fiber that is readily identifiable according to botanical origin. Peat has the lowest bulk density and the highest water content at saturation of all organic soil material.

Fine textured (heavy textured) soil. Sandy clay, silty clay, and clay.

Flooding. The temporary covering of soil with water from overflowing streams, runoff from adjacent slopes, and tides. Frequency, duration, and probable dates of occurrence are estimated. Frequency is expressed as none, rare, occasional, and frequent. *None* means that flooding is not probable; *rare* that it is unlikely but possible under unusual weather conditions; *occasional* that it occurs on an average of once or less in 2 years; and *frequent* that it occurs on an average of more than once in 2 years. Duration is expressed as *very brief* if less than 2 days, *brief* if 2 to 7 days, and *long* if more than 7 days. Probable dates are expressed in months; *November-May*, for example, means that flooding can occur during the period November through May. Water standing for short periods after rainfall or commonly covering swamps and marshes is not considered flooding.

Flood plain. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

Foot slope. The inclined surface at the base of a hill.

Forage. Plant material used as feed by domestic animals. Forage can be grazed or cut for hay.

Genesis, soil. The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum, or true soil, from the unconsolidated parent material.

Gleyed soil. A soil having one or more neutral gray horizons as a result of waterlogging and lack of oxygen. The term "gleyed" also designates gray horizons and horizons having yellow and gray mottles as a result of intermittent waterlogging.

Grassed waterway. A natural or constructed waterway, typically broad and shallow, seeded to grass as protection against erosion. Conducts surface water away from cropland.

Gravel. Rounded or angular fragments of rock up to 3 inches (2 millimeters to 7.5 centimeters) in diameter. An individual piece is a pebble.

Gravelly soil material. Material from 15 to 50 percent, by volume, rounded or angular rock fragments, not prominently flattened, up to 3 inches (7.5 centimeters) in diameter.

Ground water (geology). Water filling all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

Gully. A miniature valley with steep sides cut by running water and through which water ordinarily runs only after rainfall. The distinction between a gully and a rill is one of depth. A gully generally is an obstacle to farm machinery and is too deep to be obliterated by ordinary tillage; a rill is of lesser depth and can be smoothed over by ordinary tillage.

Hemic soil material (mucky peat). Organic soil material intermediate in degree of decomposition between the less decomposed fibric and the more decomposed sapric material.

Horizon, soil. A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. The major horizons of mineral soil are as follows:

O horizon.—An organic layer, fresh and decaying plant residue, at the surface of a mineral soil.

A horizon.—The mineral horizon, formed or forming at or near the surface, in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon most of which was originally part of a B horizon.

A2 horizon.—A mineral horizon, mainly a residual concentration of sand and silt high in content of resistant minerals as a result of the loss of silicate clay, iron, aluminum, or a combination of these.

B horizon.—The mineral horizon below an A horizon. The B horizon is in part a layer of change from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics caused (1) by accumulation of clay, sesquioxides, humus, or a combination of these; (2) by prismatic or blocky structure; (3) by redder or browner colors than those in the A horizon; or (4) by a combination of these. The combined A and B horizons are generally called the solum, or true soil. If a soil lacks a B horizon, the A horizon alone is the solum.

C horizon.—The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the A or B horizon. The material of a C horizon may be either like or unlike that from which the solum is presumed to have formed. If the material is known to differ from that in the solum the Roman numeral II precedes the letter C.

R layer.—Consolidated rock beneath the soil. The rock commonly underlies a C horizon, but can be directly below an A or a B horizon.

Humus. The well decomposed, more or less stable part of the organic matter in mineral soils.

Hydrologic soil groups. Refers to soils grouped according to their runoff-producing characteristics. The chief consideration is the inherent capacity of soil bare of vegetation to permit infiltration. The slope and the kind of plant cover are not considered, but are separate factors in predicting runoff. Soils are assigned to four groups. In group A are soils having a high infiltration rate when thoroughly wet and having a low runoff potential. They are mainly deep, well drained, and sandy or gravelly. In group D, at the other extreme, are soils having a very slow infiltration rate and thus a high runoff potential. They have a claypan or clay layer at or near the surface, have a permanent high water table, or are shallow over nearly impervious bedrock or other material. A soil is assigned to two hydrologic groups if part of the acreage is artificially drained and part is undrained.

Impervious soil. A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

Infiltration. The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or material.

Infiltration rate. The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.

Karst (topography). The relief of an area underlain by limestone that dissolves in differing degrees, thus forming numerous depressions or small basins.

Landslide. The rapid downhill movement of a mass of soil and loose rock generally when wet or saturated. The speed and distance of movement, as well as the amount of soil and rock material, vary greatly.

Large stones. Rock fragments 10 inches (25 centimeters) or more across. Large stones adversely affect the specified use.

Leaching. The removal of soluble material from soil or other material by percolating water.

Light textured soil. Sand and loamy sand.

Liquid limit. The moisture content at which the soil passes from a plastic to a liquid state.

Loam. Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Low strength. Inadequate strength for supporting loads.

Medium textured soil. Very fine sandy loam, loam, silt loam, or silt.

Metamorphic rock. Rock of any origin altered in mineralogical composition, chemical composition, or structure by heat, pressure, and movement. Nearly all such rocks are crystalline.

Mineral soil. Soil that is mainly mineral material and low in organic material. Its bulk density is greater than that of organic soil.

Minimum tillage. Only the tillage essential to crop production and prevention of soil damage.

Miscellaneous areas. Areas that have little or no natural soil, are too nearly inaccessible for orderly examination, or cannot otherwise be feasibly classified.

Moderately coarse textured (moderately light textured) soil. Sandy loam and fine sandy loam.

Moderately fine textured (moderately heavy textured) soil. Clay loam, sandy clay loam, and silty clay loam.

Morphology, soil. The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile.

Mottling, soil. Irregular spots of different colors that vary in number and size. Mottling generally indicates poor aeration and impeded drainage. Descriptive terms are as follows: abundance—*few*, *common*, and *many*; size—*fine*, *medium*, and *coarse*; and contrast—*faint*, *distinct*, and *prominent*. The size measurements are of the diameter along the greatest dimension. *Fine* indicates less than 5 millimeters (about 0.2 inch); *medium*, from 5 to 15 millimeters (about 0.2 to 0.6 inch); and *coarse*, more than 15 millimeters (about 0.6 inch).

Muck. Dark colored, finely divided, well decomposed organic soil material mixed with mineral soil material. The content of organic matter is more than 20 percent.

Munsell notation. A designation of color by degrees of the three single variables—hue, value, and chroma. For example, a notation of 10YR 6/4 is a color of 10YR hue, value of 6, and chroma of 4.

Neutral soil. A soil having a pH value between 6.6 and 7.3.

Nutrient, plant. Any element taken in by a plant, essential to its growth, and used by it in the production of food and tissue. Plant nutrients are nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, zinc, and perhaps other elements obtained from the soil; and carbon, hydrogen, and oxygen obtained largely from the air and water.

Parent material. The great variety of unconsolidated organic and mineral material in which soil forms. Consolidated bedrock is not yet parent material by this concept.

Peat. Unconsolidated material, largely undecomposed organic matter, that has accumulated under excess moisture.

Ped. An individual natural soil aggregate, such as a granule, a prism, or a block.

Pedon. The smallest volume that can be called "a soil." A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from about 10 to 100 square feet (1 square meter to 10 square meters), depending on the variability of the soil.

Percolation. The downward movement of water through the soil.

Percs slowly. The slow movement of water through the soil adversely affecting the specified use.

Permeability. The quality that enables the soil to transmit water or air, measured as the number of inches per hour that water moves through the soil. Terms describing permeability are *very slow* (less than 0.06 inch), *slow* (0.06 to 0.20 inch), *moderately slow* (0.2 to 0.6 inch), *moderate* (0.6 to 2.0 inches), *moderately rapid* (2.0 to 6.0 inches), *rapid* (6.0 to 20 inches), and *very rapid* (more than 20 inches).

Phase, soil. A subdivision of a soil series or other unit in the soil classification system based on differences in the soil that affect its management. A soil series, for example, may be divided into phases on the bases of differences in slope, stoniness, thickness, or some other characteristic that affects management. These differences are too small to justify separate series.

pH value. (See Reaction, soil). A numerical designation of acidity and alkalinity in soil.

Piping. Moving water of subsurface tunnels or pipelike cavities in the soil.

Plasticity index. The numerical difference between the liquid limit and the plastic limit; the range of moisture content within which the soil remains plastic.

Plastic limit. The moisture content at which a soil changes from a semisolid to a plastic state.

Plinthite. The sesquioxide-rich, humus-poor, highly weathered mixture of clay with quartz and other diluents that commonly appears as red mottles, usually in platy, polygonal, or reticulate patterns. Plinthite changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying, especially if it is exposed also to heat from the sun. In a moist soil, plinthite can be cut with a spade, whereas ironstone cannot be cut but can be broken or shattered with a spade. Plinthite is one form of the material that has been called laterite.

Plutonic rock. A general term applied to the class of igneous rocks that have crystallized at great depths and are generally granitoid in texture.

Polypedon. A volume of soil having properties within the limits of a soil series, the lowest and most homogeneous category of soil taxonomy. A "soil individual."

Poorly graded. Refers to soil material consisting mainly of particles of nearly the same size. Because there is little difference in size of the particles, density can be increased only slightly by compaction.

Poor outlets. Surface or subsurface drainage outlets difficult or expensive to install.

Pressure faces. Structural faces that show more evidence of clay than the natural ped surfaces but that do not have clay films. Probably caused by the shrinking and swelling of the soil.

Productivity (soil). The capability of a soil for producing a specified plant or sequence of plants under a specified system of management. Productivity is measured in terms of output, or harvest, in relation to input.

Profile, soil. A vertical section of the soil extending through all its horizons and into the parent material.

Reaction, soil. The degree of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline. The degree of acidity or alkalinity is expressed as—

	pH
Extremely acid	Below 4.5
Very strongly acid	4.5 to 5.0
Strongly acid	5.1 to 5.5
Medium acid	5.6 to 6.0
Slightly acid	6.1 to 6.5
Neutral	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	9.1 and higher

Relief. The elevations or inequalities of a land surface, considered collectively.

Residuum (residual soil material). Unconsolidated, weathered, or partly weathered mineral material that accumulates over disintegrating rock.

Rock fragments. Rock or mineral fragments having a diameter of 2 millimeters or more; for example, pebbles, cobbles, stones, and boulders.

Rooting depth. Shallow root zone. The soil is shallow over a layer that greatly restricts roots. See Root zone.

Root zone. The part of the soil that can be penetrated by plant roots.

Runoff. The precipitation discharged in stream channels from a drainage area. The water that flows off the land surface without sinking in is called surface runoff; that which enters the ground before reaching surface streams is called ground-water runoff or seepage flow from ground water.

Saline soil. A soil containing soluble salts in an amount that impairs growth of plants. A saline soil does not contain excess exchangeable sodium.

Sand. As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.

Sandstone. Sedimentary rock containing dominantly sand-size particles.

Sapric soil material (muck). The most highly decomposed of all organic soil material. Muck has the least amount of plant fiber, the highest bulk density, and the lowest water content at saturation of all organic soil material.

Saprolite (geology). Soft, earthy, clay-rich, thoroughly decomposed rock formed in place by chemical weathering of igneous and metamorphic rock. In soil survey, the term saprolite is applied to any unconsolidated residual material underlying the soil and grading to hard bedrock below.

Sedimentary rock. Rock made up of particles deposited from suspension in water. The chief kinds of sedimentary rock are conglomerate, formed from gravel; sandstone, formed from sand; shale, formed from clay; and limestone, formed from soft masses of calcium carbonate. There are many intermediate types. Some wind-deposited sand is consolidated into sandstone.

Seepage. The rapid movement of water through the soil. Seepage adversely affects the specified use.

Series, soil. A group of soils, formed from a particular type of parent material, having horizons that, except for the texture of the A or surface horizon, are similar in all profile characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineralogical and chemical composition.

Sheet erosion. The removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and runoff water.

Shrink-swell. The shrinking of soil when dry and the swelling when wet. Shrinking and swelling can damage roads, dams, building foundations, and other structures. It can also damage plant roots.

Silica. A combination of silicon and oxygen. The mineral form is called quartz.

Silt. As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.

Siltstone. Sedimentary rock made up of dominantly silt-sized particles.

Sinkhole. A depression in a landscape where limestone has been locally dissolved.

Slickensides. Polished and grooved surfaces produced by one mass sliding past another. In soils, slickensides may occur at the bases of slip surfaces on the steeper slopes; on faces of blocks, prisms, and columns; and in swelling clayey soils, where there is marked change in moisture content.

Slope. The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.

Slow intake. The slow movement of water into the soil.

Small stones. Rock fragments 3 to 10 inches (7.5 to 25 centimeters) in diameter. Small stones adversely affect the specified use.

Soil. A natural, three-dimensional body at the earth's surface that is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.

Soil separates. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes of separates recognized in the United States are as follows: *very coarse sand* (2.0 millimeters to 1.0 millimeter); *coarse sand* (1.0 to 0.5 millimeter); *medium sand* (0.5 to 0.25 millimeter); *fine sand* (0.25 to 0.10 millimeter); *very fine sand* (0.10 to 0.05 millimeter); *silt* (0.005 to 0.002 millimeter); and *clay* (less than 0.002 millimeter).

Solum. The upper part of a soil profile, above the C horizon, in which the processes of soil formation are active. The solum in mature soil consists of the A and B horizons. Generally, the characteristics of the material in these horizons are unlike those of the underlying material. The living roots and other plant and animal life characteristics of the soil are largely confined to the solum.

Stones. Rock fragments 10 to 24 inches (25 to 60 centimeters) in diameter.

Stony. Refers to a soil containing stones in numbers that interfere with or prevent tillage.

Stratified. Arranged in strata, or layers. The term refers to geologic material. Layers in soils that result from the processes of soil formation are called horizons; those inherited from the parent material are called strata.

Stripcropping. Growing crops in a systematic arrangement of strips or bands which provide vegetative barriers to wind and water erosion.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates that are separated from adjoining aggregates. The principal forms of soil structure are—*platy* (laminated), *prismatic* (vertical axis of aggregates longer than horizontal), *columnar* (prisms with rounded tops), *blocky* (angular or subangular), and *granular*. *Structureless* soils are either *single grained* (each grain by itself, as in dune sand) or *massive* (the particles adhering without any regular cleavage, as in many hardpans).

Stubble mulch. Stubble or other crop residue left on the soil, or partly worked into the soil, to provide protection from soil blowing and water erosion after harvest, during preparation of a seedbed for the next crop, and during the early growing period of the new crop.

Subsoil. Technically, the B horizon; roughly, the part of the solum below plow depth.

Substratum. The part of the soil below the solum.

Subsurface layer. Technically, the A2 horizon. Generally refers to a leached horizon lighter in color and lower in content of organic matter than the overlying surface layer.

Surface soil. The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from 4 to 10 inches (10 to 25 centimeters). Frequently designated as the "plow layer," or the "Ap horizon."

Terrace. An embankment, or ridge, constructed across sloping soils on the contour or at a slight angle to the contour. The terrace intercepts surface runoff so that it can soak into the soil or flow slowly to a prepared outlet without harm. A terrace in a field is generally built so that the field can be farmed. A terrace intended mainly for drainage has a deep channel that is maintained in permanent sod.

Terrace (geologic). An old alluvial plain, ordinarily flat or undulating, bordering a river, a lake, or the sea. A stream terrace is frequently called a second bottom, in contrast with a flood plain, and is seldom subject to overflow. A marine terrace, generally wide, was deposited by the sea.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are *sand, loamy sand, sandy loam, loam, silt, silt loam, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay,* and *clay*. The sand, loamy sand, and sandy loam classes may be further divided by specifying "coarse," "fine," or " very fine."

Thin layer. Otherwise suitable soil material too thin for the specified use.

Tilth, soil. The condition of the soil, especially the soil structure, as related to the growth of plants. Good tilth refers to the friable state and is associated with high noncapillary porosity and stable structure. A soil in poor tilth is nonfriable, hard, nonaggregated, and difficult to till.

Topsoil (engineering). Presumably a fertile soil or soil material, or one that responds to fertilization, ordinarily rich in organic matter, used to topdress roadbanks, lawns, and gardens.

Tuff. A compacted deposit 50 percent or more volcanic ash and dust.

Upland (geology). Land at a higher elevation, in general, than the alluvial plain or stream terrace; land above the lowlands along streams.

Unstable fill. Risk of caving or sloughing in banks of fill material.

Variegation. Refers to patterns of contrasting colors assumed to be inherited from the parent material rather than to be the result of poor drainage.

Volcanic rock. The class of igneous rocks that have been poured out or ejected at or near the surface. The form is synonymous with extrusive rock and effusive rock.

Water table. The upper limit of the soil or underlying rock material that is wholly saturated with water.

Illustrations

Figure 1.—Adequate drainage is essential in producing high yields of sugarcane on poorly drained Bajura clay.

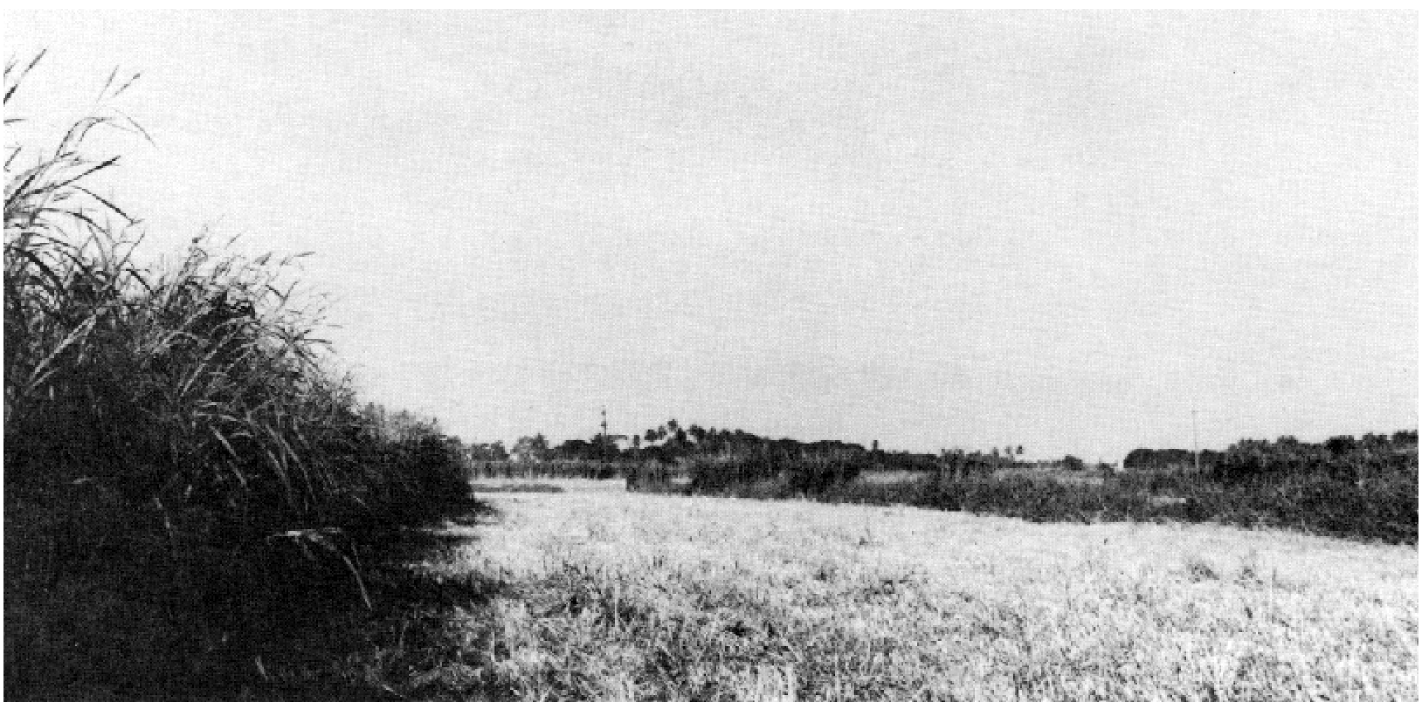

Figure 2.—High yields of Merker grass are produced on Bayamon clay, 2 to 5 percent slopes, a deep, red, acid soil on the coastal plains.

Figure 3.—Drainage ditch lowers water table and improves drainage of Coloso silty clay loam. This field is planted to sugarcane.

Figure 4.—Field of Daguey clay, 12 to 20 percent slopes, is prepared for planting to taniers and plantains.

Figure 5.—Sugarcane grown on Dique loam. This nearly level, well drained soil is on flood plains.

Figure 6.—Controlling erosion is the major concern of management in this field of Humatas clay, 20 to 40 percent slopes, planted to plantains. Hillside ditches break the length of slope and take excess runoff water slowly out of the field.

Figure 7.—Proper stocking rates and deferred grazing, as well as liming and fertilizing, are the chief management needs of this pasture on Lares clay, 5 to 12 percent slopes, eroded, planted to pangolagrass.

Figure 8.—Contour furrows and hillside ditches help overcome the rapid runoff and erosion hazard on Limones clay, 20 to 40 percent slopes.

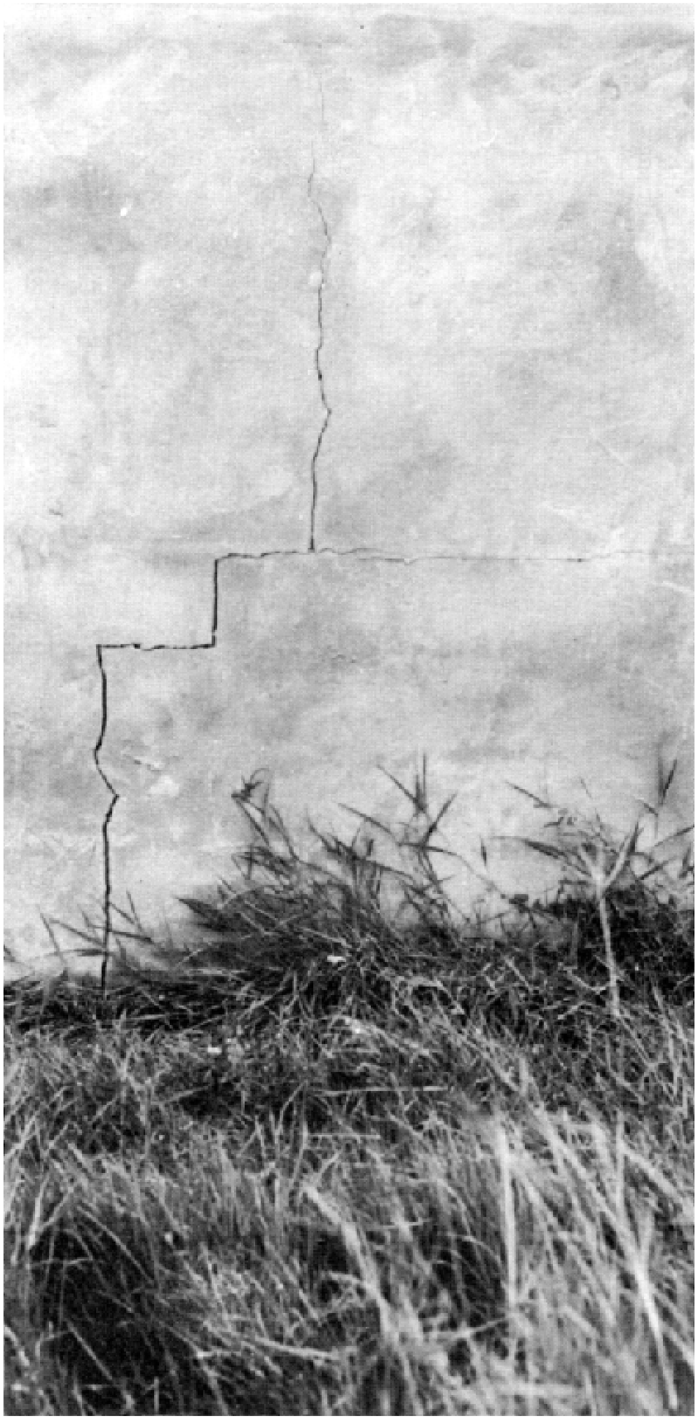

Figure 9.—High shrink-swell potential has caused cracks in this wall on Mabi clay, 0 to 2 percent slopes. This soil is severely limited for most urban uses.

Figure 10.—Crop residue management in this field of Toa silty clay loam helps maintain moisture and recycles nutrients back into the soil.

Figure 11.—Harvest of Merker grass on Vega Alta clay loam, 5 to 12 percent slopes, eroded.

Figure 12.—Hillside ditches shorten the slope and reduce runoff and erosion in field of plantains.

Tables

TABLE 1.--TEMPERATURE AND PRECIPITATION DATA

Month	Temperature[1]						Precipitation[1]				
	Average daily maximum	Average daily minimum	Average daily	2 years in 10 will have-- Maximum temperature higher than--	2 years in 10 will have-- Minimum temperature lower than--	Average number of growing degree days[2]	Average	2 years in 10 will have-- Less than--	2 years in 10 will have-- More than--	Average number of days with 0.10 inch or more	Average snowfall
	°F	°F	°F	°F	°F	Units	In	In	In		In
January	82.5	69.8	76.2	88	64	502	3.21	1.98	4.31	9	.0
February	82.9	69.5	76.2	89	64	454	2.15	1.13	2.99	5	.0
March	84.2	70.4	77.3	91	64	536	2.59	1.29	3.64	5	.0
April	84.9	72.0	78.5	92	66	555	3.52	1.52	5.13	7	.0
May	86.3	73.5	79.9	93	69	617	5.89	2.20	8.85	10	.0
June	87.7	74.8	81.3	93	71	639	5.11	2.67	7.09	10	.0
July	87.6	75.7	81.7	92	72	673	4.82	2.78	6.47	11	.0
August	88.1	75.7	81.9	93	72	679	6.27	4.49	7.90	12	.0
September	88.2	75.1	81.7	93	72	651	5.19	3.48	6.75	11	.0
October	87.7	74.4	81.1	93	70	654	5.88	3.36	7.93	10	.0
November	85.4	72.9	79.2	91	67	576	5.14	3.28	6.82	11	.0
December	83.3	71.3	77.3	89	66	536	4.86	2.77	6.56	10	.0
Year	85.7	72.9	79.4	94	63	7,072	54.63	44.96	63.50	111	.0

[1]Recorded in the period 1955-74 at San Juan, P. R.

[2]A growing degree day is a unit of heat available for plant growth. It can be calculated by adding the maximum and minimum daily temperatures, dividing the sum by 2, and subtracting the temperature below which growth is minimal for the principal crops in the area (60° F).

TABLE 2.--TEMPERATURE AND PRECIPITATION DATA

Month	Temperature[1]						Precipitation[1]				
	Average daily maximum	Average daily minimum	Average daily	2 years in 10 will have-- Maximum temperature higher than--	2 years in 10 will have-- Minimum temperature lower than--	Average number of growing degree days[2]	Average	2 years in 10 will have-- Less than--	2 years in 10 will have-- More than--	Average number of days with 0.10 inch or more	Average snowfall
	°F	°F	°F	°F	°F	Units	In	In	In		In
January----	76.1	60.2	68.2	82	56	254	3.80	2.12	5.17	10	.0
February---	77.5	59.8	68.7	83	55	244	2.13	1.35	2.83	6	.0
March------	78.9	60.7	69.8	84	56	304	3.29	1.85	4.46	6	.0
April------	80.1	61.6	70.9	85	56	327	4.27	1.68	6.36	7	.0
May--------	81.0	63.5	72.3	87	59	381	6.50	2.65	9.61	9	.0
June-------	82.0	65.4	73.7	86	62	411	3.39	1.88	4.62	8	.0
July-------	82.5	66.1	74.3	87	62	443	3.31	2.00	4.47	7	.0
August-----	82.5	66.5	74.5	88	61	450	5.18	3.43	6.77	8	.0
September--	82.7	66.0	74.4	86	61	432	5.22	3.74	6.58	9	.0
October----	81.9	66.2	74.1	88	61	437	9.03	3.80	13.27	12	.0
November---	79.7	64.2	71.9	84	59	357	6.95	3.28	9.93	10	.0
December---	77.1	61.6	69.4	84	57	291	4.03	1.77	5.85	7	.0
Year-----	80.2	63.5	71.9	89	55	4,331	57.10	39.74	73.55	99	.0

[1]Recorded in the period 1963-74 at Barranquitas, P. R.

[2]A growing degree day is a unit of heat available for plant growth. It can be calculated by adding the maximum and minimum daily temperatures, dividing the sum by 2, and subtracting the temperature below which growth is minimal for the principal crops in the area (60° F).

TABLE 3.--MAP UNITS AND THEIR POTENTIAL AND LIMITATIONS FOR SPECIFIED USE

Map unit	Extent of area	Cultivated farm crops	Specialty crops	Woodland	Urban Uses	Intensive recreation areas	Extensive recreation areas
	Pct						
1. Maricao-Los Guineos	10	Poor: slope.	Poor: slope.	Good-------	Poor: slope, too clayey.	Poor: slope, too clayey.	Good.
2. Humatas-Naranjito-Consumo	29	Poor: slope.	Poor: slope.	Good-------	Poor: slope, too clayey.	Poor: slope, too clayey.	Good.
3. Mucara-Caguabo	39	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
4. Descalabrado	1	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
5. Pandura-Lirios	7	Poor: slope.	Poor: slope.	Good-------	Poor: slope.	Poor: slope.	Good.
6. Tanama-Colinas-Soller	4	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
7. Almirante-Vega Alta-Matanzas	3	Good-------	Good-------	Good-------	Good-------	Good--------	Good.
8. Toa-Bajura-Coloso	4	Good-------	Good-------	Good-------	Poor: wetness, flooding.	Poor: wetness, flooding.	Good.
9. Mabi-Rio Arriba	2	Fair: wetness.	Fair: wetness.	Good-------	Poor: wetness, shrink-swell.	Poor: wetness, too clayey.	Good.
10. Martin Pena-Saladar-Hydraquents	1	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Good.

TABLE 4.--ACREAGE AND PROPORTIONATE EXTENT OF THE SOILS

Map symbol	Soil name	Acres	Percent
AaB	Aceitunas clay, 2 to 5 percent slopes	575	0.1
AaC	Aceitunas clay, 5 to 12 percent slopes	4,328	1.0
AbD	Aibonito clay, 12 to 20 percent slopes	276	0.1
AbE	Aibonito clay, 20 to 40 percent slopes	803	0.2
AmB	Almirante clay, 2 to 5 percent slopes	4,280	1.0
AmC	Almirante clay, 5 to 12 percent slopes	1,098	0.2
Ba	Bajura clay	4,148	0.9
BmB	Bayamon clay, 2 to 5 percent slopes	647	0.1
CaE	Caguabo clay loam, 20 to 40 percent slopes	3,674	0.8
CaF	Caguabo clay loam, 40 to 60 percent slopes	51,494	11.5
CbF	Caguabo-Rock outcrop complex, 40 to 60 percent slopes	2,324	0.5
Ce	Candelero loam	607	0.1
ClC	Catalina clay, 4 to 12 percent slopes	267	0.1
Cn	Catano loamy sand	252	0.1
Co	Cayagua sandy loam	1,822	0.4
CrD2	Colinas clay loam, 12 to 20 percent slopes, eroded	1,165	0.3
CrE2	Colinas clay loam, 20 to 40 percent slopes, eroded	2,802	0.6
CrF2	Colinas clay loam, 40 to 60 percent slopes, eroded	894	0.2
Cs	Coloso silty clay loam	2,640	0.6
CuE	Consumo clay, 20 to 40 percent slopes	2,382	0.5
CuF	Consumo clay, 40 to 60 percent slopes	17,118	3.8
CzC	Corozal clay, 5 to 12 percent slopes	219	0.1
DaC	Daguey clay, 2 to 12 percent slopes	106	([1])
DaD	Daguey clay, 12 to 20 percent slopes	6,729	1.5
DeF	Descalabrado clay loam, 40 to 60 percent slopes	1,785	0.4
DgF	Descalabrado-Rock outcrop complex, 40 to 60 percent slopes	1,239	0.3
Dm	Dique loam	296	0.1
Dr	Durados sandy loam	448	0.1
Es	Estacion silty clay loam	1,624	0.4
GuF	Guayama clay loam, 20 to 60 percent slopes	266	0.1
Hm	Humacao loam	78	([1])
HtE	Humatas clay, 20 to 40 percent slopes	19,364	4.3
HtF	Humatas clay, 40 to 60 percent slopes	21,105	4.7
HuF	Humatas-Rock outcrop complex, 20 to 60 percent slopes	1,022	0.2
Hy	Hydraquents, saline	624	0.1
JaE2	Jagueyes loam, 20 to 40 percent slopes, eroded	200	([1])
JnD2	Juncal clay, 5 to 20 percent slopes, eroded	524	0.1
JuC	Juncos clay, 5 to 12 percent slopes	754	0.2
JuD	Juncos clay, 12 to 20 percent slopes	1,272	0.3
LaB	Lares clay, 2 to 5 percent slopes	205	([1])
LaC2	Lares clay, 5 to 12 percent slopes, eroded	1,841	0.4
LmE	Limones clay, 20 to 40 percent slopes	384	0.1
LmF	Limones clay, 40 to 60 percent slopes	314	0.1
LoF2	Lirios silty clay loam, 20 to 60 percent slopes, eroded	7,346	1.6
LsE	Los Guineos clay, 20 to 40 percent slopes	3,474	0.8
LsF	Los Guineos clay, 40 to 60 percent slopes	14,588	3.3
MaA	Mabi clay, 0 to 2 percent slopes	274	0.1
MaB	Mabi clay, 2 to 5 percent slopes	2,440	0.5
MaC	Mabi clay, 5 to 12 percent slopes	2,785	0.6
Md	Made land	245	0.1
MlF	Malaya clay loam, 40 to 60 percent slopes	480	0.1
MoF	Maricao clay, 20 to 60 percent slopes	22,515	5.0
Mp	Martin Pena muck	2,339	0.5
MsB	Matanzas clay, 2 to 5 percent slopes	1,031	0.2
MtB	Montegrande clay, 2 to 5 percent slopes	72	([1])
MtC	Montegrande clay, 5 to 12 percent slopes	390	0.1
MuF2	Morado clay loam, 40 to 60 percent slopes, eroded	2,471	0.6
MxD	Mucara clay, 12 to 20 percent slopes	2,442	0.5
MxE	Mucara clay, 20 to 40 percent slopes	16,920	3.8
MxF	Mucara clay, 40 to 60 percent slopes	70,480	15.8
NaD2	Naranjito silty clay loam, 12 to 20 percent slopes, eroded	1,148	0.3
NaE2	Naranjito silty clay loam, 20 to 40 percent slopes, eroded	5,594	1.3
NaF2	Naranjito silty clay loam, 40 to 60 percent slopes, eroded	25,999	5.8
PaD	Pandura sandy loam, 12 to 20 percent slopes	1,524	0.3
PaE	Pandura sandy loam, 20 to 40 percent slopes	2,967	0.7
PaF	Pandura sandy loam, 40 to 60 percent slopes	13,171	2.9
PeF	Pellejas clay loam, 40 to 60 percent slopes	617	0.1
Re	Reilly sandy loam	539	0.1
RoB	Rio Arriba clay, 2 to 5 percent slopes	1,693	0.4
RoC2	Rio Arriba clay, 5 to 12 percent slopes, eroded	2,479	0.6

See footnote at end of table.

TABLE 4.--ACREAGE AND PROPORTIONATE EXTENT OF THE SOILS--Continued

Map symbol	Soil name	Acres	Percent
RpD2	Rio Piedras clay, 12 to 20 percent slopes, eroded	1,276	0.3
RpE2	Rio Piedras clay, 20 to 40 percent slopes, eroded	869	0.2
RpF2	Rio Piedras clay, 40 to 60 percent slopes, eroded	1,209	0.3
SaF	Sabana silty clay loam, 40 to 60 percent slopes	799	0.2
ScB	Sabana Seca clay, 2 to 8 percent slopes	590	0.1
Sm	Saladar muck	2,719	0.6
SoE	Soller clay loam, 20 to 40 percent slopes	673	0.2
SoF	Soller clay loam, 40 to 60 percent slopes	4,070	0.9
TaF	Tanama-Rock outcrop complex, 20 to 60 percent slopes	6,575	1.5
To	Toa silty clay loam	4,983	1.1
TrB	Torres loamy sand, 2 to 5 percent slopes	694	0.2
Ts	Tropopsamments	61	([1])
Ud	Urban land-Durados complex	3,461	0.8
Um	Urban land-Mucara complex	4,142	0.9
Us	Urban land-Sabana Seca complex	5,040	1.1
Uv	Urban land-Vega Alta complex	14,048	3.1
VaB	Vega Alta clay loam, 2 to 5 percent slopes	365	0.1
VaC2	Vega Alta clay loam, 5 to 12 percent slopes, eroded	1,696	0.4
Vg	Vega Baja silty clay	48	([1])
VkC2	Via clay loam, 5 to 12 percent slopes, eroded	413	0.1
Vv	Vivi loam	165	([1])
YeE	Yunes silty clay loam, 20 to 40 percent slopes	462	0.1
YeF	Yunes silty clay loam, 40 to 60 percent slopes	778	0.2
	Riverwash	524	0.1
	Urban areas	20,614	4.6
	Water	987	0.2
	Total	447,279	100.0

[1]Less than 0.1 percent.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE

[All yields were estimated for a high level of management in 1974. Absence of a yield figure indicates the crop is seldom grown or is not suited]

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Aceitunas:							
AaB	60	50	40	35	---	24	19
AaC	60	50	40	35	---	24	17
Aibonito:							
AbD	---	---	---	25	5	21	14
AbE	---	---	---	20	4	21	---
Almirante:							
AmB	60	50	40	35	---	---	19
AmC	60	50	40	35	---	---	17
Bajura:							
Ba	---	45	30	---	---	---	15
Bayamon:							
BmB	60	50	40	35	---	24	19
Caguabo:							
CaE, CaF	---	---	---	---	---	6	---
[2]CbF	---	---	---	---	---	---	---
Candelero:							
Ce	45	35	30	---	---	24	17
Catalina:							
ClC	60	50	40	35	12	21	17
Catano:							
Cn	---	---	---	---	---	20	12
Cayagua:							
Co	50	40	35	---	---	24	16
Colinas:							
CrD2	45	35	30	---	---	17	13
CrE2	---	---	---	---	---	17	---
CrF2	---	---	---	---	---	12	---
Coloso:							
Cs	60	50	40	---	---	---	18
Consumo:							
CuE	---	---	---	25	8	21	---
CuF	---	---	---	---	6	14	---
Corozal:							
CzC	60	50	40	35	12	24	17
Daguey:							
DaC, DaD	45	40	30	35	12	24	16
Descalabrado:							
DeF	---	---	---	---	---	---	---
[2]DgF	---	---	---	---	---	---	---
Dique:							
Dm	80	60	40	---	---	24	20

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Durados:							
Dr	---	---	---	---	---	20	12
Estacion:							
Es	60	50	40	---	---	2	17
Guayama:							
GuF	---	---	---	---	---	---	---
Humacao:							
Hm	60	50	40	35	---	24	19
Humatas:							
HtE	---	---	---	30	10	21	---
HtF	---	---	---	---	8	21	---
[2]HuF	---	---	---	---	---	---	---
Hydraquents:							
Hy	---	---	---	---	---	---	---
Jagueyes:							
JaE2	---	---	---	30	10	---	---
Juncal:							
JnD2	---	45	35	35	---	17	15
Juncos:							
JuC	---	40	35	35	7	24	15
JuD	---	35	30	30	7	24	14
Lares:							
LaB	45	40	35	35	12	24	19
LaC2	45	40	35	35	12	24	17
Limones:							
LmE	---	---	---	30	10	---	---
LmF	---	---	---	---	8	---	---
Lirios:							
LoF2	---	---	---	---	6	24	---
Los Guineos:							
LsE	---	---	---	25	8	20	---
LsF	---	---	---	---	6	---	---
Mabi:							
MaA	55	45	35	---	---	24	16
MaB	55	45	35	---	---	24	16
MaC	50	40	35	30	---	24	15
Made land:							
Md.							
Malaya:							
MlF	---	---	---	---	---	12	---
Maricao:							
MoF	---	---	---	---	6	20	---
Martin Pena:							
Mp	---	---	---	---	---	---	---

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Matanzas:							
MsB	60	50	40	35	---	24	19
Montegrande:							
MtB	55	45	35	---	---	---	16
MtC	55	45	35	30	---	---	15
Morado:							
MuF2	---	---	---	---	5	12	---
Mucara:							
MxD	---	35	30	30	7	24	14
MxE	---	---	---	25	6	12	---
MxF	---	---	---	---	5	12	---
Naranjito:							
NaD2	---	35	30	30	7	21	14
NaE2	---	---	---	25	6	21	---
NaF2	---	---	---	---	5	15	---
Pandura:							
PaD	---	35	30	25	---	11	12
PaE, PaF	---	---	---	---	---	8	---
Pellejas:							
PeF	---	---	---	---	6	11	---
Reilly:							
Re	---	35	30	---	---	24	15
Rio Arriba:							
RoB	55	45	35	---	---	---	16
RoC2	50	40	35	30	---	---	15
Rio Piedras:							
RpD2	---	35	30	30	10	24	13
RpE2	---	---	---	25	8	21	---
RpF2	---	---	---	---	6	21	---
Sabana:							
SaF	---	---	---	---	---	12	---
Sabana Seca:							
ScB	---	---	---	---	---	2	14
Saladar:							
Sm	---	---	---	---	---	---	---
Soller:							
SoE, SoF	---	---	---	---	---	12	---
Tanama:							
[2]TaF	---	---	---	---	---	---	---
Toa:							
To	80	60	50	---	---	24	20
Torres:							
TrB	---	---	---	---	---	1.6	10

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Tropopsamments:							
Ts	---	---	---	---	---	---	---
Urban land:							
[2]Ud	---	---	---	---	---	---	---
[2]Um	---	---	---	---	---	---	---
[2]Us	---	---	---	---	---	---	---
[2]Uv	---	---	---	---	---	---	---
Vega Alta:							
VaB	60	50	40	35	---	---	19
VaC2	60	50	40	35	---	---	17
Vega Baja:							
Vg	55	45	40	---	---	---	16
Via:							
VkC2	50	45	40	---	---	24	17
Vivi:							
Vv	60	50	40	---	---	---	16
Yunes:							
YeE, YeF	---	---	---	---	6	20	---

[1]Dry weight per acre per year.
[2]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 6.--CAPABILITY CLASSES AND SUBCLASSES

[Miscellaneous areas excluded. Absence of an entry means no acreage]

Class	Total acreage	Major management concerns (Subclass)		
		Erosion (e)	Wetness (w)	Soil problem (s)
		Acres	Acres	Acres
I	5,279	---	---	---
II	14,513	7,181	5,474	1,858
III	32,420	26,058	4,738	1,624
IV	29,590	29,051	---	539
V	---	---	---	---
VI	65,970	64,576	---	1,394
VII	244,718	173,805	2,339	68,574
VIII	5,728	---	3,343	2,385

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY

[Only the soils suitable for production of commercial trees are listed in this table. Absence of an entry in a column means the information was not available]

Soil name and map symbol	Ordination symbol	Management concerns: Erosion hazard	Management concerns: Equipment limitation	Management concerns: Seedling mortality	Potential productivity: Important trees	Potential productivity: Average yearly growth per acre	Trees to plant
						Bd ft	
Aibonito:							
AbD	2c	Slight	Moderate	Slight	Honduras pine	1200	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
AbE	2c	Moderate	Moderate	Slight	Honduras pine	1200	Honduras pine, robusta eucalyptus.
Caguabo:							
CaE	3d	Severe	Severe	Slight	Honduras pine	800	Honduras pine, robusta eucalyptus.
CaF	4d	Severe	Severe	Severe	Honduras pine	700	Honduras pine.
[1]CbF:							
Caguabo part	4d	Severe	Severe	Severe	Honduras pine	700	Honduras pine.
Rock outcrop part.							
Catalina:							
ClC	2c	Slight	Moderate	Slight	Honduras pine	1100	Honduras pine, honduras mahogany, kadam, robusta eucalyptus, mahoe.
Colinas:							
CrD2	2d	Slight	Slight	Slight	Honduras mahogany	450	Honduras pine, honduras mahogany, mahoe, teak.
CrE2	3d	Moderate	Moderate	--------	Honduras mahogany	350	Honduras mahogony.
Consumo:							
CuE	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
CuF	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
Daguey:							
DaC, DaD	2c	Slight	Moderate	Slight	Honduras pine	1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
Descalabrado:							
DeF	4d	Severe	Severe	Severe	Honduras pine	<800	Honduras pine.
[1]DgF:							
Descalabrado part	4d	Severe	Severe	Severe	Honduras pine	<800	Honduras pine.
Rock outcrop part.							
Guayama:							
GuF	4d	Moderate	Moderate	Severe	Honduras pine	<800	Honduras pine.

See footnote at end of table.

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY--Continued

Soil name and map symbol	Ordination symbol	Management concerns			Potential productivity		Trees to plant
		Erosion hazard	Equipment limitation	Seedling mortality	Important trees	Average yearly growth per acre	
						Bd ft	
Humatas:							
HtE	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
HtF	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
[1]HuF:							
Humatas part	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
Rock outcrop part.							
Jagueyes:							
JaE2	2r	Moderate	Moderate	Moderate	Honduras pine	1200	Honduras pine.
Juncal:							
JnD2	2c	Slight	Slight	Slight	Honduras pine Honduras mahogany	1200 450	Honduras pine, honduras mahogany.
Juncos:							
JuC	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.
JuD	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.
Lares:							
LaB, LaC2	2c	Slight	Moderate	Slight	Honduras pine	1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
Limones:							
LmE	2c	Moderate	Moderate	Moderate	Honduras pine	1300	Honduras pine.
LmF	3c	Severe	Severe	Moderate	Honduras pine	1000	Honduras pine.
Lirios:							
LoF2	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
Los Guineos:							
LsE, LsF	2c	Moderate	Moderate	Slight	Honduras pine	1400	Honduras pine, robusta eucalyptus.
Malaya:							
MlF	4d	Moderate	Moderate	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.
Maricao:							
MoF	2c	Moderate	Moderate	Slight	Honduras pine	1300	Honduras pine, robusta eucalyptus.
Morado:							
MuF2	3d	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Mucara:							
MxD	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.

See footnote at end of table.

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY--Continued

Soil name and map symbol	Ordination symbol	Management concerns			Potential productivity		Trees to plant
		Erosion hazard	Equipment limitation	Seedling mortality	Important trees	Average yearly growth per acre	
						Bd ft	
Mucara:							
MxE	3d	Moderate	Moderate	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
MxF	3d	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Naranjito:							
NaD2, NaE2	2c	Slight	Moderate	Slight	Honduras pine	1100	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
NaF2	3c	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Pandura:							
PaD	2o	Moderate	Slight	Slight	Honduras pine	1200	Honduras pine, robusta eucalyptus, mahoe.
PaE	2r	Severe	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus, mahoe.
PaF	3r	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Pellejas:							
PeF	3r	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Rio Piedras:							
RpD2	2c	Slight	Moderate	Slight	Honduras pine Honduras pine	1300 1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
RpE2	2c	Moderate	Moderate	Slight	Honduras pine Honduras pine	1100 1000	Honduras pine, robusta eucalyptus.
RpF2	3c	Severe	Severe	Slight	Honduras pine Honduras pine	1100 1000	Honduras pine, robusta eucalyptus.
Sabana:							
SaF	4d	Moderate	Severe	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.
Soller:							
SoE	4d	Moderate	Moderate	Slight	Honduras mahogany	350	Honduras mahogany.
SoF	4d	Severe	Severe	Severe	Honduras mahogany	350	Honduras mahogany.
Urban land:							
[1]Um:							
Urban land part.							
Mucara part	3d	Moderate	Moderate	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Yunes:							
YeE, YeF	4d	Moderate	Severe	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 8.--BUILDING SITE DEVELOPMENT

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," and "severe." Absence of an entry means soil was not rated]

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Aceitunas:				
AaB	Moderate: too clayey.	Moderate: low strength.	Moderate: corrosive, low strength.	Moderate: low strength.
AaC	Moderate: slope, too clayey.	Moderate: slope, low strength.	Severe: slope.	Moderate: slope, low strength.
Aibonito:				
AbD, AbE	Severe: slope.	Severe: slope.	Severe: slope, corrosive, low strength.	Severe: slope.
Almirante:				
AmB	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: low strength, shrink-swell.	Moderate: low strength, shrink-swell.
AmC	Moderate: slope, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Bajura:				
Ba	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell, wetness.	Severe: floods, shrink-swell, wetness.	Severe: floods, shrink-swell, wetness.
Bayamon:				
BmB	Moderate: too clayey.	Slight	Slight	Moderate: low strength.
Caguabo:				
CaE, CaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
[1]CbF:				
Caguabo part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Rock outcrop part.				
Candelero:				
Ce	Severe: wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Moderate: wetness, low strength.
Catalina:				
ClC	Moderate: slope, too clayey.	Moderate: slope, low strength.	Severe: slope.	Moderate: slope, low strength.
Catano:				
Cn	Severe: cutbanks cave.	Slight	Slight	Slight.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Cayagua:				
Co	Moderate: slope, wetness.	Moderate: slope, wetness.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Colinas:				
CrD2, CrE2, CrF2	Severe: slope, cutbanks cave.	Severe: slope.	Severe: slope.	Severe: slope, low strength.
Coloso:				
Cs	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell, corrosive.	Severe: floods, shrink-swell, low strength.
Consumo:				
CuE, CuF	Severe: slope, too clayey.	Severe: slope, low strength.	Severe: slope, low strength, corrosive.	Severe: slope, low strength.
Corozal:				
CzC	Severe: too clayey, wetness.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, shrink-swell, wetness.
Daguey:				
DaC	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: slope, corrosive, shrink-swell.	Moderate: low strength, shrink-swell.
DaD	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Descalabrado:				
DeF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
[1]DgF:				
Descalabrado part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Rock outcrop part.				
Dique:				
Dm	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Durados:				
Dr	Severe: cutbanks cave.	Severe: floods.	Severe: floods.	Moderate: floods.
Estacion:				
Es	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Guayama:				
GuF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Humacao:				
Hm	Slight	Moderate: shrink-swell, low strength.	Moderate: slope, shrink-swell, low strength.	Moderate: shrink-swell, low strength.
Humatas:				
HtE, HtF	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
[1]HuF:				
Humatas part	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
Rock outcrop part.				
Hydraquents:				
Hy	Severe: floods, wetness.	Severe: floods, low strength, wetness.	Severe: corrosive, floods, low strength.	Severe: floods, low strength, wetness.
Jagueyes:				
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Juncal:				
JnD2	Moderate: slope, hard to pack, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Juncos:				
JuC	Severe: too clayey.	Severe: low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.	Severe: low strength, shrink-swell.
JuD	Severe: slope, too clayey.	Severe: slope, low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.
Lares:				
LaB	Severe: too clayey, wetness.	Moderate: low strength, shrink-swell, wetness.	Moderate: low strength, shrink-swell, corrosive.	Severe: low strength.
LaC2	Severe: too clayey, wetness.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Severe: low strength.
Limones:				
LmE, LmF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Lirios:				
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Los Guineos:				
LsE, LsF	Severe: slope, too clayey.	Severe: slope, low strength.	Severe: slope, low strength.	Severe: slope, low strength.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Mabi:				
MaA, MaB	Severe: too clayey, wetness.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell, wetness.	Severe: shrink-swell.
MaC	Severe: too clayey, wetness.	Severe: floods, shrink-swell.	Severe: slope, shrink-swell, wetness.	Severe: shrink-swell.
Made land: Md.				
Malaya:				
MlF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Maricao:				
MoF	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
Martin Pena:				
Mp	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell, wetness.	Severe: corrosive, floods, shrink-swell.	Severe: floods, shrink-swell, wetness.
Matanzas:				
MsB	Moderate: depth to rock, too clayey.	Slight	Slight	Moderate: low strength.
Montegrande:				
MtB	Severe: too clayey, small stones.	Severe: floods, shrink-swell, low strength.	Severe: floods, shrink-swell, corrosive.	Severe: low strength, shrink-swell.
MtC	Severe: too clayey, small stones.	Severe: floods, shrink-swell, low strength.	Severe: slope, shrink-swell, corrosive.	Severe: low strength, shrink-swell.
Morado:				
MuF2	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
Mucara:				
MxD, MxE, MxF	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
Naranjito:				
NaD2, NaE2, NaF2	Severe: slope.	Severe: slope, low strength.	Severe: slope, low strength.	Severe: slope, low strength, shrink-swell.
Pandura:				
PaD, PaE, PaF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pellejas:				
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Reilly:				
Re	Severe: cutbanks cave, floods, small stones.	Severe: floods.	Severe: floods.	Severe: floods.
Rio Arriba:				
RoB, RoC2	Severe: too clayey.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell.	Severe: shrink-swell.
Rio Piedras:				
RpD2, RpE2, RpF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Sabana:				
SaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Sabana Seca:				
ScB	Severe: too clayey, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.
Saladar:				
Sm	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.
Soller:				
SoE, SoF	Severe: slope, depth to rock, too clayey.	Severe: slope.	Severe: slope.	Severe: slope, low strength, depth to rock.
Tanama:				
[1]TaF:				
Tanama part	Severe: slope, depth to rock, too clayey.	Severe: slope, depth to rock, low strength.	Severe: slope, depth to rock, corrosive.	Severe: slope, depth to rock, low strength.
Rock outcrop part.				
Toa:				
To	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Torres:				
TrB	Moderate: too clayey.	Slight	Moderate: corrosive.	Slight.
Tropopsamments:				
Ts	Severe: cutbanks cave, floods, wetness.	Severe: floods, wetness.	Severe: corrosive, floods, wetness.	Severe: floods, wetness.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Severe: cutbanks cave.	Severe: floods.	Severe: floods.	Moderate: floods.
[1]Um:				
Urban land part.				

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Urban land:				
Mucara part-------	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
[1]Us:				
Urban land part.				
Sabana Seca part--	Severe: too clayey, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.
[1]Uv:				
Urban land part.				
Vega Alta part----	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: corrosive, low strength, shrink-swell.	Moderate: low strength, shrink-swell.
Vega Alta:				
VaB---------------	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: corrosive, low strength, shrink-swell.	Moderate: low strength, shrink-swell.
VaC2--------------	Moderate: slope, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Vega Baja:				
Vg----------------	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Via:				
VkC2--------------	Moderate: slope, too clayey, small stones.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Vivi:				
Vv----------------	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Yunes:				
YeE, YeF----------	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 9.--SANITARY FACILITIES

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," "good," "fair," and other terms used to rate soils. Absence of an entry means soil was not rated]

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Aceitunas:					
AaB	Slight	Moderate: slope, seepage.	Moderate: too clayey.	Slight	Fair: too clayey.
AaC	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Fair: slope, too clayey.
Aibonito:					
AbD	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
AbE	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Almirante:					
AmB	Slight	Moderate: slope.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
AmC	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Poor: slope, hard to pack, too clayey.
Bajura:					
Ba	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey, wetness.	Severe: floods, wetness.	Poor: hard to pack, too clayey, wetness.
Bayamon:					
BmB	Slight	Moderate: slope, seepage.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
Caguabo:					
CaE, CaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, small stones.
[1]CbF:					
Caguabo part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, small stones.
Rock outcrop part.					
Candelero:					
Ce	Severe: wetness, percs slowly.	Severe: slope, floods.	Severe: wetness.	Severe: wetness.	Fair: too clayey.
Catalina:					
ClC	Moderate: slope.	Severe: slope, seepage.	Severe: seepage.	Severe: seepage.	Fair: hard to pack, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Catano:					
Cn	Slight	Severe: seepage.	Severe: too sandy, seepage.	Severe: seepage.	Poor: seepage, too sandy.
Cayagua:					
Co	Moderate: slope, wetness.	Severe: slope, seepage.	Severe: seepage.	Severe: seepage, wetness.	Fair: slope.
Colinas:					
CrD2	Severe: slope.	Severe: slope, seepage.	Severe: seepage.	Severe: slope, seepage.	Poor: slope.
CrE2, CrF2	Severe: slope.	Severe: slope, seepage.	Severe: slope, seepage.	Severe: slope, seepage.	Poor: slope.
Coloso:					
Cs	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey.	Severe: floods.	Fair: too clayey, area reclaim.
Consumo:					
CuE, CuF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Corozal:					
CzC	Severe: percs slowly, wetness.	Severe: slope.	Severe: too clayey, wetness.	Moderate: wetness.	Poor: hard to pack, too clayey.
Daguey:					
DaC	Slight	Severe: slope.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
DaD	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
Descalabrado:					
DeF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
[1]DgF:					
Descalabrado part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Rock outcrop part.					
Dique:					
Dm	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Good.
Durados:					
Dr	Moderate: floods.	Severe: seepage.	Severe: seepage, too sandy.	Severe: seepage.	Poor: seepage, too sandy, area reclaim.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Estacion:					
Es	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Poor: area reclaim, thin layer.
Guayama:					
GuF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, area reclaim.
Humacao:					
Hm	Slight	Moderate: slope, seepage.	Slight	Slight	Good.
Humatas:					
HtE, HtF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope.
[1]HuF:					
Humatas part	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope.
Rock outcrop part.					
Hydraquents:					
Hy	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Poor: wetness.
Jagueyes:					
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Juncal:					
JnD2	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Fair: slope, hard to pack, too clayey.
Juncos:					
JuC	Severe: percs slowly, depth to rock.	Severe: slope.	Severe: too clayey, depth to rock.	Moderate: slope.	Poor: too clayey, hard to pack.
JuD	Severe: slope, percs slowly, depth to rock.	Severe: slope.	Severe: too clayey, depth to rock.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Lares:					
LaB	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Poor: too clayey.
LaC2	Moderate: percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope.	Poor: too clayey.
Limones:					
LmE, LmF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Lirios:					
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Los Guineos:					
LsE, LsF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Mabi:					
MaA	Severe: percs slowly.	Slight	Severe: too clayey.	Moderate: floods, wetness.	Poor: hard to pack, too clayey.
MaB	Severe: percs slowly.	Moderate: slope.	Severe: too clayey.	Moderate: floods, wetness.	Poor: hard to pack, too clayey.
MaC	Severe: percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope, floods, wetness.	Poor: hard to pack, too clayey.
Made land:					
Md.					
Malaya:					
MlF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Maricao:					
MoF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, hard to pack, too clayey.
Martin Pena:					
Mp	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey, wetness.	Severe: floods, wetness.	Poor: hard to pack, too clayey, wetness.
Matanzas:					
MsB	Severe: depth to rock.	Moderate: slope, depth to rock.	Severe: depth to rock.	Slight	Fair: hard to pack, too clayey.
Montegrande:					
MtB	Moderate: floods, percs slowly.	Moderate: slope, seepage.	Severe: too clayey.	Moderate: floods.	Poor: hard to pack, too clayey.
MtC	Moderate: slope, floods, percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope, floods.	Poor: hard to pack, too clayey.
Morado:					
MuF2	Severe: slope, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage.	Poor: slope.
Mucara:					
MxD	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Mucara:					
MxE, MxF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.
Naranjito:					
NaD2	Severe: slope, depth to rock.	Severe: slope.	Severe: depth to rock.	Severe: slope.	Poor: slope, too clayey.
NaE2, NaF2	Severe: slope, depth to rock.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, too clayey.
Pandura:					
PaD	Severe: slope.	Severe: slope, seepage.	Severe: depth to rock, seepage.	Severe: slope, seepage.	Poor: slope, thin layer.
PaE, PaF	Severe: slope.	Severe: slope, seepage.	Severe: slope, depth to rock, seepage.	Severe: slope, seepage.	Poor: slope, thin layer.
Pellejas:					
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Reilly:					
Re	Severe: floods.	Severe: floods, seepage, small stones.	Severe: floods, seepage, small stones.	Severe: floods, seepage.	Poor: seepage, small stones, thin layer.
Rio Arriba:					
RoB, RoC2	Severe: percs slowly.	Severe: floods.	Severe: too clayey.	Moderate: floods.	Poor: hard to pack, too clayey.
Rio Piedras:					
RpD2	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
RpE2, RpF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Sabana:					
SaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Sabana Seca:					
ScB	Severe: percs slowly, wetness.	Moderate: slope.	Severe: too clayey, wetness.	Severe: wetness.	Poor: too clayey, wetness.
Saladar:					
Sm	Severe: floods, percs slowly, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: floods, wetness.	Poor: excess humus, wetness.
Soller:					
SoE, SoF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock, too clayey.	Severe: slope.	Poor: slope, thin layer, area reclaim.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Tanama:					
[1]TaF:					
Tanama part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock, too clayey.	Severe: slope.	Poor: slope, thin layer, area reclaim.
Rock outcrop part.					
Toa:					
To	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.	Fair: too clayey.
Torres:					
TrB	Moderate: percs slowly.	Moderate: slope.	Moderate: too clayey.	Slight	Fair: too clayey.
Tropopsamments:					
Ts	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, too sandy, wetness.	Severe: floods, wetness.	Poor: too sandy.
Urban land:					
[1]Ud:					
Urban land part.					
Durados part	Moderate: floods.	Severe: seepage.	Severe: seepage, too sandy.	Severe: seepage.	Poor: seepage, too sandy, area reclaim.
[1]Um:					
Urban land part.					
Mucara part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.
[1]Us:					
Urban land part.					
Sabana Seca part	Severe: percs slowly, wetness.	Moderate: slope.	Severe: too clayey, wetness.	Severe: wetness.	Poor: too clayey, wetness.
[1]Uv:					
Urban land part.					
Vega Alta part	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Fair: hard to pack, too clayey.
Vega Alta:					
VaB	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Fair: hard to pack, too clayey.
VaC2	Moderate: slope, percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope.	Fair: slope, hard to pack, too clayey.
Vega Baja:					
Vg	Severe: floods, wetness, percs slowly.	Severe: floods, wetness.	Severe: floods, too clayey.	Severe: floods, wetness.	Poor: area reclaim, hard to pack, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Via:					
VkC2	Moderate: slope.	Severe: slope.	Severe: seepage.	Severe: seepage.	Fair: slope, too clayey, small stones.
Vivi:					
Vv	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Good.
Yunes:					
YeE, YeF	Severe: slope, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage.	Poor: slope, thin layer, area reclaim.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 10.--CONSTRUCTION MATERIALS

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "good," "fair," "poor," and "unsuited." Absence of an entry means soil was not rated]

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Aceitunas:				
AaB	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
AaC	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Aibonito:				
AbD	Fair: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
AbE	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Almirante:				
AmB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: low strength, shrink-swell.
AmC	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, low strength, shrink-swell.
Bajura:				
Ba	Poor: shrink-swell, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
Bayamon:				
BmB	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: low strength.
Caguabo:				
CaE, CaF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer.
[1]CbF:				
Caguabo part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer.
Rock outcrop part.				
Candelero:				
Ce	Fair: shrink-swell, wetness, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Catalina:				
ClC	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Catano:				
Cn	Good	Good	Unsuited: excess fines.	Poor: too sandy.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Cayagua:				
Co	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope.
Colinas:				
CrD2	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
CrE2, CrF2	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Coloso:				
Cs	Poor: area reclaim, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Consumo:				
CuE, CuF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Corozal:				
CzC	Fair: low strength, shrink-swell, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey, wetness.
Daguey:				
DaC	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
DaD	Fair: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Descalabrado:				
DeF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
[1]DgF:				
Descalabrado part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Rock outcrop part.				
Dique:				
Dm	Good	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Durados:				
Dr	Good	Good	Unsuited excess fines.	Poor: too sandy.
Estacion:				
Es	Good	Unsuited: excess fines.	Good	Poor: thin layer, small stones.
Guayama:				
GuF	Poor: slope, area reclaim, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Humacao:				
Hm	Fair: low strength, shrink-swell.	Unsuited excess fines.	Unsuited excess fines	Good.
Humatas:				
HtE, HtF	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
[1]HuF:				
Humatas part	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Rock outcrop part.				
Hydraquents:				
Hy	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: excess salt, wetness.
Jagueyes:				
JaE2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Juncal:				
JnD2	Fair: area reclaim, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, area reclaim, low strength.
Juncos:				
JuC	Poor: low strength, shrink-swell, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, area reclaim.
JuD	Poor: low strength, shrink-swell, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, area reclaim.
Lares:				
LaB, LaC2	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Limones:				
LmE, LmF	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Lirios:				
LoF2	Poor: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Los Guineos:				
LsE, LsF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey.
Mabi:				
MaA, MaB, MaC	Poor: shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Made land:				
Md.				

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Malaya:				
MlF	Poor: slope, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Maricao:				
MoF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Martin Pena:				
Mp	Poor: excess humus, low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: wetness.
Matanzas:				
MsB	Fair: area reclaim, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Montegrande:				
MtB, MtC	Poor: shrink-swell, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Morado:				
MuF2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Mucara:				
MxD	Poor: shrink-swell, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
MxE, MxF	Poor: slope, shrink-swell, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
Naranjito:				
NaD2	Poor: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
NaE2, NaF2	Poor: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Pandura:				
PaD	Poor: thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
PaE, PaF	Poor: slope, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
Pellejas:				
PeF	Poor: slope.	Poor: excess fines.	Unsuited: excess fines.	Poor: slope.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Reilly:				
Re	Good	Fair: excess fines.	Fair: excess fines.	Poor: small stones, thin layer.
Rio Arriba:				
RoB, RoC2	Poor: shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Rio Piedras:				
RpD2	Fair: slope, area reclaim, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
RpE2, RpF2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Sabana:				
SaF	Poor: slope, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Sabana Seca:				
ScB	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
Saladar:				
Sm	Poor: excess humus, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: wetness.
Soller:				
SoE, SoF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
Tanama:				
[1]TaF:				
Tanama part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim.
Rock outcrop part.				
Toa:				
To	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Torres:				
TrB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Tropopsamments:				
Ts	Poor: area reclaim, wetness.	Good	Unsuited: excess fines.	Poor: excess lime, excess salt, too sandy.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Good	Good	Unsuited: excess fines.	Poor: too sandy.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Urban land:				
[1]Um:				
Urban land part.				
Mucara part	Poor: slope, shrink-swell, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
[1]Us:				
Urban land part.				
Sabana Seca part	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
[1]Uv:				
Urban land part.				
Vega Alta part	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Vega Alta:				
VaB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
VaC2	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Vega Baja:				
Vg	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Via:				
VkC2	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey, small stones.
Vivi:				
Vv	Good	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Yunes:				
YeE, YeF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, small stones.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 11.--WATER MANAGEMENT

["Seepage," and some of the other terms that describe restrictive soil features are defined in the Glossary. Absence of an entry means soil was not evaluated]

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Aceitunas:					
AaB, AaC	Seepage, slope.	Compressible, low strength.	Not needed	Slope	Favorable.
Aibonito:					
AbD, AbE	Seepage, slope.	Compressible, low strength.	Not needed	Slope	Slope.
Almirante:					
AmB, AmC	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Bajura:					
Ba	Slight	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, poor outlets, wetness.	Not needed.
Bayamon:					
BmB	Seepage	Compressible, low strength, seepage.	Not needed	Slope	Favorable.
Caguabo:					
CaE, CaF	Depth to rock, slope.	Thin layer, low strength.	Not needed	Depth to rock, slope.	Erodes easily, slope.
[1]CbF:					
Caguabo part	Depth to rock, slope.	Thin layer, low strength.	Not needed	Depth to rock, slope.	Erodes easily, slope.
Rock outcrop part.					
Candelero:					
Ce	Slope	Low strength, compressible.	Percs slowly, wetness.	Percs slowly, slope, wetness.	Percs slowly, wetness.
Catalina:					
ClC	Seepage, slope.	Compressible, hard to pack, unstable fill.	Not needed	Complex slope	Favorable.
Catano:					
Cn	Seepage	Seepage, piping.	Not needed	Too sandy, piping.	Not needed.
Cayagua:					
Co	Seepage, slope.	Low strength, piping.	Complex slope	Slope	Slope.
Colinas:					
CrD2, CrE2, CrF2	Slope, seepage, cutbanks cave.	Hard to pack, seepage, piping, cutbanks cave.	Not needed	Piping, slope.	Slope.
Coloso:					
Cs	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, wetness.	Percs slowly, wetness.
Consumo:					
CuE, CuF	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Corozal:					
CzC	Favorable	Compressible, hard to pack, low strength.	Percs slowly, wetness.	Percs slowly, wetness.	Percs slowly, wetness.
Daguey:					
DaC, DaD	Seepage, slope.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Descalabrado:					
DeF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
[1]DgF:					
Descalabrado part	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
Rock outcrop part.					
Dique:					
Dm	Seepage	Seepage, piping.	Not needed	Not needed	Favorable.
Durados:					
Dr	Seepage	Seepage, piping, unstable fill.	Not needed	Too sandy, piping.	Droughty.
Estacion:					
Es	Seepage	Seepage	Not needed	Not needed	Favorable.
Guayama:					
GuF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
Humacao:					
Hm	Favorable	Favorable	Not needed	Favorable	Favorable.
Humatas:					
HtE, HtF	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
[1]HuF:					
Humatas part	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Rock outcrop part.					
Hydraquents:					
Hy	Seepage	Hard to pack, low strength, unstable fill.	Excess salt, floods, wetness.	Not needed	Not needed.
Jagueyes:					
JaE2	Seepage, slope.	Low strength, piping, seepage.	Not needed	Slope	Slope.
Juncal:					
JnD2	Favorable	Compressible, low strength, shrink-swell.	Not needed	Slope	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Juncos:					
JuC, JuD	Slope	Compressible, hard to pack, shrink-swell.	Percs slowly	Complex slope, depth to rock, percs slowly.	Percs slowly.
Lares:					
LaB, LaC2	Favorable	Compressible, low strength, shrink-swell.	Not needed	Complex slope	Favorable.
Limones:					
LmE, LmF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Lirios:					
LoF2	Slope	Compressible, hard to pack, shrink-swell.	Not needed	Slope	Slope.
Los Guineos:					
LsE, LsF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Mabi:					
MaA, MaB, MaC	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly.	Percs slowly, slope, wetness.	Percs slowly, slope, wetness.
Made land:					
Md.					
Malaya:					
MlF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth.
Maricao:					
MoF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Martin Pena:					
Mp	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
Matanzas:					
MsB	Depth to rock, seepage.	Compressible, hard to pack, thin layer.	Not needed	Not needed	Favorable.
Montegrande:					
MtB, MtC	Slope	Compressible, hard to pack, shrink-swell.	Not needed	Slope	Slope.
Morado:					
MuF2	Slope, depth to rock.	Compressible, hard to pack, thin layer.	Not needed	Slope, depth to rock.	Slope.
Mucara:					
MxD, MxE, MxF	Slope, depth to rock.	Shrink-swell, compressible, thin layer.	Not needed	Depth to rock, slope.	Slope, depth to rock.
Naranjito:					
NaD2, NaE2, NaF2	Slope, depth to rock.	Compressible, hard to pack, low strength.	Not needed	Depth to rock, slope.	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Pandura:					
PaD, PaE, PaF	Slope, depth to rock.	Seepage, thin layer.	Not needed	Depth to rock, slope.	Droughty, slope.
Pellejas:					
PeF	Seepage, slope.	Seepage	Not needed	Slope	Droughty, erodes easily, slope.
Reilly:					
Re	Seepage	Seepage	Not needed	Not needed	Not needed.
Rio Arriba:					
RoB, RoC2	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly.	Percs slowly	Percs slowly.
Rio Piedras:					
RpD2, RpE2, RpF2	Slope	Compressible, hard to pack, low strength.	Not needed	Slope, rooting depth.	Slope.
Sabana:					
SaF	Slope, depth to rock.	Thin layer	Not needed	Depth to rock, slope, rooting depth.	Erodes easily, slope.
Sabana Seca:					
ScB	Favorable	Compressible, hard to pack, low strength.	Percs slowly, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
Saladar:					
Sm	Excess humus	Excess humus, hard to pack, seepage.	Floods, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, rooting depth, wetness.
Soller:					
SoE, SoF	Slope, depth to rock.	Compressible, low strength, thin layer.	Not needed	Depth to rock, slope.	Slope, rooting depth.
Tanama:					
[1]TaF:					
Tanama part	Depth to rock, slope.	Compressible, low strength, thin layer.	Not needed	Depth to rock, slope.	Rooting depth, slope.
Rock outcrop part.					
Toa:					
To	Favorable	Favorable	Floods	Not needed	Favorable.
Torres:					
TrB	Favorable	Compressible, low strength.	Not needed	Too sandy, slope.	Droughty.
Tropopsamments:					
Ts	Seepage	Seepage, unstable fill.	Cutbanks cave, excess salt, floods.	Not needed	Not needed.
Urban land:					
[1]Ud:					
Urban land part.					
Durados part	Seepage	Seepage, piping, unstable fill.	Not needed	Too sandy, piping.	Droughty.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Urban land:					
[1]Um:					
Urban land part.					
Mucara part	Slope, depth to rock.	Shrink-swell, compressible, thin layer.	Not needed	Depth to rock, slope.	Slope, depth to rock.
[1]Us:					
Urban land part.					
Sabana Seca part	Favorable	Compressible, hard to pack, low strength.	Percs slowly, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
[1]Uv:					
Urban land part.					
Vega Alta part	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Vega Alta:					
VaB, VaC2	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Vega Baja:					
Vg	Slight	Compressible, hard to pack, low strength.	Floods, percs slowly.	Complex slope, percs slowly.	Not needed.
Via:					
VkC2	Slope, seepage.	Compressible, low strength.	Not needed	Slope	Favorable.
Vivi:					
Vv	Seepage	Piping, low strength, hard to pack.	Not needed	Not needed	Not needed.
Yunes:					
YeE, YeF	Slope, seepage, depth to rock.	Thin layer	Not needed	Depth to rock, slope.	Slope, rooting depth.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 12.--RECREATIONAL DEVELOPMENT

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," and "severe"]

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Aceitunas:				
AaB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
AaC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Aibonito:				
AbD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
AbE	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Almirante:				
AmB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
AmC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Bajura:				
Ba	Severe: floods, wetness, too clayey.	Severe: floods, too clayey, wetness.	Severe: floods, wetness, too clayey.	Severe: too clayey, wetness.
Bayamon:				
BmB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Caguabo:				
CaE, CaF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock, too clayey.	Severe: slope.
[1]CbF:				
Caguabo part	Severe: slope.	Severe: slope.	Severe: slope, depth to rock, too clayey.	Severe: slope.
Rock outcrop part.				
Candelero:				
Ce	Severe: wetness.	Severe: wetness.	Severe: slope, wetness.	Severe: wetness.
Catalina:				
ClC	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Catano:				
Cn	Moderate: too sandy.	Moderate: too sandy.	Severe: too sandy.	Moderate: too sandy.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Cayagua:				
Co	Severe: wetness.	Severe: wetness.	Severe: slope, wetness.	Severe: wetness.
Colinas:				
CrD2	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.
CrE2, CrF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Coloso:				
Cs	Severe: floods, wetness.	Moderate: too clayey, wetness.	Moderate: too clayey, wetness.	Moderate: too clayey, wetness.
Consumo:				
CuE, CuF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Corozal:				
CzC	Severe: too clayey, percs slowly.	Severe: too clayey.	Severe: slope, too clayey, wetness.	Severe: too clayey.
Daguey:				
DaC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
DaD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Descalabrado:				
DeF	Severe: slope.	Severe: slope.	Severe: slope; depth to rock.	Severe: slope.
[1]DgF:				
Descalabrado part	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Rock outcrop part.				
Dique:				
Dm	Severe: floods.	Moderate: floods.	Moderate: floods.	Slight.
Durados:				
Dr	Slight	Slight	Slight	Slight.
Estacion:				
Es	Severe: floods.	Moderate: floods, too clayey.	Moderate: floods, too clayey.	Moderate: too clayey.
Guayama:				
GuF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Humacao:				
Hm	Slight	Slight	Moderate: slope.	Slight.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Humatas:				
HtE, HtF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
[1]HuF:				
Humatas part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Rock outcrop part.				
Hydraquents:				
Hy	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.
Jagueyes:				
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Juncal:				
JnD2	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Juncos:				
JuC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
JuD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Lares:				
LaB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.
LaC2	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Limones:				
LmE, LmF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Lirios:				
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Los Guineos:				
LsE, LsF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Mabi:				
MaA, MaB	Severe: percs slowly, too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
MaC	Severe: percs slowly, too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Made land:				
Md.				

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Malaya:				
MlF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Maricao:				
MoF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Martin Pena:				
Mp	Severe: floods, percs slowly, wetness.	Severe: floods, wetness, excess humus.	Severe: floods, wetness, excess humus.	Severe: floods, wetness, excess humus.
Matanzas:				
MsB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Montegrande:				
MtB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
MtC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Morado:				
MuF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Mucara:				
MxD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
MxE, MxF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Naranjito:				
NaD2	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.
NaE2, NaF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pandura:				
PaD	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope.
PaE, PaF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pellejas:				
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Reilly:				
Re	Moderate: floods, small stones.	Moderate: floods, small stones.	Severe: floods, small stones.	Moderate: small stones.
Rio Arriba:				
RoB, RoC2	Severe: too clayey, percs slowly.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Rio Piedras:				
RpD2, RpE2, RpF2	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Sabana:				
SaF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Sabana Seca:				
ScB	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.
Saladar:				
Sm	Severe: excess humus, floods, percs slowly.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.
Soller:				
SoE, SoF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Tanama:				
[1]TaF:				
Tanama part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, depth to rock, too clayey.	Severe: slope, too clayey.
Rock outcrop part.				
Toa:				
To	Severe: floods.	Moderate: floods, too clayey.	Moderate: floods, too clayey.	Moderate: too clayey.
Torres:				
TrB	Slight	Slight	Moderate: slope.	Slight.
Tropopsamments:				
Ts	Severe: floods, too sandy.	Severe: floods, too sandy.	Severe: floods, too sandy.	Severe: too sandy, floods.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Slight	Slight	Slight	Slight.
[1]Um:				
Urban land part.				
Mucara part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
[1]Us:				
Urban land part.				
Sabana Seca part	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Urban land:				
[1]Uv:				
Urban land part.				
Vega Alta part	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Vega Alta:				
VaB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
VaC2	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Vega Baja:				
Vg	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
Via:				
VkC2	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Vivi:				
Vv	Severe: floods.	Moderate: floods.	Moderate: floods.	Slight.
Yunes:				
YeE, YeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope, small stones.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS

[The symbol < means less than; > means greater than. Absence of an entry means data were not estimated]

Soil name and map symbol	Depth	USDA texture	Classification		Frag- ments > 3 inches	Percentage passing sieve number--				Liquid limit	Plas- ticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
Aceitunas:											
AaB, AaC----------	0-8	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	8-60	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
Aibonito:											
AbD, AbE----------	0-7	Clay------------	MH	A-7	0	100	100	90-100	75-100	60-70	20-30
	7-43	Clay------------	MH	A-7	0	100	100	95-100	90-100	60-70	20-30
	43-99	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
Almirante:											
AmB, AmC----------	0-60	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	20-30
Bajura:											
Ba----------------	0-60	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	45-55
Bayamon:											
BmB---------------	0-66	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-60	10-20
Caguabo:											
CaE, CaF----------	0-4	Clay loam-------	CL, SC	A-7	0	75-100	55-100	50-100	40-80	40-50	20-30
	4-10	Very gravelly clay loam, very gravelly silty clay loam.	GC, SC	A-2	0	40-80	25-35	22-35	18-30	30-40	10-15
	10-16	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	16	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]CbF:											
Caguabo part-----	0-4	Clay loam-------	CL, SC	A-7	0	75-100	55-100	50-100	40-80	40-50	20-30
	4-10	Very gravelly clay loam, very gravelly silty clay loam.	GC, SC	A-2	0	40-80	25-35	22-35	18-30	30-40	10-15
	10-16	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	16	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Candelero:											
Ce----------------	0-6	Loam-----------	ML, SM	A-4, A-2	0	100	100	60-95	30-75	15-25	2-7
	6-35	Sandy clay loam	SC	A-6	0	100	100	80-90	35-50	30-40	15-25
	35-58	Sandy clay loam, sandy clay.	SC, CL	A-6	0	100	100	80-95	35-60	30-40	15-25
Catalina:											
ClC---------------	0-6	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	6-84	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	84-99	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
Catano:											
Cn----------------	0-7	Loamy sand------	SP-SM	A-2, A-3	0	100	100	50-70	5-15	<20	NP
	7-58	Sand------------	SP-SM	A-2, A-3	0	100	100	50-70	5-15	<20	NP
Cayagua:											
Co----------------	0-8	Sandy loam------	SM, ML	A-2, A-4	0	100	100	60-90	30-60	30-40	2-7
	8-22	Clay, sandy clay	MH	A-7	0	100	100	85-100	50-95	60-70	20-30
	22-60	Sandy loam, sandy clay loam.	SM, ML	A-2, A-4	0	100	100	60-90	30-60	30-40	2-7
Colinas:											
CrD2, CrE2, CrF2--	0-26	Clay loam-------	CL	A-6	0	90-100	75-100	70-100	55-80	30-40	15-20
	26-52	Marl------------	CL, CL-ML	A-4	0	90-100	75-90	70-85	65-70	20-30	4-10

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number--: 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Coloso:											
Cs----------------	0-16	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	20-30
	16-70	Silty clay loam, silty clay, clay.	CL, MH, CH	A-7	0	100	100	95-100	85-95	40-70	20-35
Consumo:											
CuE, CuF----------	0-20	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	25-35
	20-46	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	70-80	25-35
Corozal:											
CzC---------------	0-9	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	9-40	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	40-60	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-35	10-15
Daguey:											
DaC, DaD----------	0-10	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	10-72	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	72-90	Silty clay loam	MH	A-7	0	100	100	85-95	70-90	70-80	25-35
Descalabrado:											
DeF---------------	0-5	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-40	15-20
	5-17	Gravelly clay, gravelly clay loam, gravelly sandy clay loam.	SC, CL	A-6	0	100	50-75	45-75	38-70	30-40	12-20
	17	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]DgF:											
Descalabrado part	0-5	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-40	15-20
	5-17	Gravelly clay, gravelly clay loam, gravelly sandy clay loam.	SC, CL	A-6	0	100	50-75	45-75	38-70	30-40	12-20
	17	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Dique:											
Dm----------------	0-54	Loam------------	ML	A-4	0	100	100	85-100	60-90	30-40	5-10
Durados:											
Dr----------------	0-14	Sandy loam------	SM	A-2	0	100	100	60-70	25-35	---	NP
	14-23	Loamy sand------	SM	A-2	0	100	100	50-75	15-30	---	NP
	23-60	Sand------------	SP-SM, SM	A-2, A-3	0	95-100	75-100	50-70	5-15	---	NP
Estacion:											
Es----------------	0-8	Silty clay loam	CL	A-6	0	95-100	70-95	65-95	50-90	30-40	15-20
	8-20	Gravelly clay loam, gravelly silty clay loam.	GM-GC, GC, CL, CL-ML	A-4	0	65-80	55-75	50-75	40-70	20-30	5-10
	20-50	Gravelly sand---	GP, GP-GM, SP, SP-SM	A-1	15-65	30-55	25-50	15-35	1-8	---	NP

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number--: 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Guayama:											
GuF	0-4	Clay loam	CL	A-6	0	100	75-100	70-100	55-80	30-40	15-20
	4-20	Gravelly clay, gravelly silty clay loam, clay.	GC, CL, SC	A-6, A-2	0	50-100	50-100	40-100	20-80	30-40	15-20
	20	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Humacao:											
Hm	0-8	Loam	ML	A-4	0	100	100	85-95	60-75	30-40	5-10
	8-60	Sandy clay loam, clay loam.	CL	A-7	0	100	100	80-90	70-80	40-50	20-30
Humatas:											
HtE, HtF	0-5	Clay	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	5-24	Clay	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	24-60	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	60-70	25-30
[1]HuF:											
Humatas part	0-5	Clay	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	5-24	Clay	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	24-60	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	60-70	25-30
Rock outcrop part.											
Hydraquents:											
Hy	0-60	Variable	---	---	0	---	---	---	---	---	---
Jagueyes:											
JaE2	0-5	Loam	SM, ML	A-2, A-4	0	100	100	60-95	30-75	---	NP
	5-41	Clay loam, sandy clay loam.	CL, SC	A-6	0	100	100	80-100	35-80	35-40	15-20
	41-62	Sandy clay loam, clay loam.	SC, SM, ML, CL	A-4	0	100	100	80-100	35-80	25-35	5-10
Juncal:											
JnD2	0-10	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
	10-48	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
	48-60	Silty clay loam	MH	A-7	0	100	100	95-100	85-95	60-70	20-25
Juncos:											
JuC, JuD	0-31	Clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	31-40	Clay	CH	A-7	0	95-100	75-100	70-100	60-95	70-80	40-50
	40	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Lares:											
LaB, LaC2	0-36	Clay	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	36-60	Clay	MH	A-7	0	85-100	85-100	75-95	60-80	60-70	20-30
Limones:											
LmE, LmF	0-79	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
Lirios:											
LoF2	0-4	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	15-25
	4-34	Clay, silty clay	MH	A-7	0	100	100	90-100	75-95	60-70	25-30
	34-60	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	15-25
Los Guineos:											
LsE, LsF	0-5	Clay	MH, CH	A-7	0	100	100	90-100	75-95	60-80	25-35
	5-60	Clay	MH, CH	A-7	0	100	100	90-100	75-95	60-80	25-35
Mabi:											
MaA, MaB, MaC	0-24	Clay	CH	A-7	0	100	90-100	85-100	70-95	55-75	40-60
	24-99	Clay	CH	A-7	0	100	90-100	85-100	70-95	55-75	40-60

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number--: 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Made land: Md.											
Malaya: MlF	0-6	Clay loam	CL, ML	A-7	0	100	100	90-100	70-90	40-50	15-20
	6-13	Gravelly clay	SC, CL, GC	A-7	0	60-80	55-75	50-75	40-70	40-50	20-30
	13-18	Gravelly clay loam.	SC, CL, SM, ML, GM, GC	A-2, A-7	0	60-80	55-75	50-75	30-60	40-50	15-20
	18	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Maricao: MoF	0-14	Clay	MH	A-7	0	100	100	90-100	75-95	60-70	25-30
	14-60	Silty clay loam, silty clay.	MH	A-7	0	100	100	95-100	85-95	50-60	15-20
Martin Pena: Mp	0-8	Muck	OH	---	0	---	---	---	---	---	NP
	8-18	Silty clay loam, clay.	CH	A-7	0	100	100	95-100	85-95	50-60	30-40
	18-63	Clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
Matanzas: MsB	0-20	Clay	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	20-53	Clay	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	53	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Montegrande: MtB, MtC	0-7	Clay	CH, MH	A-7	0	100	100	90-100	75-95	70-80	35-45
	7-29	Clay	CH, MH	A-7	0	100	100	90-100	75-95	70-80	35-45
	29-48	Very gravelly clay.	GC	A-2	0	40-50	20-35	18-20	15-19	30-40	15-20
Morado: MuF2	0-34	Clay loam	CL	A-7	0	100	100	90-100	70-80	40-50	20-30
	34	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Mucara: MxD, MxE, MxF	0-5	Clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	5-12	Clay, silty clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	12-30	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	30	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Naranjito: NaD2, NaE2, NaF2	0-4	Silty clay loam	MH	A-7	0	80-95	75-95	70-95	65-90	60-70	20-30
	4-24	Clay	MH	A-7	0	80-95	75-90	70-90	55-85	70-80	25-35
	24-40	Clay loam	CL	A-7	0	80-90	75-90	70-90	55-70	40-50	20-30
	40	Weathered bedrock.	---	---	---	---	---	---	---	---	---
Pandura: PaD, PaE, PaF	0-7	Sandy loam	SM, ML	A-2, A-4	0	100	100	60-95	30-75	<35	NP-10
	7-26	Sandy loam, loam	SM, ML	A-2, A-4	0	100	100	60-95	30-75	<35	NP-10
	26	Weathered bedrock.	---	---	---	---	---	---	---	---	---
Pellejas: PeF	0-16	Clay loam	CL	A-7	0	100	100	85-100	60-80	40-50	20-30
	16-60	Sandy loam, loamy sand.	SM	A-2	0	100	100	50-75	25-35	---	---

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Frag- ments > 3 inches	Percentage passing sieve number-- 4	10	40	200	Liquid limit	Plas- ticity index
	In				Pct					Pct	
Reilly:											
Re----------------	0-18	Sandy loam------	SM	A-2-4	0	100	100	60-70	30-35	---	---
	18-55	Stratified very gravelly sand to sand.	SP-SM, GW	A-1	0	20-55	10-50	5-35	0-8	---	---
Rio Arriba:											
RoB, RoC2---------	0-8	Clay------------	CH	A-7	0	100	100	90-100	75-95	55-75	40-60
	8-60	Clay------------	CH	A-7	0	100	100	90-100	75-95	55-75	40-60
Rio Piedras:											
RpD2, RpE2, RpF2--	0-8	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	8-28	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	28-48	Clay------------	MH	A-7	0	100	100	85-95	70-95	70-80	25-35
	48	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Sabana:											
SaF---------------	0-3	Silty clay loam	CL	A-6	0	80-100	75-100	70-100	60-95	30-40	10-20
	3-15	Silty clay, clay	CH	A-7	0	80-100	75-100	65-100	55-95	70-80	40-50
	15	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Sabana Seca:											
ScB---------------	0-70	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-60	15-20
Saladar:											
Sm----------------	0-51	Muck------------	OH	---	0	---	---	---	---	---	NP
Soller:											
SoE, SoF----------	0-5	Clay loam-------	CL	A-6	0-10	100	100	90-100	70-80	30-40	15-20
	5-12	Clay------------	CH	A-7	0-35	95-100	90-100	80-100	60-95	70-80	40-50
	12-24	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	24	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Tanama:											
[1]TaF:											
Tanama part------	0-14	Clay------------	MH	A-7	0-15	100	100	90-100	75-95	70-80	30-40
	14	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Toa:											
To----------------	0-60	Silty clay loam	CL	A-6	0	100	100	90-100	70-95	30-40	15-20
Torres:											
TrB---------------	0-28	Loamy sand------	SM, SP-SM	A-2, A-3, A-4	0	100	100	50-70	5-40	---	NP
	28-64	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-60	12-20
Tropopsamments:											
Ts----------------	0-60	Sand------------	SP, SM, SM-SC	A-2, A-3, A-4	0	100	100	52-70	2-40	---	---
Urban land:											
[1]Ud:											
Urban land part.											
Durados part-----	0-14	Sandy loam------	SM	A-2	0	100	100	60-70	25-35	---	NP
	14-23	Loamy sand------	SM	A-2	0	100	100	50-75	15-30	---	NP
	23-60	Sand------------	SP-SM, SM	A-2, A-3	0	95-100	75-100	50-70	5-15	---	NP
[1]Um:											
Urban land part.											

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number-- 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Urban land:											
Mucara part	0-6	Clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	6-12	Clay, silty clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	12-22	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	22	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]Us:											
Urban land part.											
Sabana Seca part	0-70	Clay	MH	A-7	0	100	100	90-100	75-95	50-60	15-20
[1]Uv:											
Urban land part.											
Vega Alta part	0-8	Clay loam	MH	A-7	0	100	100	90-100	70-95	60-70	20-30
	8-84	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
Vega Alta:											
VaB, VaC2	0-8	Clay loam	MH	A-7	0	100	100	90-100	70-95	60-70	20-30
	8-84	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
Vega Baja:											
Vg	0-7	Silty clay	CH	A-7	0	100	95-100	90-100	75-95	70-80	40-50
	7-50	Silty clay, clay, silty clay loam.	CH	---	0	100	95-100	90-100	75-95	70-80	40-50
	50-60	Silty clay, clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
Via:											
VkC2	0-9	Clay loam	CL	A-7	0-5	100	85-95	80-95	60-90	40-50	20-30
	9-36	Clay loam, gravelly clay loam.	CL, GC, SC	A-6	0	65-95	50-90	45-90	35-70	30-40	15-20
	36-52	Very gravelly clay loam.	GP-GC, SP-SC, GC, SC	A-2, A-6	0	25-70	10-65	9-65	7-50	30-40	15-20
Vivi:											
Vv	0-9	Loam	ML, SM	A-2, A-4	0	100	100	60-95	30-75	---	---
	9-47	Very fine sandy loam, loam.	ML	A-4	0	100	100	85-95	50-75	---	---
	47-58	Loamy sand	SP-SM, SM	A-1, A-2	0	100	85-100	45-65	5-15	---	---
Yunes:											
YeE, YeF	0-2	Silty clay loam	MH	A-7	0	100	75-100	70-100	60-95	60-70	20-30
	2-16	Very shaly silty clay loam.	GC, GP-GC	A-2	0	15-40	10-35	5-30	5-30	20-30	7-12
	16	Fragmental material.	---	---	---	---	---	---	---	---	---

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[Dashes indicate data were not available. The symbol < means less than; > means greater than. The erosion tolerance factor (T) is for the entire profile. Absence of an entry means data were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Aceitunas:									
AaB, AaC	0-8	0.6-2.0	0.10-0.15	4.5-5.5	Low	High	High	0.10	5
	8-60	0.6-2.0	0.10-0.15	4.5-5.5	Low	High	High	0.10	
Aibonito:									
AbD, AbE	0-7	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	4
	7-43	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	
	43-99	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	
Almirante:									
AmB, AmC	0-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High	High	0.17	4
Bajura:									
Ba	0-60	0.06-0.2	0.15-0.20	5.6-6.5	High	High	Moderate	---	---
Bayamon:									
BmB	0-66	0.6-2.0	0.10-0.15	4.5-5.0	Low	High	Moderate	0.10	5
Caguabo:									
CaE, CaF	0-4	0.6-2.0	0.10-0.15	6.1-6.5	Moderate	Moderate	Low	0.24	3
	4-10	0.6-2.0	0.05-0.07	6.1-6.5	Low	Low	Low	0.17	
	10-16	---	---	---	---	---	---	---	
	16	---	---	---	---	---	---	---	
[1]CbF:									
Caguabo part	0-4	0.6-2.0	0.10-0.15	6.1-6.5	Moderate	Moderate	Low	0.24	3
	4-10	0.6-2.0	0.05-0.07	6.1-6.5	Low	Low	Low	0.17	
	10-16	---	---	---	---	---	---	---	
	16	---	---	---	---	---	---	---	
Rock outcrop part.									
Candelero:									
Ce	0-6	2.0-6.0	0.05-0.10	4.5-6.0	Low	High	High	0.24	4
	6-35	0.06-0.2	0.10-0.15	4.5-6.0	Moderate	High	High	---	
	35-58	0.06-0.2	0.10-0.15	4.5-6.0	Moderate	High	Low	---	
Catalina:									
ClC	0-6	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	Moderate	0.10	5
	6-84	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	High	0.10	
	84-99	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	Moderate	0.10	
Catano:									
Cn	0-7	>20.0	<0.05	7.9-8.4	Very low	Low	Low	---	---
	7-58	>20.0	<0.05	7.9-8.4	Very low	Low	Low	---	
Cayagua:									
Co	0-8	0.6-2.0	0.11-0.13	4.5-5.5	Very low	Low	High	0.24	4
	8-22	0.6-2.0	0.13-0.15	4.5-5.5	Moderate	High	High	0.20	
	22-60	2.0-6.0	0.11-0.13	4.5-7.3	Very low	Low	High	0.24	
Colinas:									
CrD2, CrE2, CrF2	0-26	0.6-2.0	0.18-0.20	7.4-7.8	Moderate	Moderate	Low	0.17	3
	26-52	2.0-6.0	0.05-0.10	7.4-7.8	Low	Low	Low	0.10	
Coloso:									
Cs	0-16	0.2-0.6	0.14-0.18	5.6-6.0	Moderate	High	Low	---	---
	16-70	0.06-0.2	0.12-0.18	5.6-6.0	High	High	Low	---	
Consumo:									
CuE, CuF	0-20	0.6-2.0	0.12-0.18	4.5-5.0	Moderate	High	High	0.17	3
	20-46	0.6-2.0	0.10-0.16	4.5-5.0	Moderate	High	High	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea- bility	Available water capacity	Soil reaction	Shrink- swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
Corozal:									
CzC	0-9	0.06-0.2	0.15-0.20	4.5-5.0	Moderate	High	High	0.24	5
	9-40	0.06-0.2	0.15-0.20	4.5-5.0	Moderate	High	High	---	
	40-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High	High	---	
Daguey:									
DaC, DaD	0-10	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High	High	0.10	4
	10-72	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High	High	0.10	
	72-90	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High	High	0.10	
Descalabrado:									
DeF	0-5	0.6-2.0	0.15-0.20	6.6-7.3	Low	Moderate	Low	0.24	3
	5-17	0.6-2.0	0.10-0.15	6.6-7.3	Low	Moderate	Low	---	
	17	---	---	---	---	---	---	---	
[1]DgF:									
Descalabrado part	0-5	0.6-2.0	0.15-0.20	6.6-7.3	Low	Moderate	Low	0.24	3
	5-17	0.6-2.0	0.10-0.15	6.6-7.3	Low	Moderate	Low	---	
	17	---	---	---	---	---	---	---	
Rock outcrop part.									
Dique:									
Dm	0-54	2.0-6.0	0.10-0.15	5.6-6.0	Low	Low	Moderate	---	---
Durados:									
Dr	0-14	6.0-20	0.05-0.10	6.6-7.3	Low	Low	Low	---	---
	14-23	6.0-20	0.05-0.10	7.9-8.4	Low	Low	Low	---	
	23-60	>20	<0.05	7.9-8.4	Low	Low	Low	---	
Estacion:									
Es	0-8	0.6-2.0	0.12-0.15	5.6-6.5	Moderate	Moderate	Moderate	---	---
	8-20	2.0-6.0	0.12-0.15	5.6-6.5	Low	Moderate	Moderate	---	
	20-50	>6.0	0.02-0.05	5.6-6.5	Low	Low	Moderate	---	
Guayama:									
GuF	0-4	0.6-2.0	0.10-0.15	6.6-7.8	Moderate	Moderate	Low	0.24	3
	4-20	0.6-2.0	0.10-0.15	6.6-7.8	Moderate	Moderate	Low	0.20	
	20	---	---	---	---	---	---	---	
Humacao:									
Hm	0-8	2.0-6.0	0.05-0.10	5.1-6.0	Low	Low	Moderate	0.17	5
	8-60	0.6-2.0	0.10-0.15	5.1-6.0	Moderate	Moderate	Moderate	---	
Humatas:									
HtE, HtF	0-5	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High	High	0.10	4
	5-24	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High	High	---	
	24-60	0.6-2.0	0.10-0.16	4.5-5.5	Moderate	High	High	---	
[1]HuF:									
Humatas part	0-5	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High	High	0.10	4
	5-24	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High	High	---	
	24-60	0.6-2.0	0.10-0.16	4.5-5.5	Moderate	High	High	---	
Rock outcrop part.									
Hydraquents:									
Hy	0-60	---	---	7.9-9.0	---	High	High	---	---
Jagueyes:									
JaE2	0-5	2.0-6.0	0.02-0.05	4.5-5.0	Low	Low	High	0.02	4
	5-41	0.6-2.0	0.05-0.10	4.5-5.0	Low	Low	High	---	
	41-62	0.6-2.0	0.05-0.10	4.5-5.0	Low	Low	High	---	
Juncal:									
JnD2	0-10	0.6-2.0	0.15-0.20	5.6-6.5	Moderate	High	Moderate	0.17	3
	10-48	0.6-2.0	0.15-0.20	6.6-7.8	Moderate	High	Low	---	
	48-60	0.6-2.0	0.15-0.20	7.4-7.8	Moderate	Moderate	Low	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Juncos:									
JuC, JuD----------	0-31	0.06-0.2	0.15-0.17	6.1-7.3	High------	High----------	Low------------	0.17	3
	31-40	0.06-0.2	0.13-0.16	6.1-7.3	High------	High----------	Low------------	0.17	
	40	---	---	6.1-7.3	----------	--------------	---------------	---	
Lares:									
LaB, LaC2---------	0-36	0.6-2.0	0.07-0.13	4.5-5.0	Moderate	High----------	High-----------	0.10	5
	36-60	0.2-0.6	0.07-0.13	4.5-5.0	Moderate	High----------	High-----------	---	
Limones:									
LmE, LmF----------	0-79	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High----------	High-----------	0.02	4
Lirios:									
LoF2--------------	0-4	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate------	High-----------	0.17	4
	4-34	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	---	
	34-60	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate------	High-----------	---	
Los Guineos:									
LsE, LsF----------	0-5	0.6-2.0	0.15-0.17	4.5-5.5	Moderate	High----------	High-----------	0.10	4
	5-60	0.6-2.0	0.15-0.17	4.5-5.5	Moderate	High----------	High-----------	0.01	
Mabi:									
MaA, MaB, MaC-----	0-24	0.06-0.2	0.15-0.20	4.5-6.0	High------	High----------	Moderate-------	0.32	4
	24-99	0.06-0.2	0.15-0.20	7.4-7.8	High------	High----------	Low------------	---	
Made land:									
Md.									
Malaya:									
MlF---------------	0-6	0.6-2.0	0.15-0.20	5.6-6.5	Moderate	High----------	Low------------	0.24	3
	6-13	0.6-2.0	0.10-0.20	6.6-8.4	Moderate	Moderate------	Low------------	---	
	13-18	0.6-2.0	0.10-0.20	6.6-8.4	Moderate	Moderate------	Low------------	---	
	18	---	---	---	----------	--------------	---------------	---	
Maricao:									
MoF---------------	0-14	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	0.17	3
	14-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	Moderate------	High-----------	---	
Martin Pena:									
Mp----------------	0-8	0.6-2.0	0.15-0.20	6.6-7.8	Low-------	Moderate------	Low------------	---	---
	8-18	0.6-2.0	0.12-0.15	6.6-7.8	Moderate	High----------	Low------------	---	
	18-63	<0.06	0.15-0.20	6.6-7.8	High------	High----------	Low------------	---	
Matanzas:									
MsB---------------	0-20	0.6-2.0	0.15-0.20	5.6-7.3	Moderate	High----------	Low------------	0.10	4
	20-53	0.6-2.0	0.15-0.20	5.6-7.3	Moderate	High----------	Low------------	0.10	
	53	---	---	---	----------	--------------	---------------	---	
Montegrande:									
MtB, MtC----------	0-7	0.2-0.6	0.15-0.17	5.1-6.5	High------	High----------	Moderate-------	0.17	4
	7-29	0.2-0.6	0.15-0.17	6.1-7.3	High------	High----------	Moderate-------	---	
	29-48	0.6-2.0	0.10-0.15	6.6-7.3	Moderate	Moderate------	Low------------	---	
Morado:									
MuF2--------------	0-34	0.6-2.0	0.10-0.15	6.1-7.3	Moderate	Moderate------	Low------------	0.17	3
	34	---	---	---	----------	--------------	---------------	---	
Mucara:									
MxD, MxE, MxF-----	0-5	0.6-2.0	0.15-0.17	6.1-6.5	High------	High----------	Low------------	0.17	3
	5-12	0.6-2.0	0.15-0.17	6.1-6.5	High------	High----------	Low------------	---	
	12-30	---	---	6.6-7.3	----------	--------------	---------------	---	
	30	---	---	---	----------	--------------	---------------	---	
Naranjito:									
NaD2, NaE2, NaF2--	0-4	0.6-2.0	0.16-0.20	4.5-5.5	Moderate	High----------	High-----------	0.17	3
	4-12	0.6-2.0	0.15-0.17	4.5-5.5	High------	High----------	High-----------	0.17	
	12-40	0.6-2.0	0.15-0.19	4.5-5.5	Moderate	High----------	High-----------	0.17	
	40	---	---	---	----------	--------------	---------------	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Pandura:									
PaD, PaE, PaF	0-7	2.0-6.0	0.02-0.10	5.1-6.0	Very low	Low	Moderate	0.24	3
	7-26	2.0-6.0	0.02-0.10	5.1-6.0	Low	Low	Moderate	---	
	26	2.0-20	0.02-0.05	5.1-6.0	Very low	Low	Moderate	---	
Pellejas:									
PeF	0-16	0.6-2.0	0.16-0.21	4.5-5.5	Moderate	Low	High	0.24	3
	16-60	6.0-20	0.06-0.13	4.5-5.5	Low	Low	High	0.32	
Reilly:									
Re	0-18	2.0-6.0	0.05-0.10	5.6-6.5	Very low	Low	Moderate	---	---
	18-55	>20	<0.05	5.6-6.5	Very low	Low	Moderate	---	
Rio Arriba:									
RoB, RoC2	0-8	0.2-0.6	0.15-0.20	5.6-7.8	High	High	Low	0.17	4
	8-60	0.2-0.6	0.15-0.20	5.6-7.8	High	High	Low	---	
Rio Piedras:									
RpD2, RpE2, RpF2	0-8	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High	High	0.17	4
	8-28	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High	High	0.17	
	28-48	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High	High	0.17	
	48	---	---	---	---------	-------------	-------------	---	
Sabana:									
SaF	0-3	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate	High	0.24	3
	3-15	0.6-2.0	0.20-0.24	4.5-5.5	High	High	High	---	
	15	---	---	---	---------	-------------	-------------	---	
Sabana Seca:									
ScB	0-70	<0.06	0.15-0.20	3.6-5.0	Moderate	High	High	0.24	4
Saladar:									
Sm	0-51	0.06-0.2	0.15-0.20	6.6-7.8	Low	Moderate	Low	---	---
Soller:									
SoE, SoF	0-5	0.6-2.0	0.10-0.15	6.6-8.4	Moderate	High	Low	0.17	3
	5-12	0.6-2.0	0.18-0.20	6.6-8.4	High	High	Low	0.17	
	12-24	---	---	---	---------	-------------	-------------	---	
	24	---	---	---	---------	-------------	-------------	---	
Tanama:									
[1]TaF:									
Tanama part	0-14	0.6-2.0	0.15-0.20	6.1-7.8	Moderate	High	Low	0.24	1
	14	---	---	---	---------	-------------	-------------	---	
Rock outcrop part.									
Toa:									
To	0-60	0.6-2.0	0.15-0.20	6.1-7.3	Moderate	Moderate	Low	---	---
Torres:									
TrB	0-28	6.0-20	0.02-0.05	4.5-5.5	Low	Low	High	---	---
	28-64	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High	High	---	
Tropopsamments:									
Ts	0-60	>20.0	<0.05	7.9-8.4	Low	High	High	---	---
Urban land:									
[1]Ud:									
Urban land part.									
Durados part	0-14	6.0-20	0.05-0.10	6.6-7.3	Low	Low	Low	---	---
	14-23	6.0-20	0.05-0.10	7.9-8.4	Low	Low	Low	---	
	23-60	>20	<0.05	7.9-8.4	Low	Low	Low	---	
[1]Um:									
Urban land part.									

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
Urban land:									
Mucara part	0-6	0.6-2.0	0.15-0.17	5.6-7.3	High	High	Low	0.17	3
	6-12	0.6-2.0	0.15-0.17	5.6-7.3	High	High	Low	---	
	12-22	---	---	---	---	---	---	---	
	22	---	---	---	---	---	---	---	
[1]Us:									
Urban land part.									
Sabana Seca part	0-70	<0.06	0.15-0.20	3.6-5.0	Moderate	High	High	0.24	4
[1]Uv:									
Urban land part.									
Vega Alta part	0-8	0.6-2.0	0.15-0.20	4.5-5.5	Low	Moderate	Moderate	0.17	4
	8-84	0.6-2.0	0.15-0.20	4.5-5.5	Low	High	Moderate	---	
Vega Alta:									
VaB, VaC2	0-8	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate	Moderate	0.17	4
	8-84	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High	Moderate	---	
Vega Baja:									
Vg	0-7	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	4
	7-50	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	
	50-60	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	
Via:									
VkC2	0-9	0.6-2.0	0.17-0.20	3.6-4.4	Moderate	Moderate	Moderate	0.17	5
	9-36	0.6-2.0	0.12-0.20	6.1-6.5	Moderate	Moderate	Low	0.17	
	36-52	2.0-6.0	0.03-0.07	5.6-6.0	Low	Low	Low	0.20	
Vivi:									
Vv	0-9	2.0-6.0	0.11-0.18	4.5-5.5	Very low	Moderate	High	---	---
	9-47	2.0-6.0	0.15-0.18	4.5-5.5	Very low	Moderate	High	---	
	47-58	6.0-20.0	0.04-0.08	4.5-5.5	Very low	Moderate	High	---	
Yunes:									
YeE, YeF	0-2	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate	High	0.17	3
	2-16	2.0-6.0	0.10-0.15	4.5-5.5	Low	Moderate	High	0.17	
	16	---	---	---	---	---	---	---	

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 15.--SOIL AND WATER FEATURES

[Absence of an entry indicates the feature is not a concern. See text for descriptions of symbols and such terms as "rare," "brief," and "perched." The symbol < means less than; > means greater than]

Soil name and map symbol	Hydro-logic group	Flooding: Frequency	Flooding: Duration	Flooding: Months	High water table: Depth	High water table: Kind	High water table: Months	Bedrock: Depth	Bedrock: Hard-ness	Subsidence: Ini-tial	Subsidence: Total
					Ft			In		In	In
Aceitunas: AaB, AaC	B	None	---	---	>6.0	---	---	>60	---	---	---
Aibonito: AbD, AbE	C	None	---	---	>6.0	---	---	>60	---	---	---
Almirante: AmB, AmC	B	None	---	---	>6.0	---	---	>60	---	---	---
Bajura: Ba	D	Frequent	Brief	Jul-Sep	0.5-2.5	Apparent	Jul-Sep	>60	---	---	---
Bayamon: BmB	B	None	---	---	>6.0	---	---	>60	---	---	---
Caguabo: CaE, CaF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
[1]CbF: Caguabo part	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Rock outcrop part.											
Candelero: Ce	C	Rare	---	---	1.0-1.5	Perched	Aug-Sep	>60	---	---	---
Catalina: ClC	B	None	---	---	>6.0	---	---	>60	---	---	---
Catano: Cn	A	None	---	---	>6.0	---	---	>60	---	---	---
Cayagua: Co	C	None	---	---	0.5-1.5	Perched	Aug-Oct	>60	---	---	---
Colinas: CrD2, CrE2, CrF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Coloso: Cs	D	Frequent	Brief	Jul-Sep	2.0-4.0	Apparent	Jul-Sep	>60	---	---	---
Consumo: CuE, CuF	B	None	---	---	>6.0	---	---	>60	---	---	---
Corozal: CzC	C	None	---	---	0-1.0	Perched	Jul-Oct	>60	---	---	---
Daguey: DaC, DaD	C	None	---	---	>6.0	---	---	>60	---	---	---
Descalabrado: DeF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
[1]DgF: Descalabrado part	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Rock outcrop part.											
Dique: Dm	B	Common	Very brief	Jun-Oct	>6.0	---	---	>60	---	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydrologic group	Flooding			High water table			Bedrock		Subsidence	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness	Initial	Total
					Ft			In		In	In
Durados: Dr	A	Rare	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Estacion: Es	B	Common	Very brief	Jun-Oct	>6.0	---	---	>60	---	---	---
Guayama: GuF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Humacao: Hm	B	None	---	---	>6.0	---	---	>60	---	---	---
Humatas: HtE, HtF	C	None	---	---	>6.0	---	---	>60	---	---	---
[1]HuF: Humatas part	C	None	---	---	>6.0	---	---	>60	---	---	---
Rock outcrop part.											
Hydraquents: Hy	D	Frequent	Very long	Jul-Jun	0-1.0	Apparent	Jul-Jun	>60	---	---	---
Jagueyes: JaE2	B	None	---	---	>6.0	---	---	>60	---	---	---
Juncal: JnD2	C	None	---	---	>6.0	---	---	>60	---	---	---
Juncos: JuC, JuD	D	None	---	---	>6.0	---	---	>36	Rippable	---	---
Lares: LaB, LaC2	C	None	---	---	>6.0	---	---	>60	---	---	---
Limones: LmE, LmF	B	None	---	---	>6.0	---	---	>60	---	---	---
Lirios: LoF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Los Guineos: LsE, LsF	C	None	---	---	>6.0	---	---	>60	---	---	---
Mabi: MaA, MaB, MaC	D	Rare	Brief	Jun-Oct	1.5-3.0	Perched	Jun-Oct	>60	---	---	---
Made land: Md.											
Malaya: MlF	D	None	---	---	>6.0	---	---	12-20	Hard	---	---
Maricao: MoF	B	None	---	---	>6.0	---	---	>60	---	---	---
Martin Pena: Mp	D	Frequent	Very long	Jun-Oct	0.5-1.0	Apparent	Jun-Oct	>60	---	---	---
Matanzas: MsB	B	None	---	---	>6.0	---	---	30-58	Hard	---	---
Montegrande: MtB, MtC	D	Rare	---	---	>6.0	---	---	>60	---	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydrologic group	Flooding			High water table			Bedrock		Subsidence	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness	Initial	Total
					Ft			In		In	In
Morado:											
MuF2	C	None	---	---	>6.0	---	---	22-42	Rippable	---	---
Mucara:											
MxD, MxE, MxF	D	None	---	---	>6.0	---	---	20-36	Rippable	---	---
Naranjito:											
NaD2, NaE2, NaF2	C	None	---	---	>6.0	---	---	29-45	Rippable	---	---
Pandura:											
PaD, PaE, PaF	D	None	---	---	>6.0	---	---	12-19	Rippable	---	---
Pellejas:											
PeF	B	None	---	---	>6.0	---	---	>60	---	---	---
Reilly:											
Re	A	Occasional	Very brief	Aug-Oct	2.5-5.0	Apparent	Aug-Oct	>60	---	---	---
Rio Arriba:											
RoB, RoC2	D	Rare	Brief	Jun-Oct	>6.0	---	---	>60	---	---	---
Rio Piedras:											
RpD2, RpE2, RpF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Sabana:											
SaF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Sabana Seca:											
ScB	D	None	---	---	2.0-3.0	Apparent	Jul-Oct	>60	---	---	---
Saladar:											
Sm	D	Frequent	Very long	Jun-Oct	0-0.5	Apparent	Jun-May	>60	---	---	18
Soller:											
SoE, SoF	D	None	---	---	>6.0	---	---	20-34	Hard	---	---
Tanama:											
[1]TaF:											
Tanama part	D	None	---	---	>6.0	---	---	12-20	Hard	---	---
Rock outcrop part.											
Toa:											
To	B	Occasional	Brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Torres:											
TrB	A	None	---	---	>6.0	---	---	>60	---	---	---
Tropopsamments:											
Ts	A	Frequent	Very brief	Jul-Jun	0-3.0	Apparent	Jul-Jun	>60	---	---	---
Urban land:											
[1]Ud:											
Urban land part.											
Durados part	A	Rare	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
[1]Um:											
Urban land part.											
Mucara part	D	None	---	---	>6.0	---	---	20-36	Rippable	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro-logic group	Flooding: Frequency	Flooding: Duration	Flooding: Months	High water table: Depth	High water table: Kind	High water table: Months	Bedrock: Depth	Bedrock: Hard-ness	Subsidence: Ini-tial	Subsidence: Total
					Ft			In		In	In
Urban land:											
[1]Us:											
Urban land part.											
Sabana Seca part	D	None--------	---	---	2.0-3.0	Apparent	Jul-Oct	>60	---	---	---
[1]Uv:											
Urban land part.											
Vega Alta part--	C	None--------	---	---	>6.0	---	---	>60	---	---	---
Vega Alta:											
VaB, VaC2--------	C	None--------	---	---	>6.0	---	---	>60	---	---	---
Vega Baja:											
Vg---------------	C	Occasional	Brief-----	Jul-Sep	1.5-3.0	Apparent	Jul-Sep	>60	---	---	---
Via:											
VkC2-------------	B	None--------	---	---	>6.0	---	---	>60	---	---	---
Vivi:											
Vv---------------	B	Occasional	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Yunes:											
YeE, YeF---------	D	None--------	---	---	>6.0	---	---	10-20	Rip-pable	---	---

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 16.--CLASSIFICATION OF THE SOILS

Soil name	Family or higher taxonomic class
Aceitunas	Clayey, oxidic, isohyperthermic Typic Palehumults
Aibonito	Clayey, oxidic, isohyperthermic Orthoxic Tropohumults
Almirante	Clayey, oxidic, isohyperthermic Plinthic Paleudults
Bajura	Fine, mixed, nonacid, isohyperthermic Vertic Tropaquepts
Bayamon	Clayey, oxidic, isohyperthermic Typic Haplorthox
Caguabo	Loamy-skeletal, mixed, isohyperthermic Lithic Eutropepts
Candelero	Fine-loamy, mixed, isohyperthermic Aeric Tropaqualfs
Catalina	Clayey, oxidic, isohyperthermic Tropeptic Haplorthox
Catano	Carbonatic, isohyperthermic Typic Tropopsamments
Cayagua	Fine, mixed, isohyperthermic Aeric Tropaqualfs
Colinas	Fine-loamy, carbonatic, isohyperthermic Eutropeptic Rendolls
Coloso	Fine, mixed, nonacid, isohyperthermic Aeric Tropic Fluvaquents
Consumo	Clayey, mixed, isohyperthermic Dystropeptic Tropudults
Corozal	Clayey, mixed, isohyperthermic Aquic Tropudults
Daguey	Clayey, oxidic, isohyperthermic Orthoxic Tropohumults
Descalabrado	Clayey, mixed, isohyperthermic Lithic Vertic Ustropepts
Dique	Fine-loamy, mixed, isohyperthermic Fluventic Eutropepts
Durados	Sandy, mixed, isohyperthermic Fluventic Hapludolls
Estacion	Fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls
Guayama	Clayey, mixed, isohyperthermic Lithic Haplustalfs
Humacao	Fine-loamy, mixed, isohyperthermic Fluventic Eutropepts
Humatas	Clayey, kaolinitic, isohyperthermic Typic Tropohumults
Hydraquents	Hydraquents
Jagueyes	Fine-loamy, mixed, isohyperthermic Orthoxic Tropudults
Juncal	Fine, mixed, isohyperthermic Typic Tropudalfs
Juncos	Fine, montmorillonitic, isohyperthermic Vertic Eutropepts
Lares	Clayey, mixed, isohyperthermic Aquic Tropohumults
Limones	Clayey, kaolinitic, isohyperthermic Epiaquic Orthoxic Tropohumults
Lirios	Clayey over loamy, mixed, isohyperthermic Typic Tropudults
Los Guineos	Clayey, mixed, isothermic Epiaquic Tropohumults
Mabi	Fine, montmorillonitic, isohyperthermic Vertic Eutropepts
Malaya	Clayey, mixed, isohyperthermic Lithic Eutropepts
Maricao	Clayey, mixed, isothermic Dystropeptic Tropudults
Martin Pena	Fine, mixed, nonacid, isohyperthermic Tropic Fluvaquents
Matanzas	Clayey, oxidic, isohyperthermic Tropeptic Eutrorthox
Montegrande	Fine, mixed, isohyperthermic Vertic Eutropepts
Morado	Fine-loamy, mixed, isohyperthermic Typic Eutropepts
Mucara	Clayey, montmorillonitic, isohyperthermic, shallow Vertic Eutropepts
Naranjito	Clayey, mixed, isohyperthermic Typic Tropohumults
Pandura	Loamy, mixed, isohyperthermic, shallow Typic Eutropepts
Pellejas	Fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Typic Dystropepts
Reilly	Sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls
Rio Arriba	Fine, mixed, isohyperthermic Vertic Paleudalfs
Rio Piedras	Clayey, kaolinitic, isohyperthermic Typic Tropudults
Sabana	Clayey, mixed, isohyperthermic Lithic Dystropepts
Sabana Seca	Clayey, mixed, isohyperthermic Oxic Plinthaquults
Saladar	Euic, isohyperthermic Fluvaquentic Troposaprists
Soller	Clayey, mixed, isohyperthermic, shallow Eutropeptic Rendolls
Tanama	Clayey, mixed, isohyperthermic Lithic Tropudalfs
Toa	Fine, mixed, isohyperthermic Fluventic Hapludolls
Torres	Clayey, oxidic, isohyperthermic Plinthic Palehumults
Tropopsamments	Tropopsamments
Vega Alta	Clayey, mixed, isohyperthermic Plinthic Tropudults
Vega Baja	Fine, mixed, isohyperthermic Aeric Tropaqualfs
Via	Fine-loamy, mixed, isohyperthermic Typic Tropudalfs
Vivi	Coarse-loamy, mixed, isohyperthermic Fluventic Eutropepts
Yunes	Loamy-skeletal, mixed, isohyperthermic, shallow Typic Dystropepts

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Hydrogeology of the Karst of Puerto Rico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1012

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HYDROGEOLOGY OF THE KARST OF PUERTO RICO

Poem by a foremost Puerto Rican concerning the "Karstic Spring" at Aguadilla, Puerto Rico.

Hydrogeology of the Karst of Puerto Rico

By ENNIO V. GIUSTI

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1012

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CONVERSION FACTORS

Metric units	*Conversion factor*	*Foot-pound-second units*	*Remarks*
meter (m)	3.28	foot (ft)	
millimeter (mm)	.039	inch (in.)	
kilometer (km)	.62	mile (mi)	
square kilometer (km^2)	.386	square mile (mi^2)	
degree Celsius (° C)	1.8	degree Farenheit (° F)	add 17.8 to ° C
liter per second (L/s)	15.9	gallon per minute (gal/min)	
kilogram per square centimeter (kg/cm^2)	14.22	pound per square inch (lb/in^2)	
centimeter per second (cm/s)	2,850	foot per day (ft/d)	
cubic meter per second (m^3/s)	35.4	cubic foot per second (ft^3/s)	
milligram per liter (mg/L)	~1	parts per million (ppm)	for dilute solutions
gram per cubic centimeter (g/cm^3)	62.5	pound per cubic foot (lb/ft^3)	
gram (g)	.0022	pound (lb)	
tonne per year (t/yr)	1.1	short ton per year (ton /yr)	

NOTE:—Multiply units in first column by the conversion factor to obtain units of third column. The order of the units shown follows that used in the report.

HYDROGEOLOGY OF THE KARST OF PUERTO RICO

By Ennio V. Giusti

ABSTRACT

About one-fifth of Puerto Rico is covered by a tropical karst formed on a series of six limestone formations ranging in age from middle-Oligocene to middle Miocene. These formations strike east to west and crop out over the north coast of the island. Structurally, the rocks form a simple wedge abutting southward against a mountain chain of volcanic origin and thickening northward to about 1,400 meters by the seashore. All stages of karstification are present: from the incipient, found at the western end of the belt to the residual, found at the eastern end. Maximum development of sinkholes occurs on the Aguada Limestone and upper part of the Aymamón Limestone. These formations have a $CaCO_3$ content range from about 85 to 95 percent. The semi-impermeable Cibao Formation has developed a fluvial drainage. An analysis of stream channel orientations indicates that the present topographic drainage oriented toward the northeast is superimposed on a former drainage system oriented toward the northwest. Transition from the northwestern to the northeastern drainage orientation is ascribed to Pleistocene eastward tilting of the Puerto Rican platform. This tilt is thought to have affected the subterranean drainage pattern as well, so that springs are found mainly on the western wall of northward-oriented valleys. Estimates of the water budget indicate that the karstic stream basins behave on an annual basis much as other stream basins that are not on limestone terrane. Average incoming solar radiation (expressed as evaporated water) and rainfall (2,900 mm and 1,750 mm, respectively) result in an evapotranspiration of about 1,100 mm (millimeters) annually and a discharge of 650 mm. This discharge is accommodated fluvially in areas underlain by the Cibao Formation and by the lower part of the Lares Limestone and subterraneally through the karst elsewhere.

Base flow of streams in limestone in Puerto Rico is less than in streams in volcanic terrane, owing to fast disposal of rainfall through networks of subterranean solution channels. Ground water is found under water-table conditions in the Aymamón and Aguada and under artesian conditions in parts of the Cibao and the Lares. The unconfined groundwater discharges along a strip near the shoreline into swamps and lagoons; the artesian water discharges through a submarine face an unknown distance from the coast and possibly, in part, along a presumed fault near the coast. In the western part of the belt, ground water discharges through the sea bottom, possibly as springs. Permeability is found to decrease exponentially with stratigraphic depth.

Except for lake waters resting on terra rossa, most waters of the limestone belt are saturated or supersaturated with respect to calcite, and as much as 86 percent of the solution is computed to arise mainly from enrichment of rainwater with CO_2 in the soil from the decomposition of organic acids. The denudation rate of the limestone belt through solution is computed as 0.070 mm per year with some evidence that abrasion may increase the denudation rate locally by as much as 40 percent. Calculations based on a projected initial limestone surface and the computed solution rate reveal that the limestone belt emerged from the sea about 4 million years ago and that the eastward tilt of the Puerto Rican platform, reported in the literature, occurred about 1 million years ago. Of the factors pertinent to karst development, aquifer permeability, both vertical and lateral, and primary rock porosity are thought to be the basic control for the existence and morphology of the karst. Assuming sufficiently pure limestone, climate is considered of secondary importance.

INTRODUCTION

Most men of science of ancient times thought that all the water about them originated from large underground caverns, perennially replenished by the sea or by condensation of moist air. This view, along with most scientific theories prevailing at that time, was the legacy of Aristotelian thinking; and it is interesting, within the context of this report, to speculate that only a karst land—the Grecian one, in this instance—could have been responsible for fostering such a theory. Only the karst develops underground rivers, and only carbonate and other soluble rock terranes develop karst. However, not all limestone terranes become karst, and not all karsts contain underground rivers. A great range of conditions occur in many limestone regions; some areas show little effects of solutional erosion, whereas other areas show advanced stages of karst development. A limestone area can occupy any intermediate position within these two limiting conditions; one of the objectives of this report is to place the north coast limestone area of Puerto Rico within such a perspective. The main purpose is to describe the hydrologic and geologic conditions of the karst terrane of the north coast of Puerto Rico.

The writer appreciates the cooperation of the Puerto Rico Aqueduct and Sewer Authority for providing data on well logs and pumpage and for providing a crew to drill holes in well casings to measure water levels.

DATA AVAILABLE AND PREVIOUS INVESTIGATIONS

Areal photographs are available for the area, and topographic quadrangle maps may be obtained at the scale of 1:20,000 with contour intervals of 5–10 m in regions of high relief, and of 1 m in regions of low relief. Geologic maps, also at a scale of 1:20,000, have been published for each quadrangle in the region. Meteorological data include records from about 25 daily rainfall stations scattered throughout the north coast limestone belt and the nearby mountain slopes, and records from 5 evaporation sites at different altitudes in the area. Hydrologic data available prior to this study were limited to monthly water levels from a skeleton network of 5 wells, and miscellaneous low-flow discharge measurements from 20 sites. In addition to these hydrologic data from the limestone area proper, data were available from three long-term (more than 10 year of record), and two short-term (2 years of record) streamflow stations located in the volcanic area near the contact of the limestone belt. Chemical analyses of ground and surface water have been published in basic-data reports.

Reports on the limestone belt include geologic mapping, principally by Monroe (1962, 1968a, 1969a), Briggs (1961, 1966), and Briggs and Akers (1965) and the excellent studies of the karst morphology by Monroe (1964, 1966, 1968b, 1969b). Detailed work on a portion of the area but with conclusions significantly applicable to the limestone belt in general can be found in Williams (1965). Older and more general works, such as those of Lobeck (1922), Meyeroff (1933), and Zapp and others (1948), yield much useful information on the geology and geomorphology of the limestones. The coastal features and shoreline investigation of Kaye (1959), and various geophysical investigations such as the gravity work of Myers (1955) and Shurbet and Ewing (1956), provide information for a better understanding of the three-dimensional boundaries of the limestone belt.

An investigation of the hydrogeology of Puerto Rico, which includes a comprehensive study of the ground-water conditions of the north coast limestone area, was made by McGuinness (1948). Birot and others (1967) present a quantitative evaluation of the water budget of a karst stream basin, and field-analyzed chemical data of karstic water. Bennett and Giusti (1972) evaluated the hydrology of the Laguna Tortuguero area; Diaz (1973 mapped the chemical quality at the Caño Tiburones; and Jordan (1970) reported on ground-water movement in the upper Río Tanamá basin.

THE LIMESTONE AREAS OF PUERTO RICO

The limestones of Puerto Rico are found scattered throughout the island as caps of mountains or as belts draped over the north and south coasts. These limestones (see fig. 1) range in age from early Cretaceous (Briggs and Akers, 1965), the oldest of the patches being found in the interior, to middle Miocene and perhaps as young as middle Pliocene (G. Seiglie, oral commun., 1969), the youngest proposed age for the youngest formation found in the north coast belt. The limestones of the interior represent the remnants of reefs that fringed the Cretaceous volcanoes of Puerto Rico (Meyerhoff, 1933), whereas the north and south belts, were deposited later over the eroded volcanic core, in shallow clear-water environments with open circulation, on a generally stable shelf.

The limestones of the north coast cover an area about 125 km (kilometers) in length from Aguada to Loiza and as much as 22 km in width near Arecibo, encompassing about 1,600 km^2, or one-fifth of the land area of Puerto Rico. The altitude of the north coast belt is about 400 m (meters) at the contact with the volcanic core and decreases northward to sea level.

The discussion in this report is confined to the north coast belt west of the Río de la Plata because it contains important aquifers; moreover, it is the only area that has developed prominent karst topography.

GEOLOGY

VOLCANIC BASEMENT

The limestones of the north coast belt rest unconformably on a faulted and folded volcanic base that is no younger than Eocene in age (Briggs, 1961). The surface of the volcanic rocks beneath the limestone is highly irregular as evidenced by the variability of the angles of the dips and their azimuths reported from seismic reflection work carried out in the search for oil structures (Myers, 1955).

LIMESTONES

The limestones on the north coast were deposited in shallow clear water with open circulation, on a

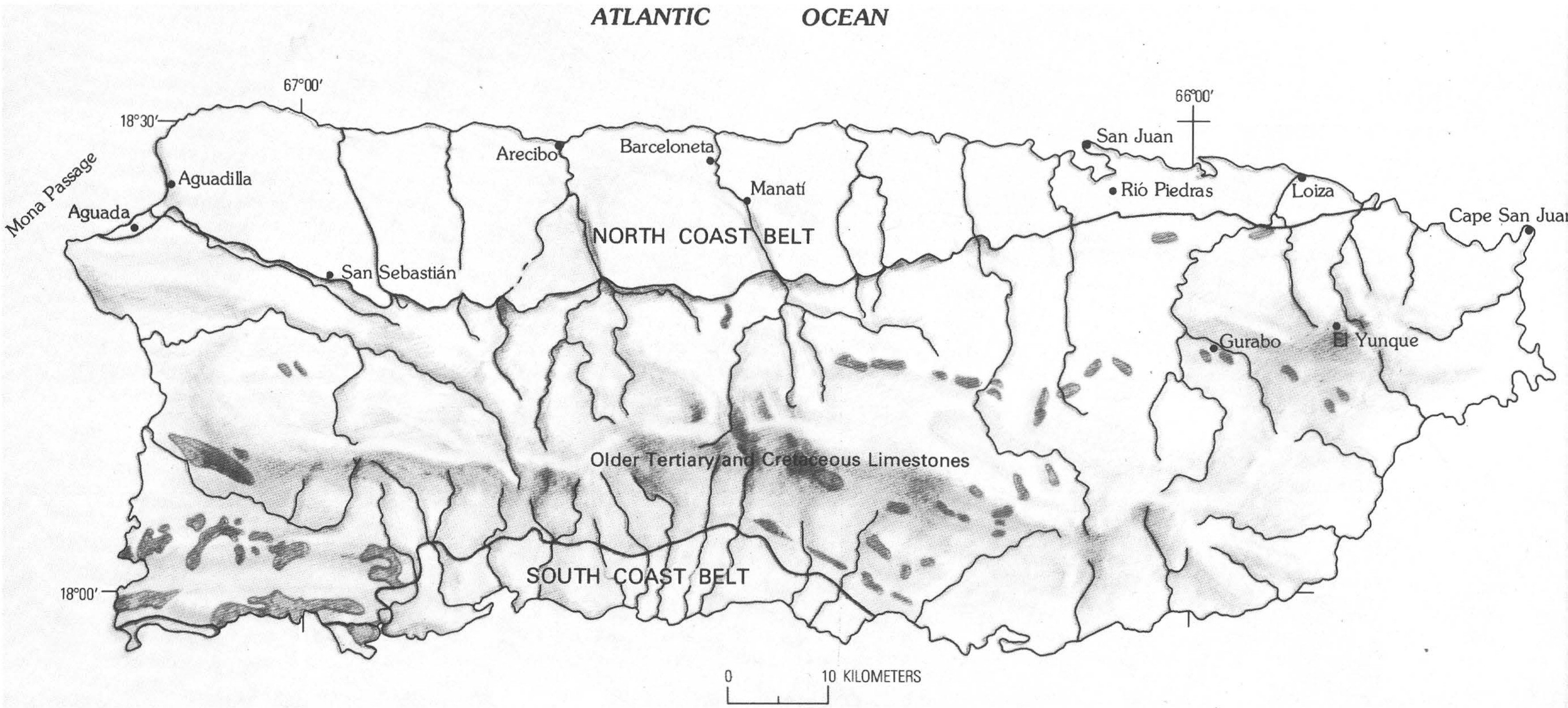

FIGURE 1.—Location of the limestone areas (slightly modified from Briggs and Akers, 1965).

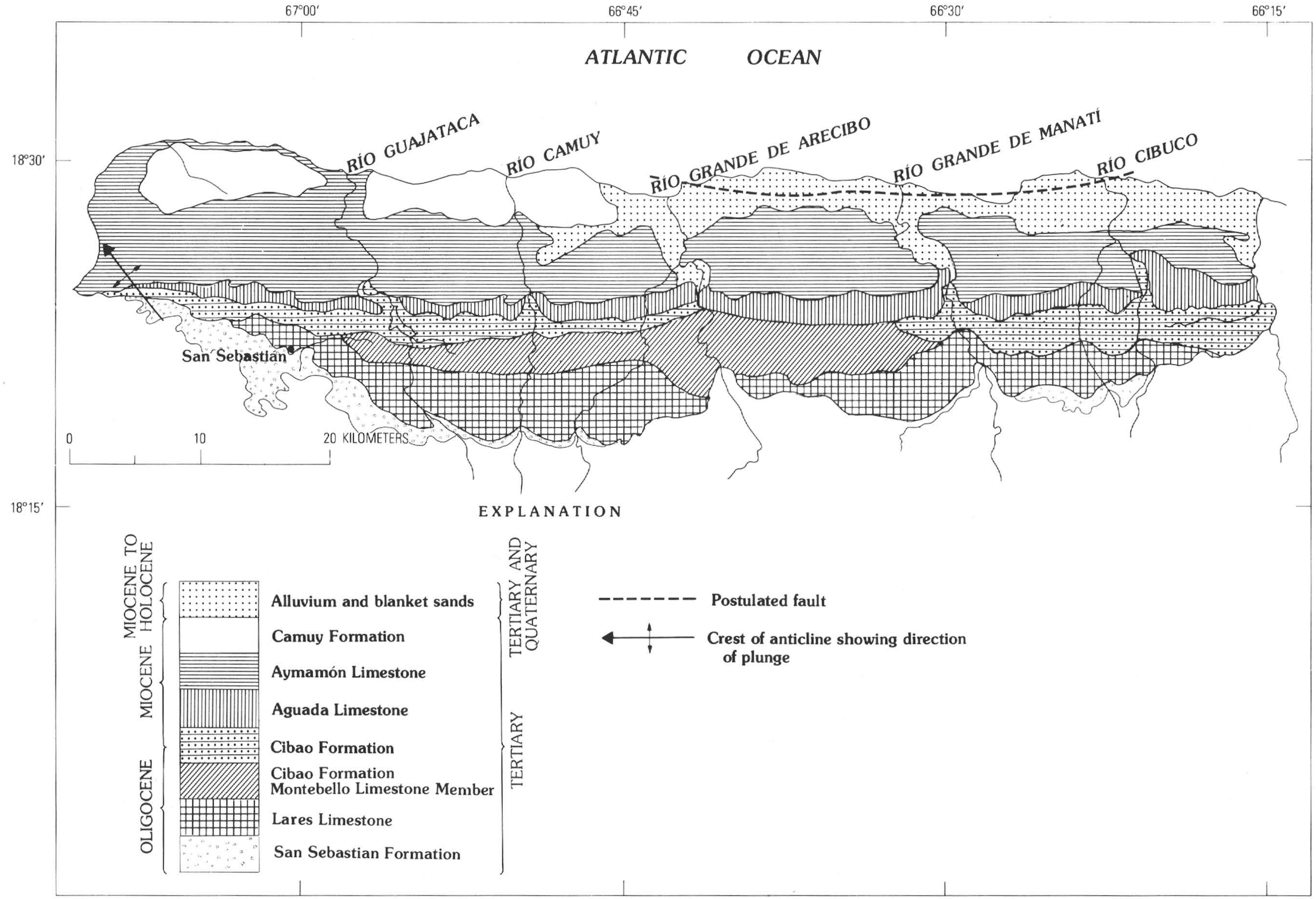

FIGURE 2.—Geologic formations of the north coast limestone area (adapted from Briggs and Akers, 1965).

generally stable shelf, and have undergone little postdepositional structure changes. Most investigators consider the age of the limestones to range from middle Oligocene to middle Miocene.

Above the volcanic base, six formations are recogized (fig. 2); these are described herewith from oldest to youngest (lithology of the rocks units are adapted from the several reports of Briggs and Monroe.).

SAN SEBASTIÁN FORMATION

Essentially the Formation is a poorly cemented shaly bedded claystone, but contains layers of siltstone, sandstone, conglomerate, and locally has lenses of limestone and lignite. The thickness ranges from zero in the middle part of the belt to about 300 m near the town of San Sebastián. The age is controversial. Most investigators consider it to be of middle Oligocene age; Gordon (1959), however, believes that no rock of the north coast Tertiary sequence is older than Miocene. Generally the San Sebastián is too impermeable to serve as a source of ground water and acts as a confining bed in most of the area. In the vicinity of San Juan, however, conglomerate and sandstone zones form part of an important aquifer.

LARES LIMESTONE

The Lares gradationally overlies the San Sebastián. It is a thin-bedded limestone at the base, changing upward to a thick-bedded and massive dense limestone. In the center of the belt it is a very pure limestone about 300 m thick; but it thins both eastward and westward and eventually pinches out at the margins of the belt. The age controversy of the San Sebastián applies to the Lares, but most investigators consider it to be of middle and late Oligocene age. The Lares is a poor aquifer where it crops out because of low permeability; however, in the center of the belt where it is overlain by younger rocks it becomes an important aquifer because of high potentiometric head.

CIBAO FORMATION

The Cibao is the most variable formation of the north coast, to the extent that at least two members are recognized: The Montebello Limestone Member and the Quebrada Arenas Member.

Generally the Cibao is an interbedded sequence of marl, chalk, limestone, sand, and clay as much as 230 m thick. In the eastern and western parts of the belt, clastics are predominant. In the middle part, limestones are predominant.

The Cibao Formation acts either as a confining bed or as an aquifer, depending upon the lithology. In the San Juan area, an artesian aquifer capped by clays that are in turn overlain by water-bearing limestones are all part of the Cibao Formation.

The Quebrada Arenas and the Montebello Members are present in the middle of the belt. These members are thick-bedded to massive finely crystalline to granular limestones. The Montebello Member, which is chalky in some places, is among the purest limestones of the north coast. The Montebello Member at depth is an important artesian aquifer in the middle part of the limestone belt.

The Cibao Formation ranges from Oligocene to Miocene in age, or, according to Gordon (1959), is entirely Miocene.

AGUADA LIMESTONE

The Aguada consists of hard thick-bedded to massive calcarenite, locally rubbly to finely crystalline, alternating with beds of clayey limestone. Maximum thickness is about 90 m. The age is early Miocene. Water-bearing properties of the Aguada are considered to range from poor to fair, reflecting differences in lithology.

AYMAMÓN LIMESTONE

The basal part of the Aymamón is a massive to thick-bedded limestone, finely crystalline, about 70 m in thickness. The middle and upper parts are very pure chalky limestone, riddled with solution channels. Total thickness is about 300 m; the age is early Miocene. The basal part of the Aymamón is similar to the Aguada in its water-bearing properties. The middle and upper parts of the limestone are highly permeable.

CAMUY FORMATION

The youngest limestone formation of the north coast belt is areally extensive only west of Arecibo. The lithology of the rock unit varies from a calcarenite to a limestone conglomerate in a clayey matrix. Some parts of the Camuy are quartz sandstone. Maximum thickness is about 200 m. The age is middle Miocene according to most investigators but may be as young as Pliocene according to micropaleontological work by G. A. Seiglie of the University of Puerto Rico, (oral commun., 1969). In general, the Camuy is not an aquifer because it is above the water table.

UNCONSOLIDATED DEPOSITS

BLANKET SANDS

Overlying the limestone formations are the so-called blanket sands. A sandy-silty-clayey mixture, they fill most depressions of the north coast belt surface to an average depth of about 10 m, though an infill of 30 m is not uncommon nearer the coast. There are some debatable points concerning their formation—some workers attribute them to a reworking of marine sediments (Monroe, 1969b); others (Briggs, 1966) favor a fluvial origin. The latter view appears to be more plausible (Williams, 1965) in view of the fact that no fossils have been found in the blanket sands. Briggs believes the blanket sands to be contemporary with arching of the Puerto Rican platform, being therefore the deposits of the first rivers flowing from the newly risen island. These deposits were later augmented by the insoluble residues of solution of the limestone formations (especially the clastic Camuy). The age of the blanket sands would range, therefore, from late Miocene (or Pliocene) to the present. The blanket sands are important as recharge media, but insignificant as aquifers.

QUATERNARY DEPOSITS

The Quaternary deposits of the north coast belt include the alluvium of the river flood plains, a mixture of unconsolidated sand, gravel, and clay ranging in thickness from 0 to about 100 m. Locally the alluvium is a good aquifer. Other Quaternary deposits include the carbonaceous muck in lagoons and swampy areas, some landslide material at the foot of limestone escarpments, cemented sand dunes along the coast, and recent beach deposits. Some of them, especially the cemented sand dunes, provide important clues to the geologic past of the island (Kaye, 1959). Except for the swamps, which mark areas of ground-water discharge, none of these deposits are involved materially in the hydrogeology of the north coast limestone belt. The geologic map of figure 2 shows the most important unconsolidated deposits.

STRUCTURE

The general attitude of the limestone sequence is that of a homocline gently inclined to the north. Figure 3 shows histograms of the angle and azimuths of the dips. In terms of average values the limestone formations dip 5° in a direction N. 0° 47′ E.

A plot of dip angles with latitude is shown in figure 4. Although there is extensive scatter, a relation line can be drawn through the field of points to show a decrease in dip toward the coast. The decrease of dip angles with latitude (northward) reflects the steeper inclination that the limestone belt must have had near the center of the island, at the contact with the volcanic core, when it arched up in Miocene and Pliocene time. This steeper dip of the Tertiary belt in the interior of the island was noted by Briggs (1961), who stated that the dips ranged from about 3° at the Aymamón-Aguada contact to as much as 6° in the older formations. In the same paper, Briggs discusses the thickening of the formations in a seaward direction as shown in an analysis of the rock material drilled by a deep oil test that penetrated the entire Tertiary sequence.

Shurbet and Ewing (1956), on the strength of gravity data and assumed rock densities, inferred a structure for the north coast limestone belt that showed a thickening of rock seaward. Figure 5, a generalized geologic section through longitude 66° 43′, is derived from the relation line of figure 4 and the structural interpretation made by Shurbet and Ewing.

This sample wedge structure contains a few gentle folds such as the one described by Monroe (1962) in the Manatí area. Most of the folds probably reflect structural features of the basement complex and do not inherently affect the overall struc-

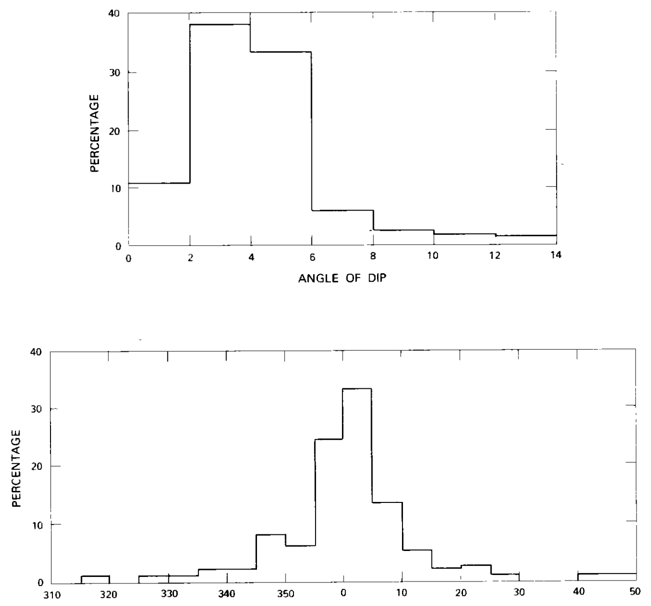

Figure 3.—Histograms of north coast limestone dips and orientations.

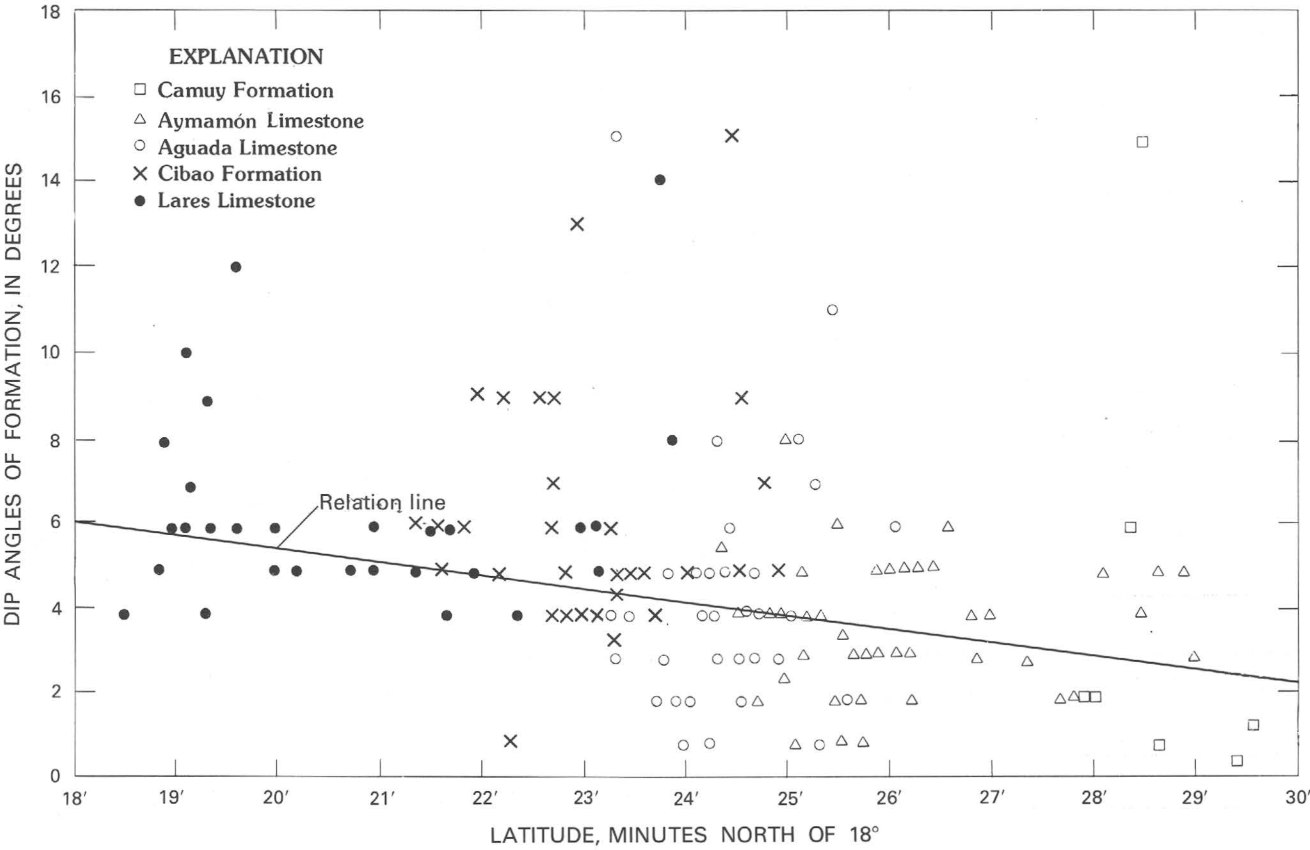

FIGURE 4.—The dip of the limestone decreases in a seaward direction.

tural aspect of the north coast belt. One exception toward the western margin of the belt, southeast of Aguadilla, is a northwest plunging anticline (see fig. 2) accompanied by a few normal faults also alined in a northwest-southeast direction (Monroe, 1969a); possibly there is ongoing tectonic activity related to the Puerto Rican trench and Mona Passage, both known to be seismically active. This anticline and associated faults are probably related to the raised shoreline of the western part of the limestone belt.

Briggs (1961) postulated a major strike fault along the north coast extending from Arecibo east to the Río Cibuco (see fig. 2)—a distance of nearly 40 km.

LANDFORMS—THE KARST

An aerial view of the north coast belt shows the karst as a flat, highly pitted surface lapping against the mountains of the central core (fig. 6). This surface is crossed by two large valleys in the eastern part; westward one can barely discern the sinuous trace of three or four river valleys, not wide enough to provide a clear gap in the flat surface. The terrain, on closer inspection, appears as clusters of hills separated from each other by rounded depressions (fig. 7)—the "lunar landscape" of Monroe (1968b).

A common feature of limestone surfaces is depressions (sinkholes) that drain internally. The areal distribution of sinkholes may be used to draw inferences on the physical-chemical properties of the rocks and on the hydrology of the area. The quantitative map of karst development in figure 8 was prepared from topographic maps by dividing the

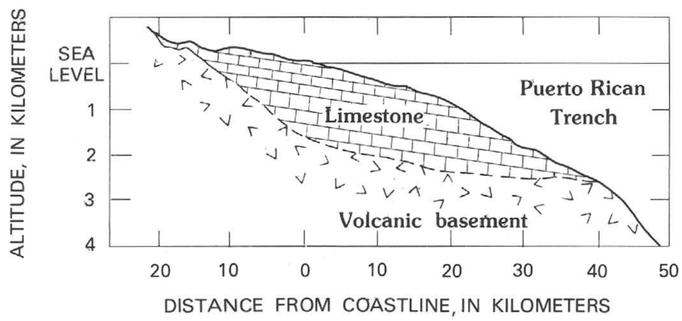

FIGURE 5.—Section of the north coast limestone belt through longitude 66°43′ (adapted from Shurbet and Ewing, 1956).

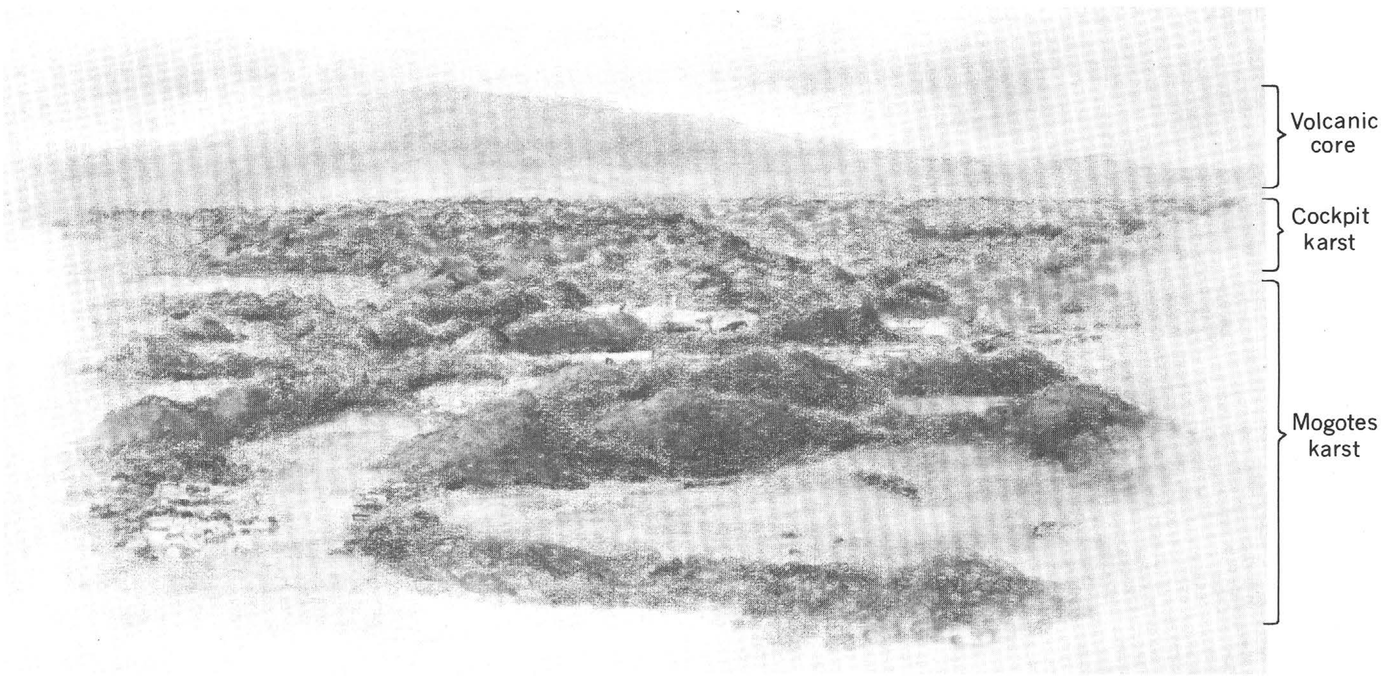

FIGURE 6.—The karst is a highly pitted surface lapping against the central volcanic core of the island.

FIGURE 7.—Rounded depressions mark the bottom of the karst. Here the depressions have coalesced to form a narrow valley.

region into rectangles of 1-minute longitude by 1-minute latitude, and measuring the percentage of the area of each rectangle falling within closed topographic contours. The topographic maps used were at the scale of 1:20,000 with contour intervals of 5 and 10 m. The maximum karst development (100 percent) as defined by this topograhic method occurs where half of the chosen sample area is covered by closed contoured depressions and half by hills separating them. A close correlation between geologic properties of the formations and degree of karst development is indicated. (Compare figs. 2 and 8.)

Some degree of karstification has taken place on all the limestones with the exception of the predominantly clastic San Sebastián Formation. In the far western part of the area the Lares Limestone has a normal fluvial development of streams that drain southward to the Río Culebrinas. Eastward, however, the Lares Limestone has developed slight to moderate karstification. The Cibao Formation shows but slight karst development in the eastern and western parts of the area, where it is predominantly clastic (figs. 9 and 10). In the center of the north coast belt, however, where the Cibao Formation is a pure limestone (Montebello Limestone Member), an extensive karst has developed. Karstification increases northward in the overlying Aguada Limestone and reaches its maximum development in the southern outcrop area of the Aymamón Limestone;

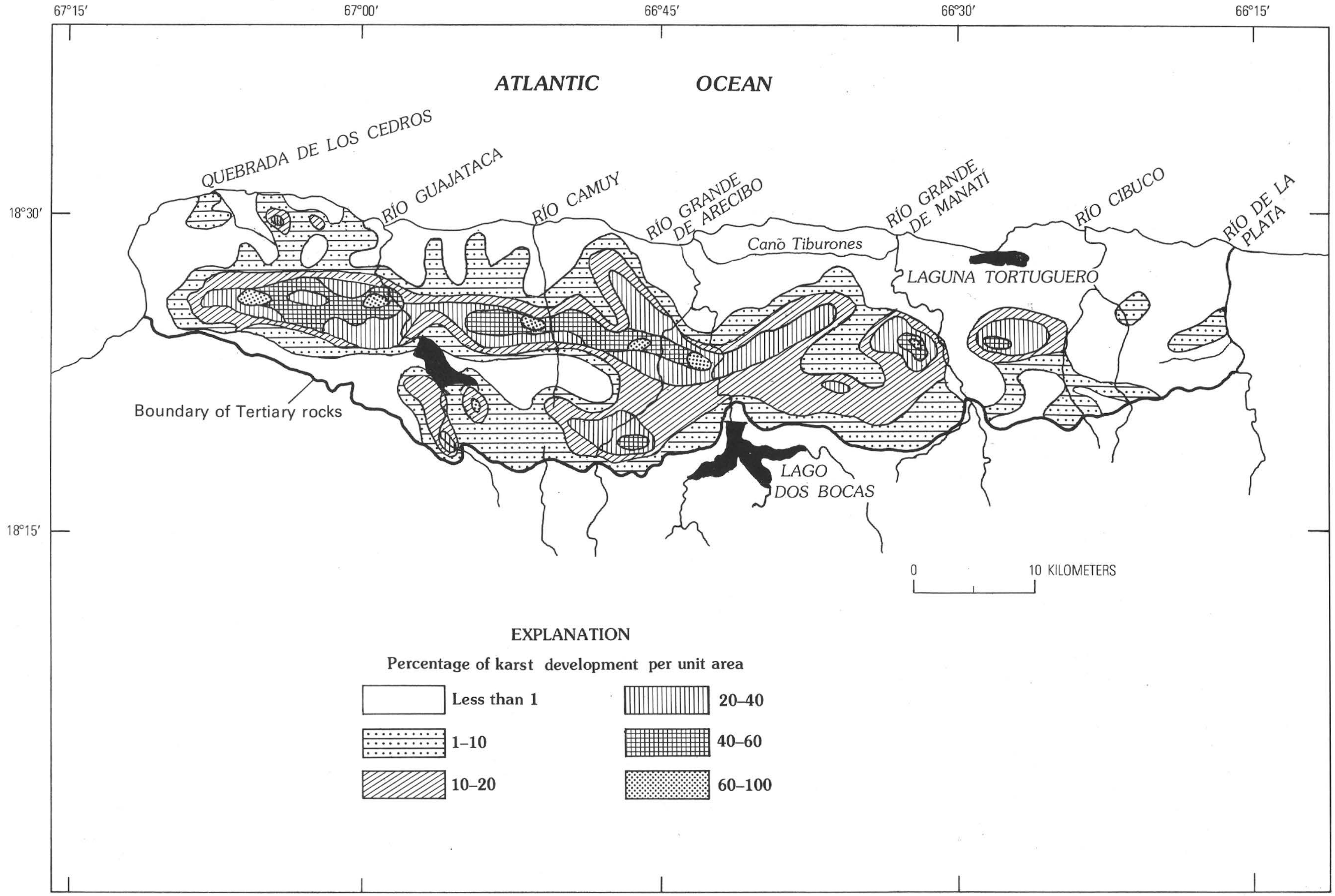

FIGURE 8.—Karst development of the north coast limestone belt.

FIGURE 9.—The Cibao topography is one of rolling hills—no karst. Aguada karst in background.

it then decreases seaward. The small degree of karstification in the northwestern part of the belt reflects a youthful stage of incipient karst development. The equal lack of karstification in the northeastern part of the belt reflects the opposite—a mature to old stage which marks the final dissolution phase.

Monroe (1966, 1968b) believes that the formation of the Puerto Rican karst is the result of limestone solution and reprecipitation, with the karst morphology depending on the lithology and structure of the limestones. He describes the surface of the limestone hills as a pitted hardened shell, a few meters thick at most, covering a soft interior. This feature can be seen in most roadcuts. The hard shell, as well as the asymmetry of the hills (mogotes), which show a flatter gradient on the eastern side, is explained in terms of the preferential soaking of the eastern side by rain, wind, driven from the east, and in terms of reprecipitation of calcium carbonate supersaturated overland flow near the foot of the hills. The flat areas of land between mogotes are, in Monroe's view, where the limestone is actively being dissolved at the contact beneath the cover of the blanket sands. Organic acids, which are associated with the dense vegetation growing on the limestones and washed down into the blanket sand-covered depressions, greatly increase the solubility of the limestones. The influence of the lithology and structure on the different landforms of the karst is related to the purity of the limestones and to their bedding thickness. Thus, areas in warm and humid climates underlain by massive pure limestone can develop into cockpit karst (Kegelkarst) marked by subconical hills separated by steep-walled valleys. Mogotes, typified by subconical hills rising out of a blanket-sand covered plain are found on the pure somewhat chalky Aymamón Limestone. Zanjones, or trenchlike elongated depressions somewhat parallel to each other, have developed where limestone is thin bedded and brittle. Caves and natural bridges have formed in areas of alternating beds of hard and soft limestone.

FIGURE 10.—Rolling topography of the Quebrada Arenas Limestone Member of the Cibao Formation.

In this report, the mogote karst is regarded as a phase of the karst development, being somewhat the equivalent of the monadnocks of the Piedmont region of the eastern continental United States, representing the last geomorphic expression prior to complete obliteration of land relief. From the classical geomorphic approach of stage development, the northwestern area of the north coast limestone represents the youthful stage: it is marked by a plateaulike surface slightly pitted with shallow closed depressions. The next or mature stage is represented by the rugged cockpit karst found throughout the Aguada Limestone and lower part of the Aymamón Limestone in the middle of the belt, and in patches on the Lares Limestone. The next phase, or old stage, would be the mogote karst. It, in turn, would further degrade to a fluvial drainage developed on blanket sands, evidence of which appears in the eastern part of the north coast belt. These stages, of course, allow for local features caused by lithologic and structural differences; however, in general, attributing morphology to the purity and thickness of limestone is not sufficient to explain the landform development other than in a restricted area.

The mogote karst may once have been a cockpit karst; the cockpit may develop into mogote karst in due time—just as the plateaulike northwestern part of the belt will mature into a cockpit area eventually. Figure 11 illustrates the relation between karst development and topographic altitude; this figure was constructed from the results of the analysis of percent karst development that were utilized in constructing figure 8. The horizontal axes in figure 11 represent karst development in percent, as previously defined, and topographic relief in meters. Frequency of occurrence, shown on the vertical axis, represents the number of 1-minute map rectangles at a given average altitude which exhibit a given percent of karst development. The maximum development of the karst—the cockpit karst—is in areas where the relief ranges from about 80 to 120 m. Beyond this range of relief the author interprets figure 11 to imply that the karst

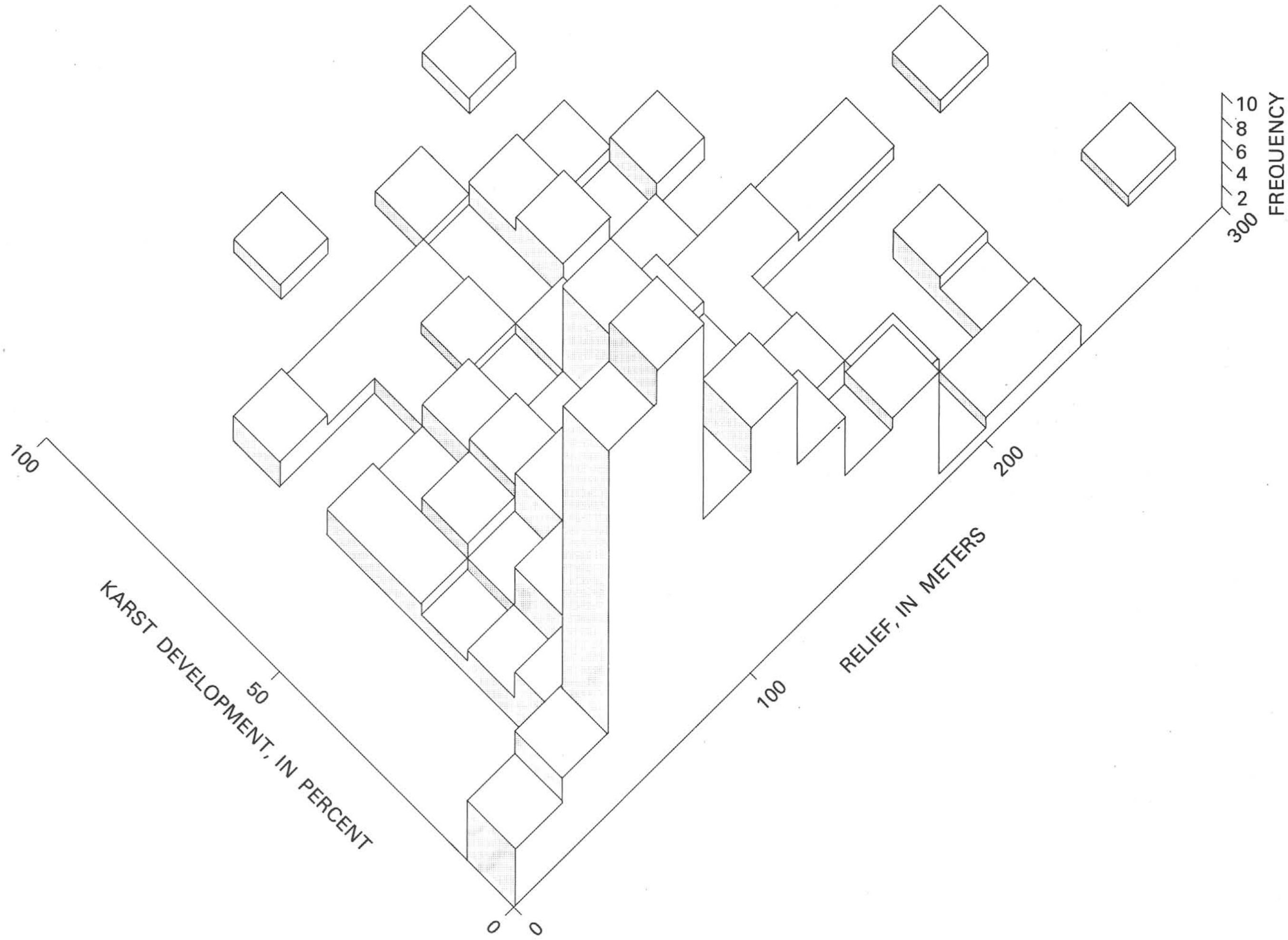

FIGURE 11.—Distribution surface of karst areas.

decreases by collapse of underground caves or surfaces erosion and that the stream courses begin to develop.

STREAM NETWORK

The limestone belt is traversed by six rivers whose headwaters are found in the volcanic terrane to the south. Figure 12 shows the stream network developed on the north coast limestone, the major springs, and the altitude contours of land surface. (The stream network is shown in more detail in pl. 1.) The contours represent the mean altitude above sea level of each 1-minute square of the limestone belt. The mean altitudes were computed by dividing each 1-minute square into 25 grid points, and averaging the altitude of these points as taken from a topographic map. The average direction (azimuth) of the topographic slope is about N. 5° E. compared with a geologic dip direction essentially due north. The major rivers generally cross the belt in a direction west of north (Williams, 1965, p. 160–182).

In the general area southeast of Lago de Guajataca (fig. 13) the alinement of the sinkholes area is peculiarly in a northwesterly direction. The portion of Río Guajataca shown in the southwestern corner of the map of figure 13 was probably formed by the collapse of a series of these northwesterly oriented sinkholes. There is an indication that this preferential alinement is related to the drainage patterns of the original fluvial system that formed at the time of emergence of the Puerto Rican platform from the sea.

Whatever major tributaries there are enter the rivers from the west within the limestone belt. The short segments of streams shown about the middle of figure 12 reflect the fluvial development formed on top of the Cibao Formation; and it should be noted that even these short segments tend to orient themselves so that they would, if

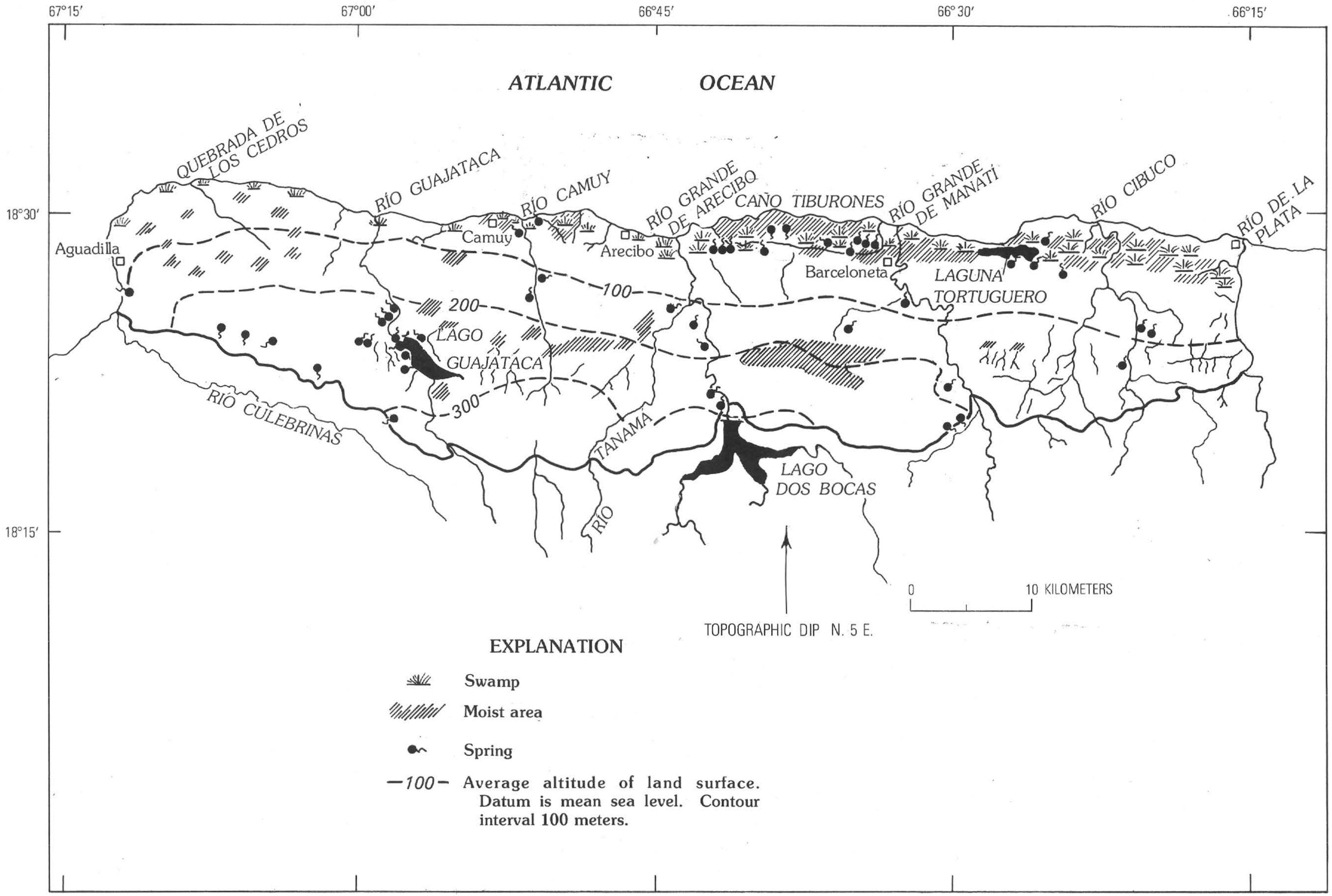

FIGURE 12.—Average altitude of land surface, stream network, and major springs of the limestone belt.

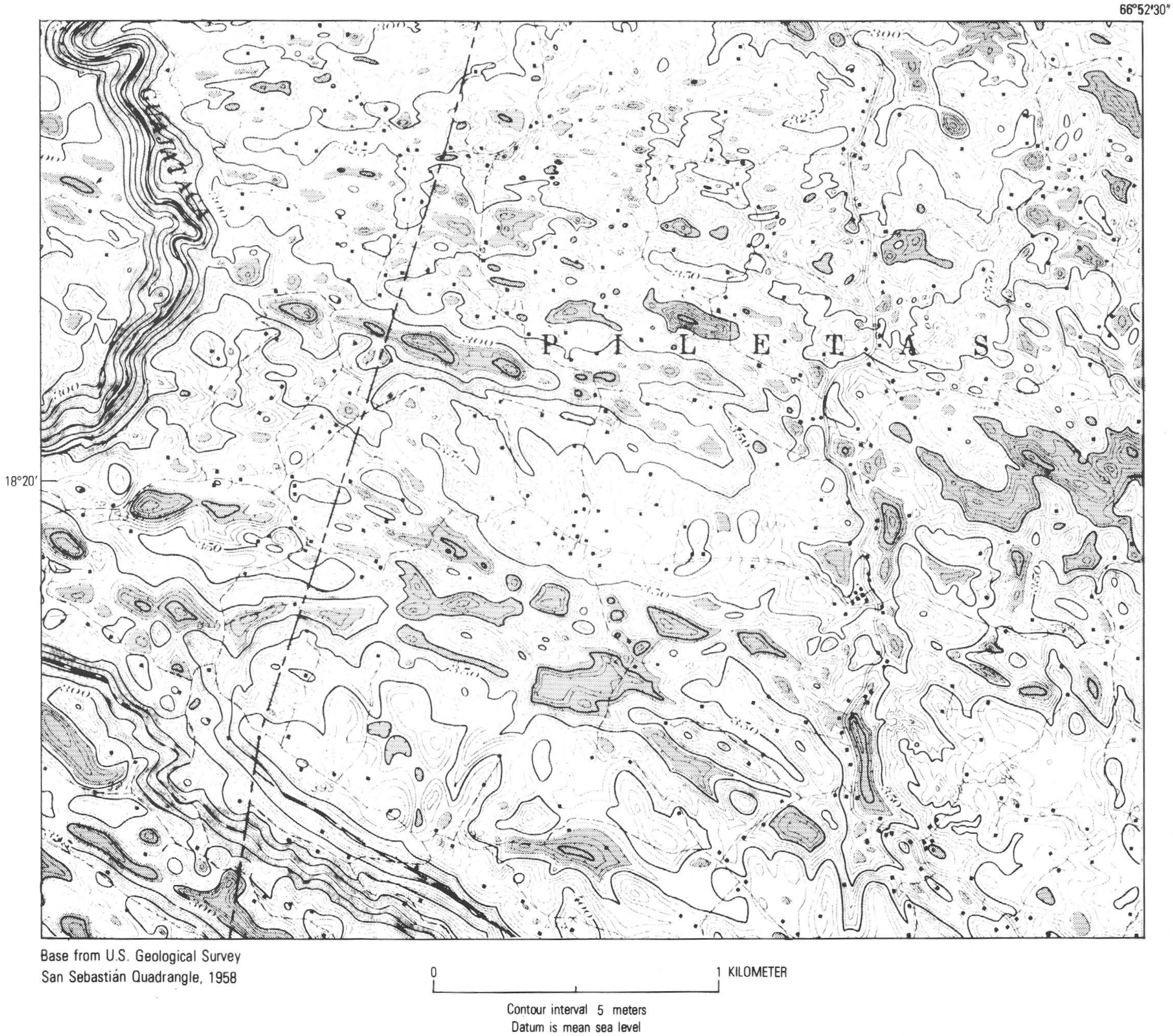

FIGURE 13.—Northwest-southeast alinement of the sinkholes in the Lares Limestone southeast of Lago de Guajataca.

linearly extended, enter the main rivers from the west. This preferential alinement could not develop on a lithologically uniform surface dipping gently northward. The main reason for the anomaly is to be found in the eastward tilt of the entire Puerto Rican platform. This tilt, which was argued for by Lobeck (1933) and Meyerhoff (1933) on the basis of the raised coastline found along the western margin of the north coast, is thought to have occurred sometime during the Pleistocene. Monroe

(1968a) found terraces at altitudes of 40 to 70 m on top of the raised limestone platform in the west, which he dates from the Pleistocene, though he favors eustatic rather than tectonic movements to explain the existence of the raised beach deposits.

Most of the rivers flow in normal valleys open to the sky, but both the Río Camuy and the Río Tanamá flow underground for some stretches. The Río Camuy disappears underground soon after entering the limestone and emerges at a straight-line distance of about 6 km downstream. The surface where the Río Camuy flows underground is marked by "lines of steep-walled collapsed sinks" (Monroe, 1968b). The Río Camuy flows through the lower part of a series of caves lying at different levels; they have been only partly explored (Gurnee, R. H., and others, 1966). The Río Tanamá flows underground at different points, for distances of less than a kilometer. Its course can readily be interpolated between its points of disappearances and reappearances. Clearly, at least parts of these river courses have formed through the collapse of caves or sinkholes.

Another river, the Río Guajataca, shows evidence of collapsed caves, the floor of its canyon being strewn in places with a chaotic rubble of collapsed blocks of limestone. In fact, at places the arch of former caves can be easily reconstructed (fig. 14). The Río Guajataca is probably an example of the next stage of development that follows that of the Río Tanamá; a canyon has been opened to the sky, but except for some isolated inland reaches and a short interval near the coast, there has been no development of a proper channel with river banks and a flood plain. The development of a proper channel, which is usually concurrent with the development of meandering, marks the approach to the equilibrium stage described by Mackin (1948). In the north coast belt, the equilibrium stage is achieved by the Río Grande de Manatí (fig. 15), Río Grande de Arecibo (fig. 16), and the Río Cibuco.

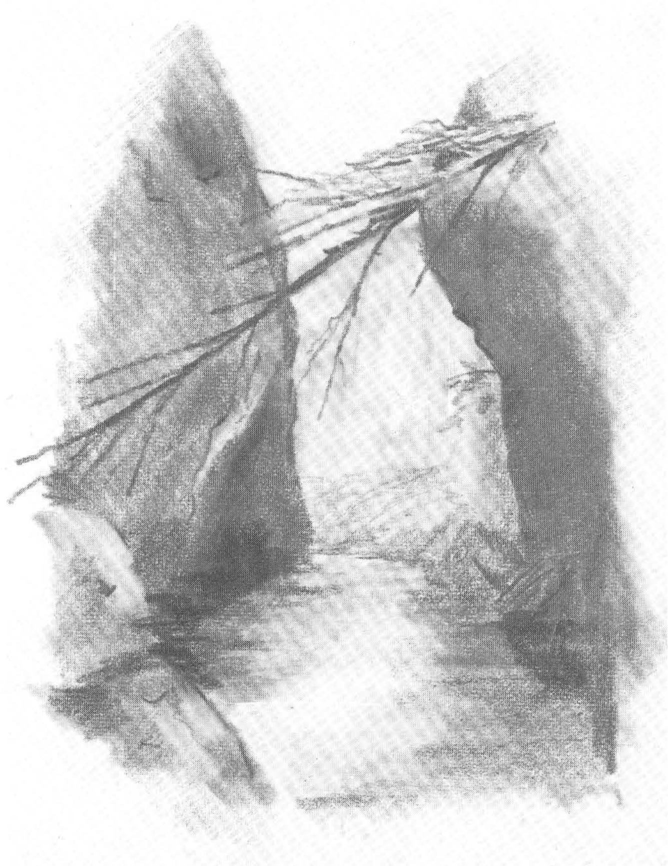

FIGURE 14.—Former cave of the Río Guajataca.

DRAINAGE AREAS

The computation of water balances of river basins required the quantitative assessment of rainfall, evaporation, and streamflow as well as the determination of storage changes; thus the area of the drainage basins were needed.

It became apparent early in the study that drainage divides in the karst areas could not be unequivocally determined from the available maps. Because the divides about many sinkholes occurred at the same altitude, it was not known whether a given sinkhole area was to be assigned to one river basin or to another. Two criteria were used to obtain at least a first estimate of interbasin boundaries and thus of drainage areas:

1. Any sinkhole was assumed to drain to the neighboring sinkhole of lowest altitude.
2. Where neighboring sinkholes lay at the same altitude the preferential path was chosen according to the general orientation of stream courses. An example of the application of these criteria is shown on a portion of a topographic map in figure 17.

A number of indeterminate drainage areas that did not seem to belong to any stream basin were found; their probable drainage pattern is discussed later with the streamflow data. The results of the water-balance computation were themselves used to evaluate the reliability of the computed drainage areas. An error made in the drainage area evaluation, therefore, would have affected the results of the water-balance computations.

FIGURE 15.—The Río Grande de Manatí exhibits a well developed flood plain.

OTHER LANDFORMS

The limestone terminates abruptly near the coast west of Arecibo (figs. 18 and 19) in sea cliffs, or is separated from the sea by a narrow strip of beach (Kaye, 1959). East of Arecibo large swampy areas have formed, the Caño Tiburones between the Río Grande de Manatí and the Río Grande de Arecibo, and Laguna Tortuguero between the Río Grande de Manatí and the Río Cibuco are prominent features of this swampy terrain, and are notable for the large amounts of nearly freshwater they discharge. The alinement of these areas of freshwater outflow was taken by Briggs (1961) as suggesting, though he qualified the evidence as circumstantial, the presence of a large strike fault (discussed in the chapter on structure). Stringfield (written commun., 1971) interpreted these swamps as drowned karst features that formed during a low stand of the Pleistocene sea. Other landforms found in a narrow belt north of the swampy areas, along the coast, and even drowned offshore, are sea cliffs and cemented sand dunes; these are described by Kaye (1959).

CLIMATE

The climate of northern Puerto Rico is humid tropical (Picó, 1950). As an aid to numerical comparison, climate can be conveniently represented as a function of rainfall and evaporation only; the latter integrating the effects of solar radiation, wind, and temperature. In terms of the climatic index of Thornthwaite (1931), northern Puerto Rico has an index of about 90 (Giusti and Lopez, 1967), which correlates with the meteorologically based description of humid, or, on the basis of vegetation pattern, with the forest province. Thus, the north coast belt is climatically consonant with the popular image of Puerto Rico.

RAINFALL, TEMPERATURE, AND WIND

The average annual rainfall on the north coast limestones is 1,800 mm (millimeters), and rainfall

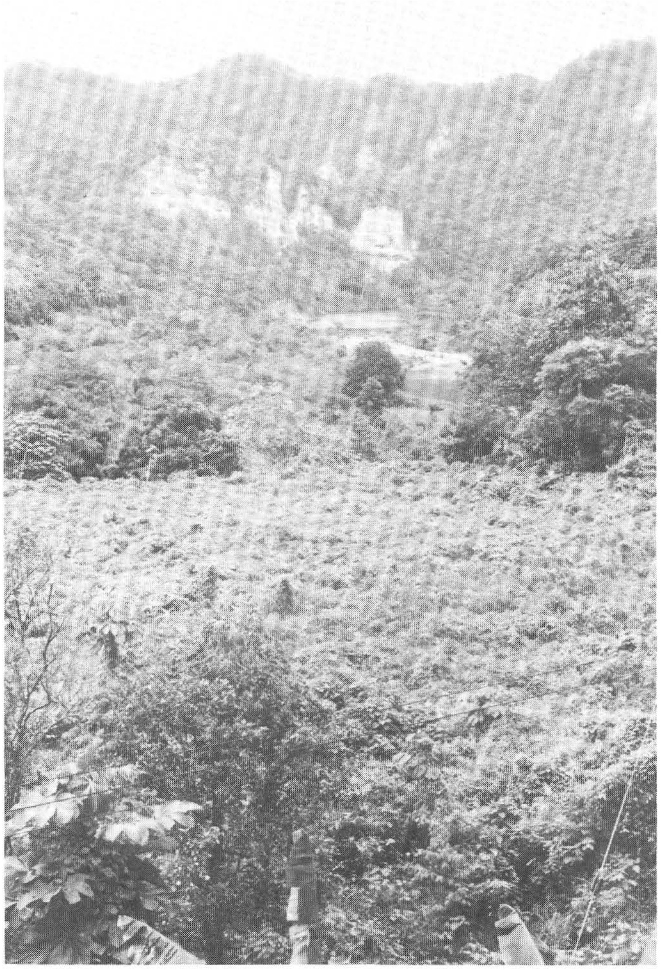

FIGURE 16.—The flood plain (foreground) of the Río Grande de Arecibo begins where the river emerges from the canyon.

ranges from 1,550 mm on the coast to 2,300 mm inland in the areas where the limestones are in contact with the mountains of the central core. To the extent that rainfall in Puerto Rico increases rapidly with altitude, the small range of rainfall found on the north coast belt reflects the slight differences of relief. The variability within the year follows an islandwide trend: a generally dry period that begins in December and usually ends in March or April, a spring rainfall period in April and May, an erratic, semidry period in June-July, and a wet season from August through November. Greatest monthly rainfall is in September. The hurricane season is from June through October and in any 1 year can produce a very wet June or July.

The average annual air temperature is 24° C on the north coast belt and varies but a few degrees from winter to summer.

Puerto Rico lies in the path of the easterly trade winds which are almost constantly blowing across the island. Data published by Briscoe (1966) indicate that the winds vary from month to month and that there is a yearly average ranging from 16 km/h (kilometers per hour) at Cabezas de San Juan on the east coast to 5 km/h at Gurabo in the interior. In general, there are more constant and stronger winds in the coastal areas than in the interior areas. Differential heating between the sea and land also produces an onshore breeze during the day and an offshore breeze at night.

EVAPOTRANSPIRATION

Evapotranspiration is a major factor in the water balance of the north coast limestone region. Unfortunately, field data on evapotranspiration are sparse; for this reason it is desirable to establish a relation between evapotranspiration and a more readily available hydrologic parameter. Because reasonably good rainfall records are available for the karst region, an analysis was made to relate evapotranspiration to precipitation. Before presenting the results of this analysis, certain theoretical concepts will be reviewed, with the aim of showing that a relationship between evapotranspiration and precipitation can be accepted with reasonable confidence.

Potential evapotranspiration represents the maximum possible rate of evapotranspiration from an area—that is, the rate which is observed under a full plant cover, when an unlimited supply of water is available for evapotranspiration. Actual evapotranspiration depends upon the available water supply, and is generally much less than potential evapotranspiration. Potential evapotranspiration is a function of such factors as solar radiation and the moisture content of the atmosphere. Actual evapotranspiration also depends upon these factors, but depends as well upon the available water and the plant cover. In the limiting case of a desert area, potential evapotranspiration is very high, whereas actual evapotranspiration is low because of the lack of available water. In more humid areas potential evapotranspiration is lower because of reduced solar radiation and increased humidity, while actual evapotranspiration is higher. In permanently wet areas, such as a rain forest, the theory of Bouchet (1963), verified by the work of Morton (1965) and Solomon (1967), predicts that potential evapotranspiration and actual evapotranspiration should approach the same value, equal to one-half the absorbed solar radiation as expressed in millimeters

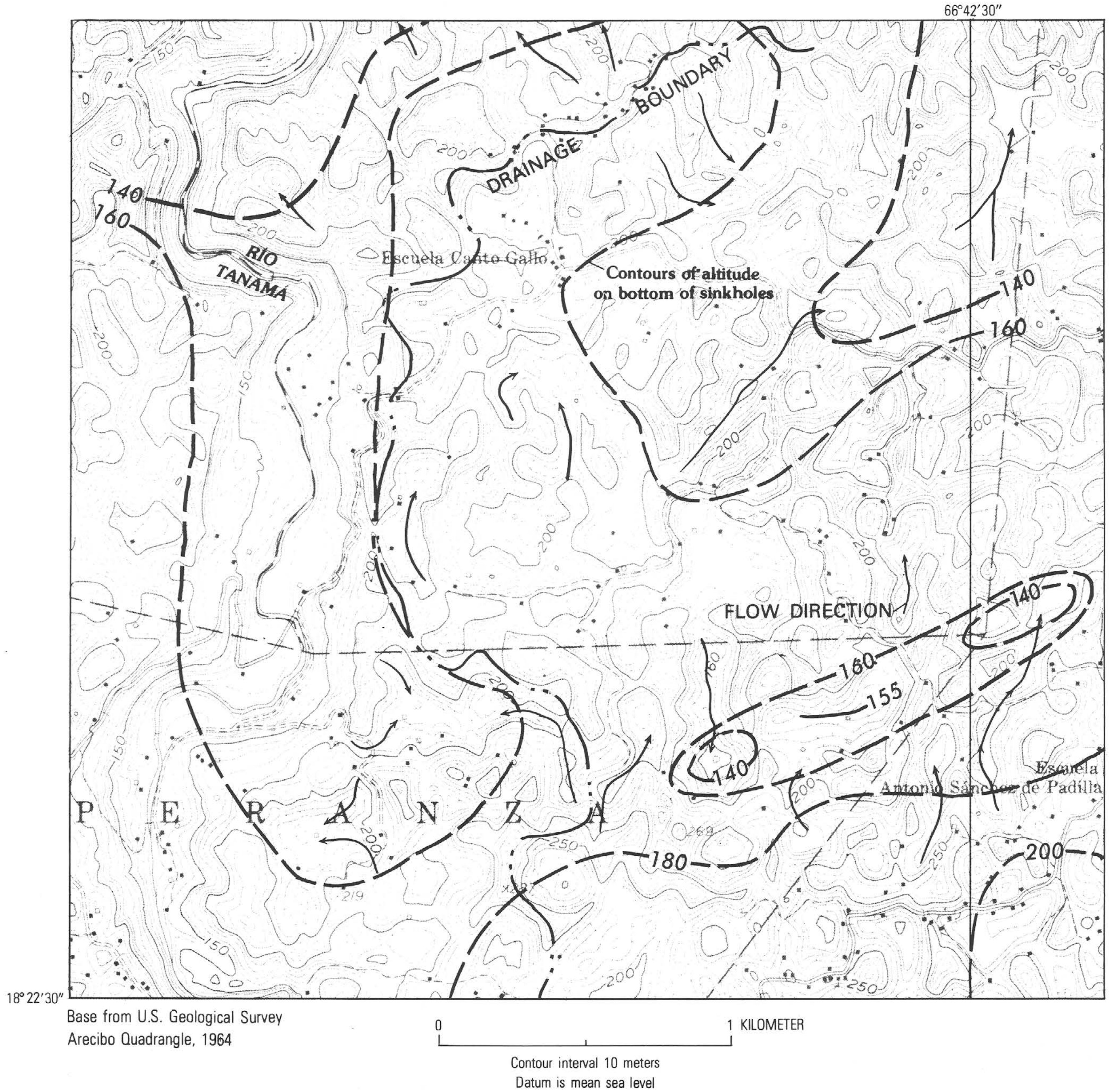

FIGURE 17.—Example of criteria used to delineate drainage boundaries in karst terrane. The dashed lines are contours of the altitude on the bottom of the sinkholes.

of evaporated water. Thus potential values should decrease with increasing precipitation, while actual values should increase with increasing precipitation, until the two become approximately equal for the limiting case of a very humid region.

As a first step in developing a relation between evapotranspiration and precipitation, an analysis was made of the relation between solar radiation and precipitation in the north coast area. The basic assumption was that a relation between evapotranspiration and precipitation would follow from an underlying relation between solar radiation and precipitation. This approach also provided a means of estimating solar radiation in areas (or over periods) for which direct data were lacking.

The theoretical annual extraterrestrial solar

FIGURE 18.—Coastline west of Arecibo. Raised shoreline in the distance.

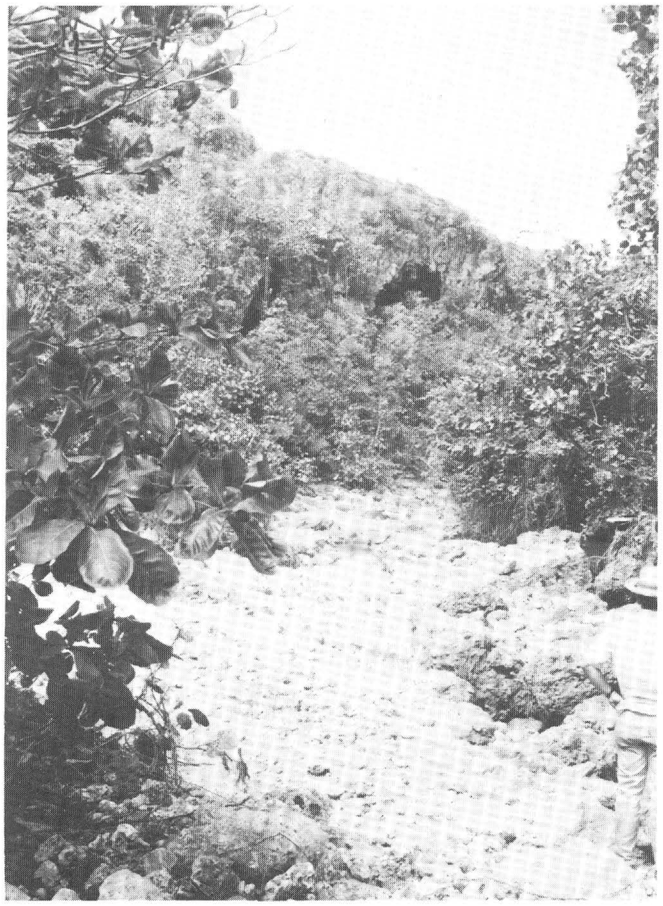

FIGURE 19.—Sea caves on Aymamón Limestone cliffs, west of Arecibo.

radiation—that is the radiation at the upper limit of the atmosphere—is equivalent to 5,000 mm of evaporated water per year, at the latitude of Puerto Rico (Smithsonian Meteorological Tables, 1966). This very high total is distributed monthly as shown in figure 20. Figure 21 shows a plot of the ratio Rg/Ra versus precipitation, where Rg is the observed annual incoming radiation, and Ra is the theoretical annual extraterrestrial radiation, 5,000 mm of water per year. The observed radiation values are based upon a few years of record (M. Capiel, oral commun., 1970) and averages (Briscoe, 1966) of total incoming solar radiation. For values of rainfall between 500 and 2,500 mm, the line whose equation is

$$\frac{Rg}{Ra} = (0.73 - 0.00009P) \qquad (1)$$

where

P = rainfall, in millimeters

provides a fair fit to the data. For an average Ra of 5,000 mm for the island

$$Rg = 3{,}650 - 0.45P. \qquad (2)$$

The equation of Glover and MacCullock, as given by Roche (1963), may be used to show the relation indicated in figure 21, and equation 2 gives results which fall within reasonable limits. Their equation is

$$\frac{Rg}{Ra} = 0.29 \cos\lambda + 0.52\frac{n}{N} \qquad (3)$$

where

Rg and Ra are as previously defined, and
λ = latitude in degrees,
n = number of observed hours of insolation, and
N = number of maximum possible hour of insolation.

To obtain an upper limit for Rg/Ra, the fraction n/N may be set equal to 1.0, approximating a condition of zero rainfall—that is, maximum insolation; to obtain a lower limit, n/N may be set equal to zero, corresponding to a condition of no days of sunshine. For the latitude of Puerto Rico, taking n/N as 1.0 gives a maximum value for Rg/Ra of

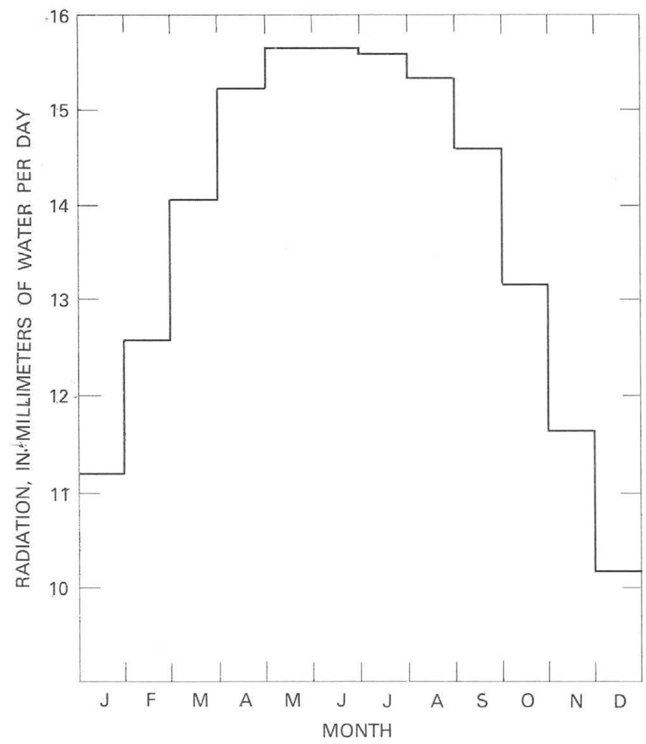

FIGURE 20.—Mid-monthly theoretical solar radiation in equivalent evaporated water for Puerto Rico.

about 0.8. This would presumably correspond to a condition of zero rainfall. The equation of Glover and MacCullock gives 0.28 as a minimum value of *Rg/Ra;* however, because of the very low probability of occurrence of a year with no days of sunshine, a value of 0.35 is probably a more realistic lower limit for *Rg/Ra,* corresponding to a year of very high precipitation. Examination of figure 21 shows that these limiting values bracket the field data very reasonably.

Bouchet (1963) gives the equation

$$Ep+ET=(1-a)Rg \qquad (4)$$

Where *Ep* represents potential evapotranspiration; *ET* is actual evapotranspiration; *Rg,* as before, is solar radiation (expressed as equivalent evaporated water) ; and *a* is the albedo of the region. The term $(1-a)Rg$ represents the absorbed solar radiation. Equation 4 is applicable provided the underlying assumption of the theory, that there is no net exchange of energy between the region and its surrounding areas, is satisfied. Where such border exchanges (termed "oasis effects" in the theory) do occur, deviations can be expected.

In terms of equation 4, the limiting conditions referred to previously may be expressed as follows:

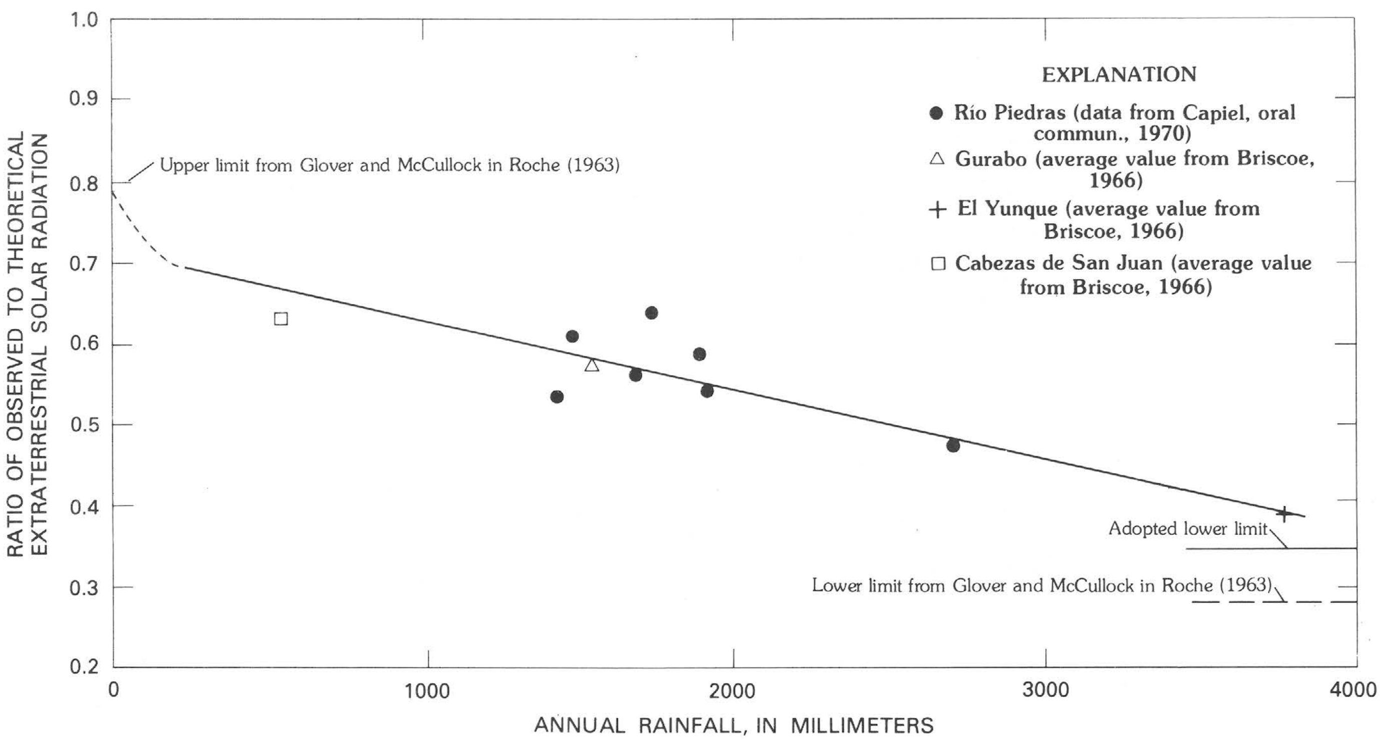

FIGURE 21.—Variation of fractional radiation (ratio of observed to theoretical solar radiation) with rainfall, annual values.

for rainless regions,

$$ET=0 \text{ and } Ep=(1-a)\ Rg \quad (5)$$

for permanently wet regions,

$$ET=Ep=0.5(1-a)Rg \quad (6)$$

Thus the ratio $Ep/((1-a)Rg)$ decreases from a maximum of 1.0 at no precipitation to a minimum of 0.5 at very high values of precipitation; while the ratio $ET/((1-a)Rg)$ increases from a minimum of zero at no precipitation to a maximum of 0.5 at very high values of precipitation.

Figure 22 shows a plot of the ratios $E/((1-a)Rg)$ and $ET/((1-a)Rg)$ versus precipitation, where E represents pan evaporation and ET represents regional evapotranspiration as determined by local water budget calculations. The values of Rg used in forming these ratios were taken from figure 21. Pan evaporation, E, may be taken here as an approximate measure of potential evapotranspiration, Ep. The estimates of actual evapotranspiration were made by considering closed basins in various parts of Puerto Rico for which net inflow and outflow of ground water could reasonably be considered zero, over periods for which the storage change was zero, and computing the difference between precipitation and stream discharge.

The relations shown in figure 22 conform closely to the behavior predicted by Bouchet's theory. Although there is scatter due to data errors and due to border ("oasis") effects near the coast, the limiting conditions established by the theory are clearly satisfied.

In figure 23, values of annual pan evaporation

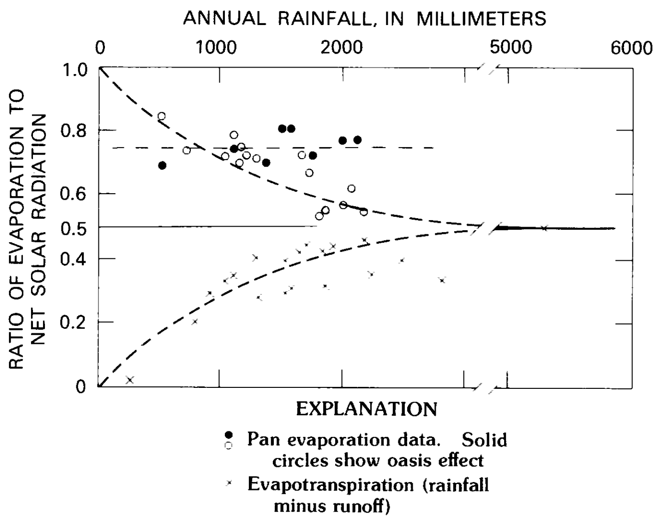

FIGURE 22.—Evaporation to net solar radiation ratio as a function of rainfall in Puerto Rico.

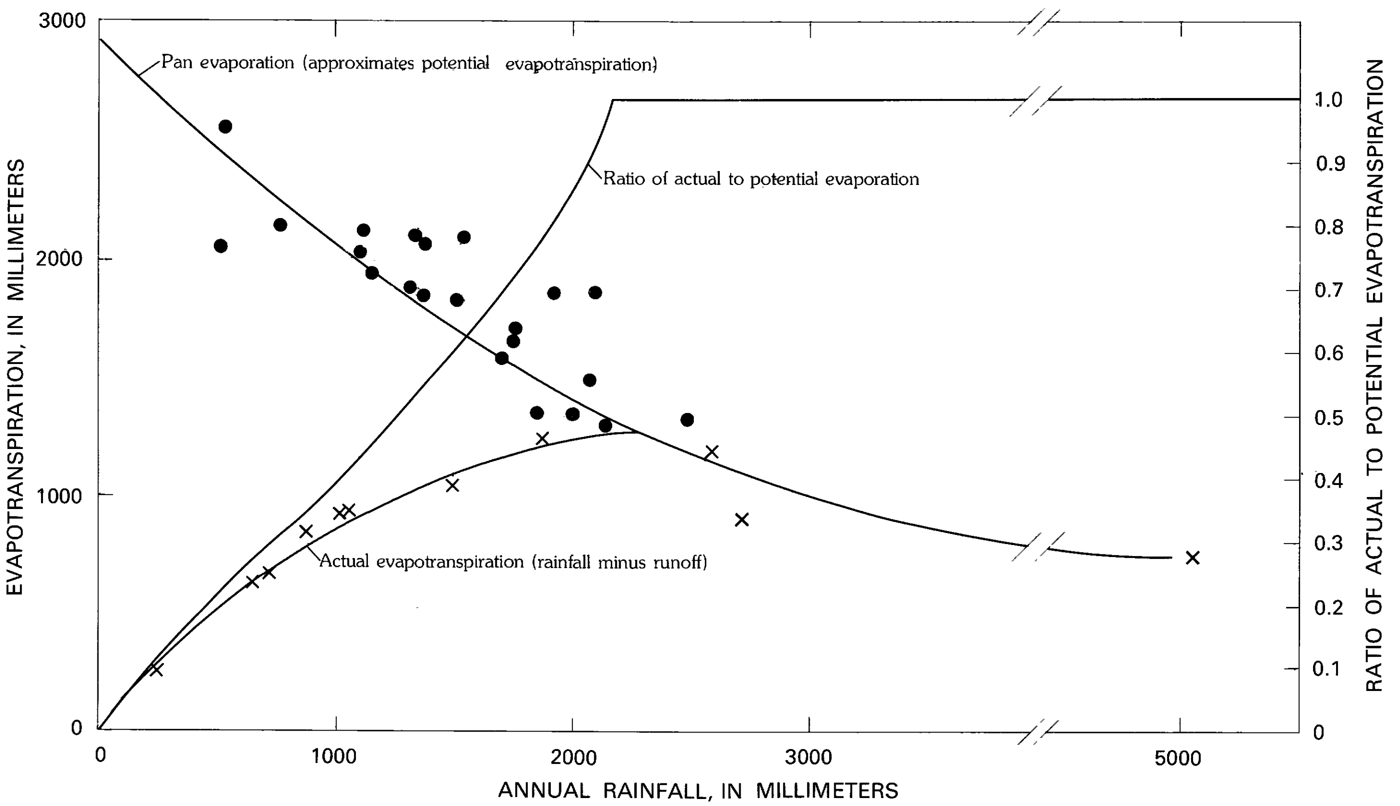

FIGURE 23.—Potential and actual evaporation and their ratio as a function of rainfall.

and evapotranspiration, and values of the ratio of evapotranspiration to pan evaporation, are plotted as functions of annual precipitation. From this graph, the average evapotranspiration from the north coast limestone area, corresponding to the average annual rainfall of 1,800 mm, appears to be about 1,150 mm. Taking pan evaporation as roughly equivalent to potential evapotranspiration, the corresponding average value of ET/Ep is about 0.76. However, it should be noted that this is an average value; the actual value of the ratio depends upon precipitation. The relationship shown in figure 23 was utilized in a water-budget analysis for the limestone area to compute actual evapotranspiration from pan evaporation and precipitation data; this is described in a later section of the report.

HYDROLOGY

The decision at the beginning of this investigation was that the most practical approach to the study of the area would be to obtain a water balance of the entire limestone belt. This goal required assessment of all inflows and outflows; therefore, 10 stream inflows from the volcanic terrane were gaged continuously where they entered the limestone belt, and 12 stream outflow points from the limestone were gaged as far downstream as possible. The difference between the discharge of the upstream and downstream sites constitutes the contribution to streamflow from the limestone area. Rainfall and pan evaporation (potential evaporation) were obtained from the available data published by the National Weather Service, supplemented by data from a few temporary sites to fill some gaps in the areal distribution of the existing meteorological network. Rainfall and pan evaporation data were collected at 25 and 5 sites respectively. About 40 wells were used to gather information on the water-table configuration.

GROUND WATER

WATER-TABLE LEVELS

A contour map of the water-table surface is shown on plate 1. River-bed altitudes were used as control points in constructing this map. In the pattern of ground-water flow suggested by these contours, recharge in the topographically high areas moves radially outward toward the streams and the coast. The streams, the swampy features along the coast, and to some extent the sea floor itself thus all function as drains for the groundwater system. Within the most seaward part of the Aymamón Limestone, the altitude of the water table is just above mean sea level, with an average slope of about 0.0007, reflecting the high permeability of the Aymamón in this area. Southward the gradient steepens to about 0.045 within a transition zone which varies locally, but that in general includes the less permeable lower part of the Aymamón and Aguada Limestone. The gradient flattens again to about 0.003 within the Cibao Formation and the Lares Limestone, possibly indicating higher permeability or a smaller component of lateral groundwater movement.

ARTESIAN ZONES

Until July 1968, the known aquifers in the area were under water-table conditions, although conditions of local confinement had apparently been encountered occasionally by well drillers. No large-yield flowing well had ever been drilled in the north coast limestone belt; however, no well deeper than about 250 m had ever been drilled in the area. In July 1968, a disposal well was drilled in the Cruce Dávila area of Barceloneta. To obtain permission to use the well for disposal of certain industrial effluents, the law required that the well reach salty water. Therefore, the well was drilled deeper than any other water well in Puerto Rico. At a depth of about 350 m below the surface the well penetrated a "crumbly limestone layer" from which water flowed at a rate of 160 L/s (liters per second) with about 7 kg/cm^2 (kilograms per square centimeter)/ of shut in pressure at the land surface. The water was fresh.

The artesian zone occurs within the Montebello Limestone Member of the Cibao Formation which, in the outcrop area, is a very pure chalky limestone. The driller's report indicates that a massive limestone layer was penetrated above the crumbly limestone of the artesian aquifer, while W. H. Monroe (written commun., 1970) reports several meters of clay above the artesian zone. Both types of material undoubtedly contribute to the confinement of the Montebello artesian zone.

A second artesian zone was found at a depth of about 500 m, in the Lares Limestone. Since 1968 several more deep wells have been drilled in the same vicinity; all have penetrated the upper artesian zone and some the lower zone. A first approximation to an average potentiometric surface for the artesian zones is shown in cross section $C-C'$ of plate 2. This surface was constructed by linear interpolation between an average water-table altitude in the

Cibao-Lares outcrop area, and an average static head in the artesian wells at Cruce Dávila.

Drilling in the Tortuguero area in 1972 confirmed the existence of a very limited artesian zone in the Cibao in that area, together with a thick and well-defined artesian zone in the Lares. However, only in the east-central part of the limestone belt, between Río Grande de Arecibo and Río Cibuco, has it been proved that ground water flows under water-table conditions within the Aymamón and possibly the Aguada Limestones, and under artesian head within the Montebello Member of the Cibao Formation and the Lares Limestone. Elsewhere there is only indirect evidence to indicate probable paths of flow.

PERMEABILITY DISTRIBUTION AND GROUND-WATER FLOW

To compute the ground-water flow requires a knowledge of the permeability of the aquifer, as well as information on the head gradient and the cross-sectional area of the flow. These factors are utilized in Darcy's Law to compute the rate of ground-water flow, under the assumption that the flow approximates uniform movement through a porous medium when considered on a regional scale. Because of the possibility that in limestone the flow may be concentrated locally in "pipes" or along bedding planes or through fractures, Darcy's Law may not be applicable in a local sense. However, at the scale of regional flow it is assumed that the networks of solution pipes, fractures, and bedding planes are interconnected and spaced so as to approximate flow through a porous medium. The degree to which results from the application of Darcy's Law agree with the water-budget evaluation will give an indication of the reasonableness of these assumptions.

Estimates of permeability for the water-producing intervals of the rocks were obtained using specific capacity data from all wells in the north-coast limestone area for which information on lithology and well construction was available. The method of estimation was based on Thiem's equation for steady-state radial flow to a pumping well, and thus again involved the assumption that Darcy's Law was applicable in a general sense over the area of influence of the well. The equation used was

$$K = 37 \frac{Q}{SM} \log \frac{re}{rw} \qquad (7)$$

where

K = permeability, in centimeters per second;
Q = well discharge, in cubic meters per second;
S = drawdown, in meters;
M = screened or open intervals of the well, in meters;
re = the radius of a plan view of the cone of depression, in meters, taken arbitrarily as 150 meters in all cases; and
rw = radius of casing, in meters.

The error involved in using an assumed radius of influence is probably small. Because the term re/rw appears in the logarithm, an error in K of only 100 percent is introduced when re is in error by 1,000 percent.

The permeability values computed in this way ranged from less than 10^{-4} cm/s (centimeter per second) to about 1 cm/s. The estimated average permeability south of Caño Tiburones is shown in figure 24. An estimate of the ground-water flow through the area south of Caño Tiburones can be made substituting the values for permeabilities from figure 24 and the gradients from plate 2 in the equation for Darcy's Law. For 1-kilometer width of aquifer:

$$Q = 10\, K\, I\, t \qquad (8)$$

where

Q = discharge, in cubic meters per second;
K = permeability, in centimeters per second;
I = head gradient, dimensionless; and
t = thickness of aquifer, in meters.

For the Aymamón and Aguada Limestones, the head gradient was taken as the water-table gradient; for the Cibao and Lares formations, the gradient was taken as the difference between the average water-table altitude in the Cibao-Lares outcrop area and the average artesian level in the wells at Cruce Dávila, divided by the distance of flow. The discharges for the various aquifers are as follows:

Aymamón
$Q = 10 \times 0.2 \times 0.00095 \times 60 = 0.11$ m^3/s

Aguada
$Q = 10 \times 0.02 \times 0.00095 \times 100 = 0.02$ m^3/s

Cibao (Montebello Limestone Member)
$Q = 10 \times 0.005 \times 0.0021 \times 180 = 0.02$ m^3/s

Lares
$Q = 10 \times 0.0002 \times 0.0021 \times 75 = 0.0003$ m^3/s

The flow through the entire limestone section south of Caño Tiburones, calculated using a width of 15 km (derived from the flow pattern shown on plate 1), amounts to about 2.3 m^3/s or 0.15 m^3/s per kilometer width.

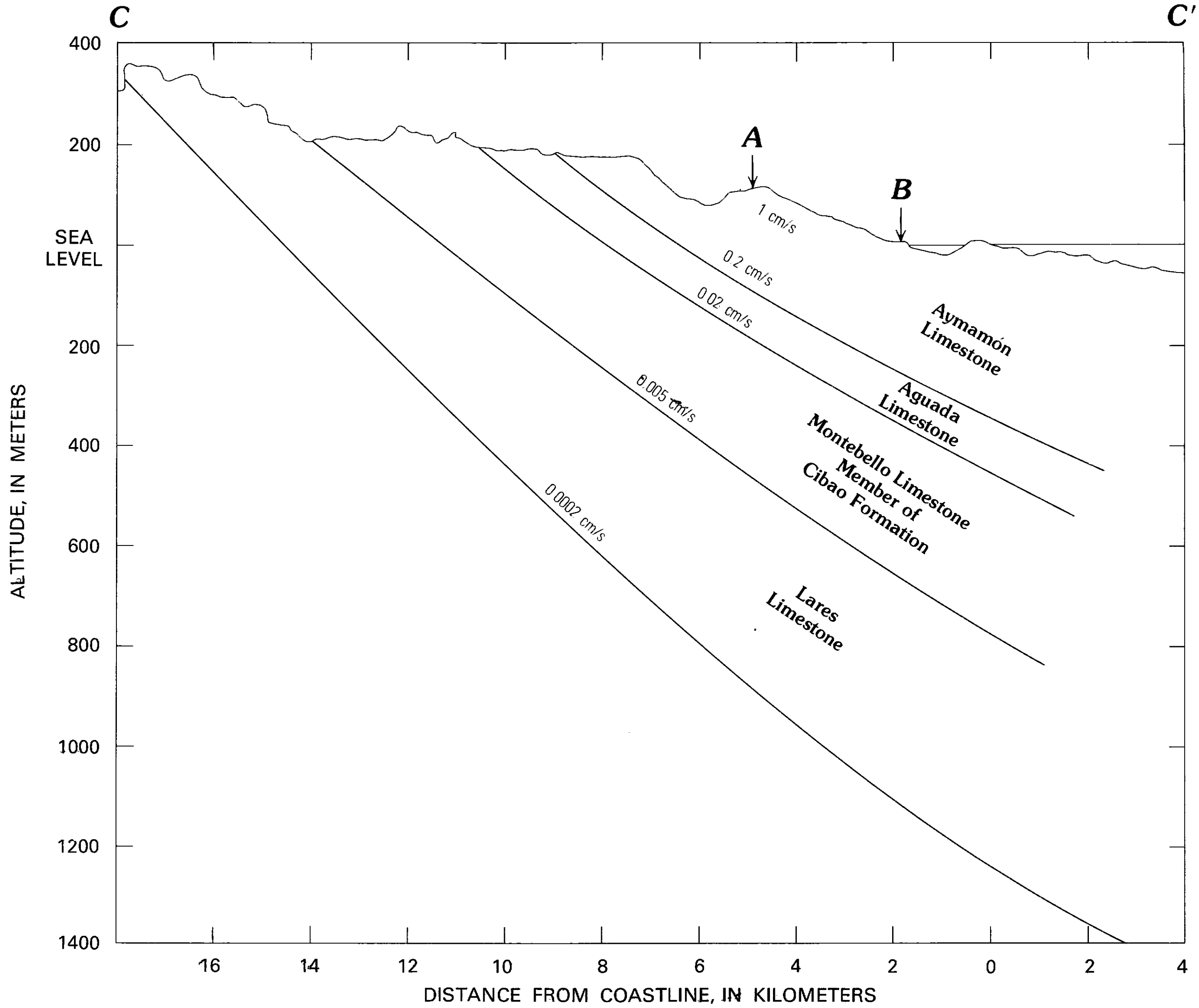

FIGURE 24.—Average permeability distribution within cross section *C–C'* through the Caño Tiburones area between points A and B. See plate 1 for location of cross section.

Similar calculations carried out for various sections shown on plate 2 are summarized in table 1. The results for the sections through the Río Cibuco basin, Laguna Tortuguero, Caño Tiburones, and the Río Camuy basin are more reliable than the results for the sections through the Río Guajataca basin and through the westernmost part of the belt, which were based on data projected from sections to the east. These results will be compared later in this report with the budget results computed from streamflow and meteorological data.

The data in figure 24 clearly show a permeability decrease from a high in the Aymamón to a low in the Lares. A plot showing all the computed permeabilities as a function of stratigraphic depth, measured from the projected top of the Aymamón Limestone, is shown in figure 25. The plot is semilogarithmic, and the average straight line indicates an exponential decrease in permeability with stratigraphic depth. However, this relationship refers only to the permeability of the aquifer intervals and should not be inferred to mean a continuous change of permeability with depth. Low permeability layers —that is, aquitards (for which no permeability calculations were made)—are found intermixed with the more permeable zones. The permeability of the massive limestone found on top of the artesian aquifers south of Caño Tiburones is orders of magnitude lower than that of either the overlying or the underlying layers.

TABLE 1.—*Ground-water flow of the north coast limestones*
[Sections are shown on plate 2]

Formation	Thickness (meters)	Slope	Permeability (cm/s)	Discharge (m^3/s per km width)
		Vega Alta-La Plata		
Aymamón Limestone	60	0.00076	0.1	0.046
Aguada Limestone	75	.00076 ?	.02	.011
Cibao Limestone	150	.0028 ?	.002	.008
Lares Limestone	130	.0028 ?	.0005	.002
Total	---	------	-----	.067 = .80 for 12 km
		Manatí-Tortuguero		
Aymamón Limestone	90	0.00057	0.1	0.0510
Aguada Limestone	60	.00057 ?	.005	.0020
Cibao Limestone	170	.0028	.0005	.0024
Lares Limestone	110	.0028 ?	.0002	.0006
Total	---	------	-----	.0560= .67 per 12 km
		Arecibo-Barceloneta		
Aymamón Limestone	60	0.00095	0.2	0.1140
Aguada Limestone	100	.00095 ?	.02	.0190
Cibao Formation	180	.0021	.005	.0190
Lares Limestone	75	.0021	.0002	.0003
Total	---	------	-----	.1523=2.28 for 15 km
		Camuy-Arecibo		
Aymamón Limestone	60	0.001	0.05	0.0300
Aguada Limestone	90	.001	.002	.0018
Cibao Limestone	170	.003 ?	.001	.0051
Lares Limestone	300	.003 ?	.0002	.0018
Total	---	------	-----	.0387= .43 for 11 km
		Guajataca-Camuy		
Aymamón Limestone	60	0.001 ?	0.02	0.0120
Aguada Limestone	90	.001 ?	.002	.0018
Cibao Limestone	200	.003 ?	.0005 ?	.0030
Lares Limestone	300	.003 ?	.0002 ?	.0018
Total	---	------	-----	.0186= .20 for 11 km
		Aguadilla-Guajataca		
Aymamón Limestone	60	0.001 ?	.02 ?	.0120
Aguada Limestone	90	.001 ?	.002 ?	.0018
Cibao Limestone	200	.001 ?	.0005 ?	.0010
Total	---	------	-----	.0148= .25 for 17 km

NOTE: Total for entire belt = 4.6 m^3/s.

GROUND-WATER FLOW PATTERNS

The caves found in the karst of the north coast belt are almost invariably tunnellike and develop from limestone solution along bedding planes. As a result, the regional ground-water flow lines tend to follow the bedding of the limestone layers down dip, presumably along preferential paths of higher permeability.

ARTESIAN FLOW PATTERNS

In the section through the Caño Tiburones area in figure 26, three possible patterns of ground-water outflow from the artesian zones are illustrated. The simplest pattern is direct discharge to sea in a submarine outflow area; it is illustrated by the arrows in the lower right corner of figure 26. In such submarine outflow, the ground water must discharge against the static head exerted by the column of seawater above the outflow area. This head can be measured in terms of an equivalent freshwater potentiometric head, defined as the height above sea level to which freshwater would rise in a piezometer inserted to the seabed. This equivalent freshwater head increases seaward as the depth of saltwater increases. The solid line above the sea surface in figure 26 shows the trend of the equivalent freshwater head.

The potentiometric head of the artesian zones beneath the sea can presumably be found by extending the artesian-head gradients measured on land. Extensions of the potentiometric head of the artesian aquifers seaward in this manner involves the assumptions that there are no changes in permeability within the artesian zones and that there is no gradual loss of flow from these zones by upward leakage. If these assumptions are satisfied, the

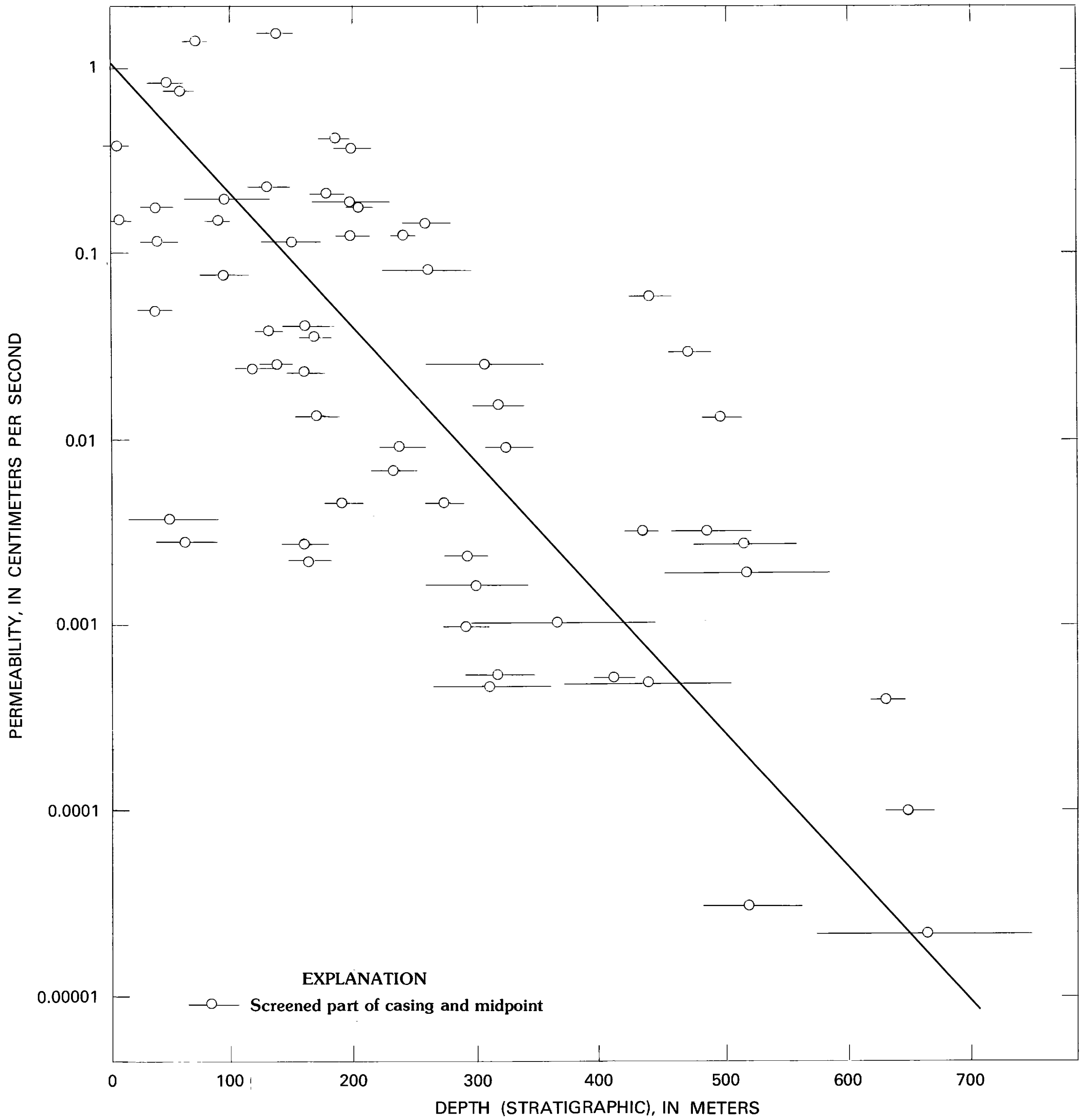

FIGURE 25.—Variability of permeability with stratigraphic depth from projected top of Aymamón Limestone.

upper dashed line in figure 26 is obtained as an average potentiometric surface for the Cibao and Lares systems. Discharge at a submarine area requires that the artesian head in the aquifer balance the equivalent freshwater head of the column of sea water above the discharge area. In figure 26, this condition is indicated by the intersection of the dashed line representing artesian head with the solid line representing equivalent freshwater head at the sea floor. This intersection occurs approximately 30 kilometers offshore; this is in reasonable agreement with locations of the submarine outcrops of the artesian zones, as obtained by extrapolation of the dip seaward. However, the extrap-

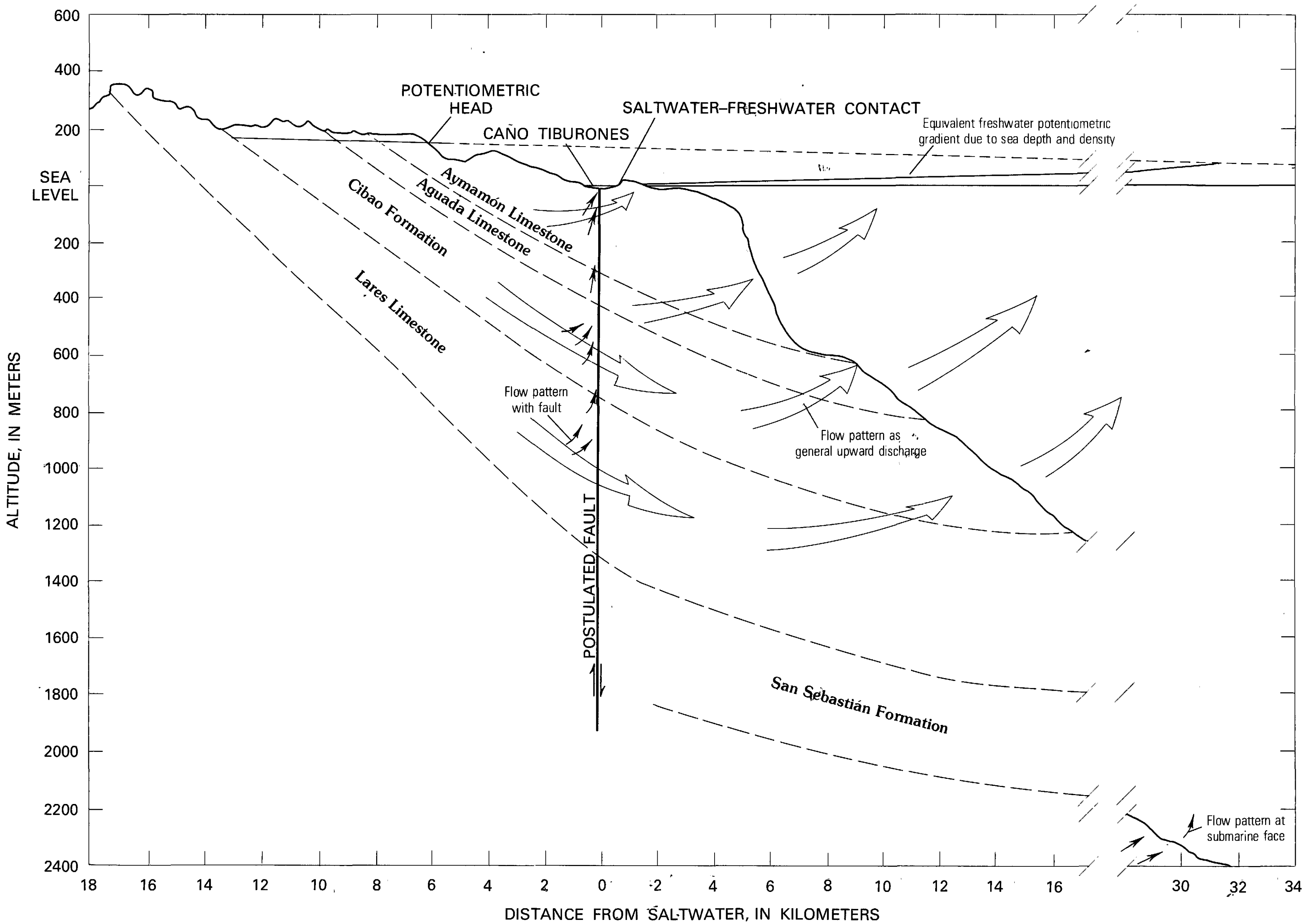

Figure 26.—Possible patterns of ground-water flow in Caño Tiburones area.

olation of head gradients and geologic dips for tens of kilometers is questionable, and this agreement may be no more than fortuitous.

A second possible pattern of ground-water discharge is shown by the large arrows in figure 26. If the permeability of the artesian zones decreases seaward, the head gradient in the aquifer cannot be linear, and the above extrapolation of heads would not be valid. Rather, the loss in head per kilometer would increase seaward, and the artesian head would be dissipated much closer to shore than 30 km. If a permeability decrease were gradual with distance and with the stratigraphic depth, the result would probably be a widespread upward discharge of ground water through the confining beds (large arrows of figure 26). Some of this upward seepage would probably escape through the sea floor and some through discharge areas on land.

A third possible pattern of discharge is related to the faulting postulated by Briggs (1961) in the Caño Tiburones area. Such faulting would presumably have thrown rock of low permeability against the artesian zones, and the barrier so created would block or impede flow seaward and force discharge upward. It is possible that fracturing associated with the postulated faulting could have produced a zone of high vertical permeability along the fault trace, creating conditions favorable to vertical outflow. The pattern of ground-water flow that might result from these conditions is shown by the small solid arrows in figure 26.

WATER-TABLE FLOW PATTERNS

Throughout the limestone area, but particularly east of Arecibo, ground water under water-table conditions discharges through springs and by areal seepage, either directly to sea or to the swampy areas along the coast. These swampy areas discharge, in turn, by evapotranspiration or by surface drainage to the sea.

A two-dimensional steady-state electric analog analysis of conditions south of Laguna Tortuguero was made by G. D. Bennett (Bennett and Giusti, 1972). The results of this analysis are shown in figure 27. The model, made of conducting paper of fixed resistance, was designed to simulate the water-table aquifer with a vertical to horizontal ratio of permeability of 1 to 10. The results of measuring the electric current at the boundaries, equivalent to measuring the ground-water flow, indicated that 75 percent of the outflow takes place inland from the coast and is disposed of through Laguna Tortuguero's direct outflow to sea, and by evapotranspiration from swampy areas, while 25 percent of the outflow takes place along the sea bottom in a zone a few hundred meters wide. Conditions in the Río Cibuco basin can be expected to be very similar to those in the Tortuguero area. Original conditions in the Caño Tiburones area were probably also similar. At the present time, however, agricultural drainage within the Caño Tiburones has lowered the water table several feet, so that all ground-water flow toward the coast enters the Caño Tiburones itself and discharges either by evapotranspiration or into drains, from which it is pumped to the sea. The water table in the northern part of the Caño Tiburones has in fact been lowered below sea level, inducing a substantial inflow of sea water, which makes up roughly one-third of the total pumpage from the drain system of the Caño.

West of Arecibo the conditions of ground-water outflow in the water-table zone are more speculative. From water-budget data to be presented later, it appears that the Río Tanamá, Camuy, and Guajataca act as highly efficient ground-water drains, and therefore only a small part of the regional flow from the areas between these rivers can be expected to discharge to coastal swampy areas or through the sea bottom.

The coastline west of Arecibo is formed by cliffs that rise several meters above the sea. No springs were noticed issuing from these cliffs. A few ponds and swampy areas occur at the foot of the sea cliffs, but these are the only evidence of ground-water outflow inland from the coast. No large freshwater springs are known to occur at sea with the exception of one unverified report about such an offshore spring near the town of Camuy. The evidence points to ground-water outflow mainly as the base flow of streams.

The pattern of ground-water outflow in the westernmost part of the limestone belt, between Río Guajataca and the west coast, remains unknown. In the southernmost part of this region, the outcrop area of the Lares is drained southward by streams tributary to Río Culebrinas (fig. 12). The Cibao Formation in this area is a nearly impermeable clayey marl.

In the northern part of this area west of the Guajataca, the karst is well developed in the Augada and lower part of the Aymamón. The younger Camuy Formation crops out on a flat surface of youthful stage karst. The estimate of ground-water outflow to the north, given in table 1, is much larger than the estimated maximum evapotranspiration outflow from swampy areas at the foot of the sea

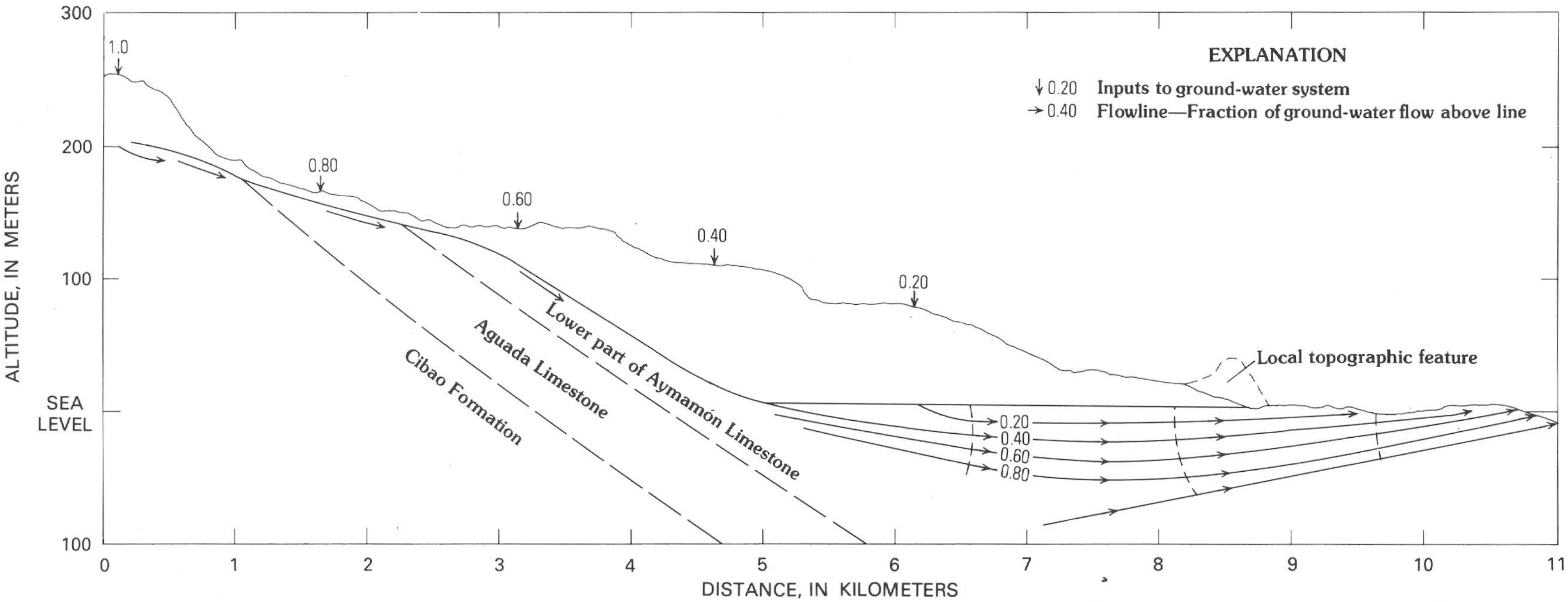

FIGURE 27.—Ground-water flow pattern in the Tortuguero area (Bennett and Giusti, 1972).

cliffs. Quebrada de los Cedros, the only stream in the area, is normally dry. Thus the most reasonable explanation at this time is that the ground-water outflow from the northwestern corner of the limestone belt is mainly through the sea bottom.

SPRINGS

There are thousands of springs within the limestone area. Those springs of large yield which were found in the field are located on the map of figure 12. The springs discharging near the coast rise through the blanket sands or swamp deposits, and give rise to Caño Tiburones (figs. 28 and 29) and to Laguna Tortuguero. Springs contributing water to rivers issue from cliffs (figs. 30 and 31) or emerge through the alluvium. A few springs (fig. 32) flow only after heavy rains; during droughts they stand as nearly circular pools of water marking the surface of the water table.

In regions where horizontal strata are cut by a river, one would normally expect to find an equal

FIGURE 29.—Large spring at the south end of Caño Tiburones.

FIGURE 28.—Small spring (cancora) in the Caño Tiburones area. Hundreds of such springs flow upward through the muck of this former lagoon.

FIGURE 30.—Salto Collazo Spring, from the Lares Limestone, discharges southward to the Río Culebrinas drainage system.

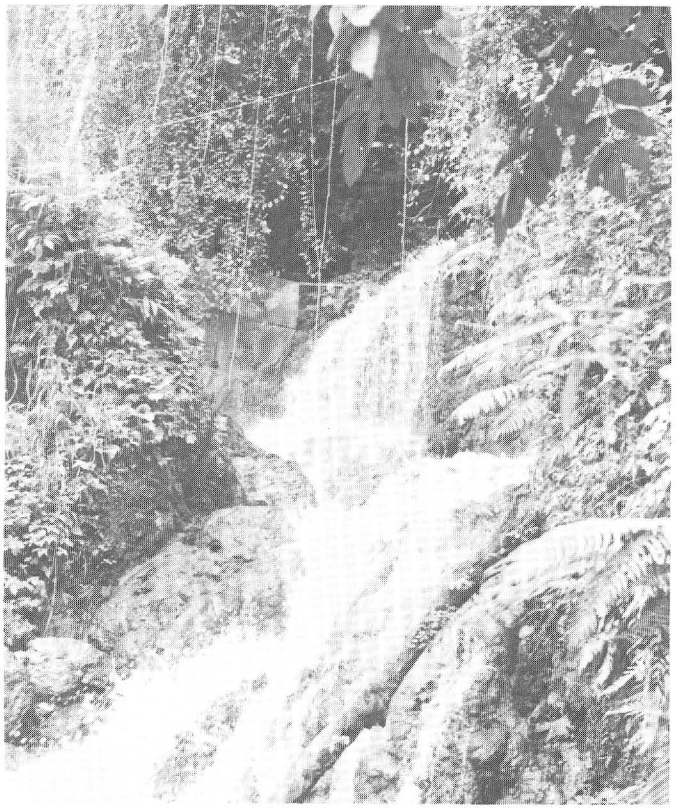

FIGURE 31.—Spring El Chorro to Río Grande de Arecibo—note travertine deposits in lower right.

FIGURE 32.—Spring in flood plain of Río Grande de Arecibo. This spring flows only after heavy rains.

number of springs on both sides of the river valley. Instead, springs along the rivers in the north coast limestone occur mainly on the west sides of the river valleys. Their position suggests that the eastward tilt of the Puerto Rican platform has affected the pattern of drainage of ground water.

STREAMFLOW AND WATER BUDGET

To test whether the results of water-budget calculations would yield important clues to the ground-water movement in the north coast limestones, data were collected for a period of approximately a year and a half on streamflow, rainfall, and pan evaporation in the limestone drainage basins. For those streams draining both volcanic and limestone terranes, the streamflow was recorded both where the streams entered the limestone belt and at their mouths; by difference, therefore, the contribution from the limestone part of the basin could be assessed. The data shown in table 2 cover selected drainage basins for 1 year of record—the period between November 1969 and October 1970. This choice of period reflects the most reliable data; the streamflow at the beginning and at the end of this period was nearly equal.

In table 2, the drainage basins are grouped geologically into those draining volcanic terrane and those draining limestone terrane. Measurement sites are indicated by number and by the name of the gaged stream, and are located on the map of plate 1. The numbers in column 1 are the rainfall in millimeters over the basin, as obtained from Thiessen averaging. Column 2 lists the evapotranspiration, computed by multiplying a Thiessen averaged pan evaporation (shown in column 6) by the ratio of evapotranspiration to pan evaporation; this ratio was taken from figure 23, as a function of precipitation. More properly, the ratio between evapotranspiration and pan evaporation should have been treated as a constant for the permanently moist parts of the basins, such as flood plain, swamp, or lake areas, and as a function of precipitation, according to Bouchet's theory, elsewhere in the basin. However, the quantity and quality of the available data did not appear to warrant this refinement, particularly as the period of record was about 20 percent wetter than normal (2,200 versus 1,800 mm).

The stream discharge per unit drainage area is listed in column 3. For those streams that drain volcanic terrane there is no reason to assume that the topographically derived drainage areas (column 5) may be in error; therefore, anomalies in the figures for streamflow per unit area cannot be ascribed to errors in drainage area. Not so, however, for the streamflow per unit area from limestone basins; for those streams there is an inherent difficulty in

TABLE 2.—*Water-budget results of the north coast limestone belt for the period November 1969–October 1970*

	Streamflow site	(1) Rainfall P, mm	(2) ET, mm	(3) Discharge Q, mm	(4) ±ΔS, mm	(5) Drainage area, km²	(6) Pan evaporation, mm
	Basins in volcanic terrane						
1	Upper Camuy	2,210	1,240	960	0	19.7	1,370
2	Criminales	2,210	1,240	1,120	−140	11.7	1,370
3	Arecibo below Lago	2,360	1,200	1,090	+70	438	1,320
4	Upper Tanamá	2,230	1,240	920	+70	47.8	1,370
5	Upper Manatí	2,540	1,140	1,270	+130	330	1,320
6	Upper Cibuco	2,360	1,200	1,040	+120	39.0	1,370
7	Mavilla	2,440	1,170	1,730	−460	24.6	1,370
8	Unibón	2,230	1,240	1,200	−210	13.7	1,370
9	Cialitos	2,310	1,220	960	+130	44.0	1,370
10	Upper Guajataca	2,210	1,240	860	+110	8.3	1,400
	Basins in limestone terrane [1]						
11	Guajataca to Lago	2,230	1,240	760	+230	79.0	1,800
12	Guajataca to mouth	2,030	1,220	560	+250	76.6	1,650
13	Lower Camuy	2,110	1,240	840	+30	170	1,520
14	Lower Tanamá	2,080	1,240	560	+280	103	1,500
15	Lower Arecibo	1,860	1,200	15	+650	76	1,570
16	Lower Manatí	1,860	1,200	860	−200	174	1,320
17	Lower Cibuco	2,030	1,220	890	−80	170	1,500
18	Lajas	2,080	1,220	1,090	−230	21.8	1,370
19	Quebrada de los Cedros	1,730	1,170	25	+530	37.8	1,800
20	South Canals	1,320	1,040	51	+220	53.4	1,800
21	Caño Tiburones	1,320	1,040	2,110	−1,830	46.3	1,800
22	Laguna Tortuguero	1,730	1,170	510	+50	43.5	1,570

[1] For basins that begin in volcanic terrane, discharge is the difference between total downstream flow minus upstream flow. Other data refer to limestone portion of basin only. Location of sites, including those in volcanic terrane, is shown on plate 1.

computing drainage areas for the basins. The drainage areas shown in column 5 for the limestone basins represent a first estimate, to be tested for hydrologic reasonableness as shown later.

The term $\pm \Delta S$ of column 4 is simply the residual from the budget equation:

$$\pm \Delta S = P - ET - Q \qquad (9)$$

where P represents precipitation, ET is evapotranspiration, and Q is stream discharge per unit area. Assuming that ground-water inflow and outflow from the basin are negligible. ΔS represents the change in water storage per unit area in the basin; a plus sign indicates that water was taken into storage, while a minus sign indicates that water was released from storage.

A plot of the streamflow per unit area versus the difference between the rainfall and the estimated evapotranspiration is shown in figure 33. The deviations of the points from the 45-degree line indicate change in storage, ground-water inflow or outflow across the borders of the basin, or data error. Most of the points fall within a band ±20 percent of the 45-degree line. One basin in volcanic terrane plots slightly over +30 percent. There are, however, four basins in the limestone terrane that deviate excessively from the 45-degree line, and their deviation must be explained. The basin numbered 21 is Caño Tiburones. Its discharge per unit area was computed from a drainage area of 47 km²; from plate 1, this represents the immediate surface drainage area as interpreted from the topographic divides. It should be remarked that the actual outflow from Caño Tiburones is a mixture of freshwater and seawater. The discharge shown in table 2 represents only the freshwater portion, calculated on the basis of a chemical rating table. Clearly this freshwater discharge of Caño Tiburones cannot be accounted for by a drainage area of 47 km²; thus the discharge must include a large proportion of ground-water flow from the area to the south (pl. 1), which has no apparent drainage to the sea. This area includes extensive outcrop areas of the Aymamón and Aguada Limestones, and smaller outcrop areas of the Cibao Formation and Lares Limestone. (The flow into Caño Tiburones may also include a small amount of leakage from the artesian zones of the Cibao and Lares; this would represent ground-water inflow even in terms of the extended drainage area.) A new calculation of streamflow per unit area was therefore made for the Caño Tiburones, in which the previously unassigned drainage area to the south was included (refer to pl. 1 for drainage area boundaries). Rainfall and evapotranspiration were taken equal to those of the lower Arecibo basin. It can be seen from figure 33 that, with the new drainage area, Caño Tiburones plots within the main scatter field, thus indicating that the newly assumed drainage boundaries are generally correct.

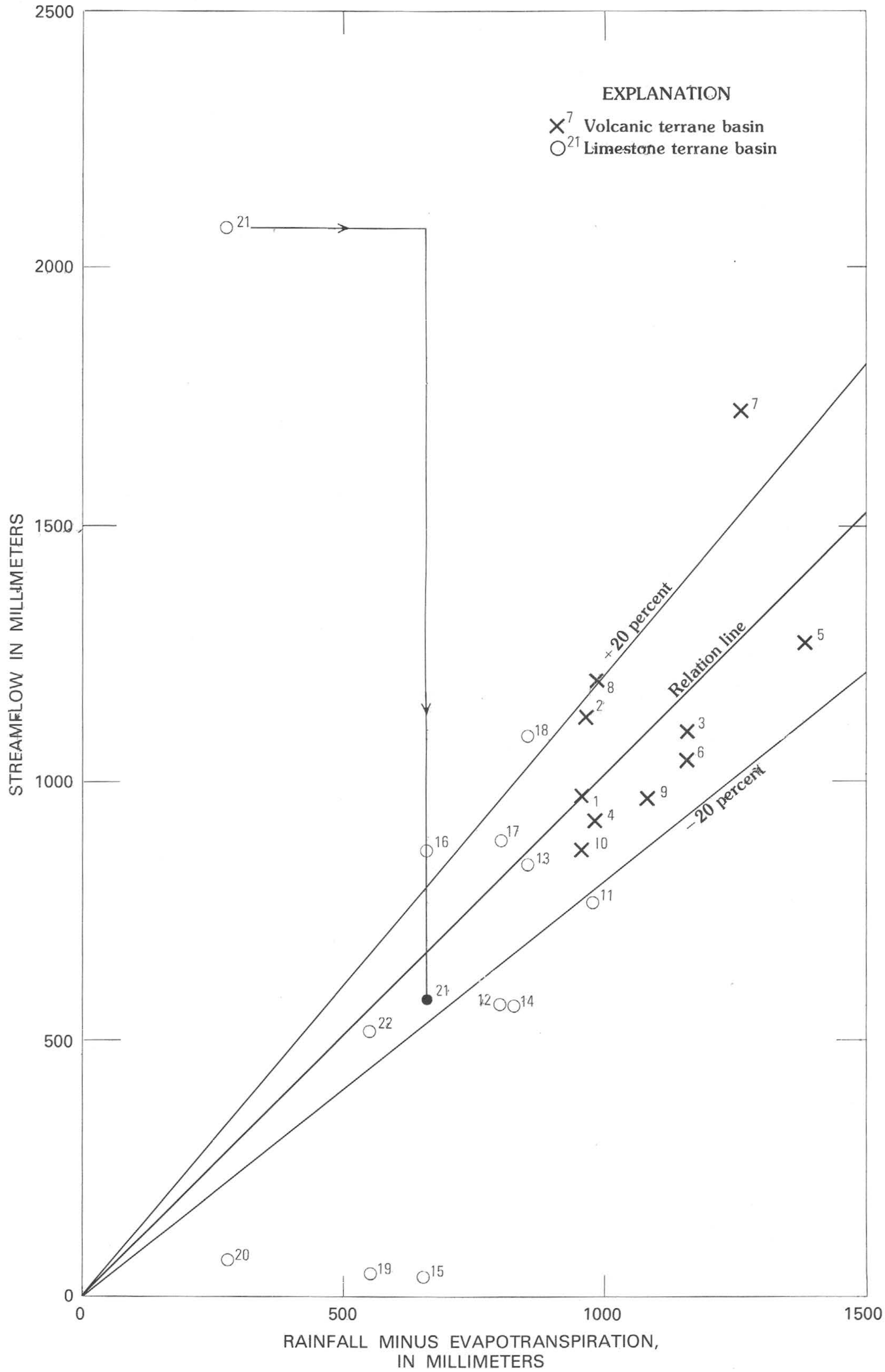

FIGURE 33.—Streamflow versus differences between precipitation and evapotranspiration. Data from table 2.

The basin numbered 15 is the lower Arecibo. It consists largely of valley plain downstream from Lago Dos Bocas. A yearly discharge of 56 mm is obtained by including the discharge of one spring whose flow is diverted from the basin for public supply (a direct subtraction of upstream from downstream flow would have resulted in a negative flow, indicating a loss). To a certain extent, the valley of the Río Grande de Arecibo acts like a sponge, absorbing water from the river during high flow and releasing it to the stream channel during the dry season, with an apparent near-zero net yearly contribution to the streamflow. Actually, from figure 23, for a rainfall of 1,800 mm, the drainage area between the upstream and the downstream site should yield a discharge of 600 mm for the year, about 550 mm greater than calculated. The excess probably flows into Caño Tiburones through the very permeable upper part of the Aymamón Limestone. The cluster of springs at the west end of Caño Tiburones is interpreted to mark the outflow area for this interflow from the Río Grande de Arecibo basin.

The remaining two basins showing excessive deviation from the 45-degree line of figure 33 are numbers 19 and 20. They are, respectively, Quebrada de los Cedros, and an area to the south of Caño Tiburones, which is drained by canals. Quebrada de los Cedros is usually dry, as its bed lies above the water table; it flows only after prolonged rainfall. Its drainage area is, therefore, only that part of the basin which has direct communication with the main channel, or fraction of the 38 km^2 assigned to it on the basis of sinkhole alinement. In addition, during storm runoff, this stream loses water through its bed all along its course. The canal-drained area south of Caño Tiburones (area 20) was assigned a drainage area of 54 km^2. Evidently the canals flow only in response to direct rainfall, and most of the rainfall outside their immediate area emerges as springflow in Caño Tiburones.

BASE FLOW

The separation of streamflow into components of floodflow and base flow involves definitions that are somewhat arbitrary. As used in this report, the term "floodflow" refers to that part of streamflow that produces discrete and clearly defined peaks on the hydrograph. (See fig. 34.) The remainder of the streamflow is considered base flow. It should be noted these definitions are based upon the shape of the surface-water hydrograph, rather than upon the origin of the water making up the various flow components.

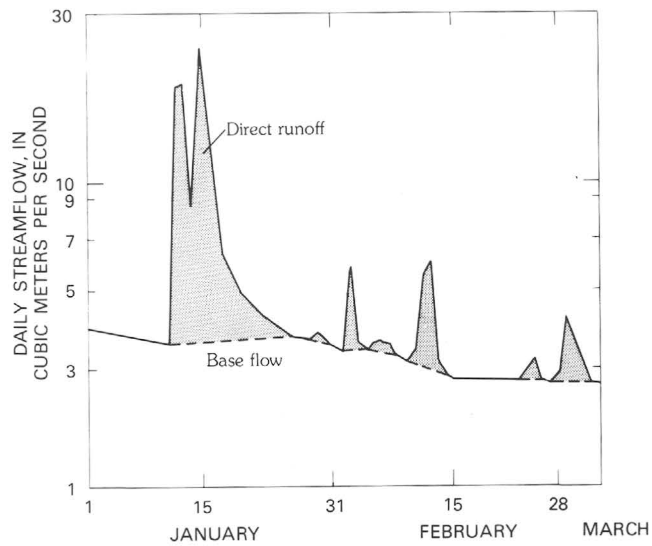

FIGURE 34.—An example of base-flow separation by computer.

A computer program to separate base flow from the total streamflow was adapted for the purposes of this study by T. D. Steele of the U.S. Geological Survey. This program is based on the recognition of points of minima in the hydrograph of daily flows; an empirical function allows for the separate computation of base flow and direct runoff, with the sum of the two being the total discharge. An example of this base-flow separation is shown in figure 34. In general, the program served its purpose well except for a few sites where the base-flow component was somewhat underestimated. The results are shown in table 3.

Two results of the hydrograph separation analysis deserve comment. The first is that the ratio of base flow to total flow, which is plotted against total flow in figure 35, is generally lower, for the major rivers, in the limestone than in the volcanics. The second is that the total base-flow from the limestone region is considerably higher than the total computed ground-water flow in table 1.

Both of these results can be explained by assuming that a certain fraction of the water which infiltrates the land surface in limestone terrane is routed rapidly to the streams through shallow circulation. In some cases this may represent circulation above the normal water table, through conduits which are dry except following a recharge event; in other cases it may represent rapid infiltration to the water table, followed by a correspondingly rapid discharge

TABLE 3.—*Base flow of limestone basins during period November 1969–October 1970*

	Streamflow site	Average base flow (m^3/s)	Lowest flow recorded (m^3/s)	Total flow (m^3/s)	Ratio of base flow to total flow
		Basins in volcanic terrane			
1	Upper Camuy	0.32	0.10	0.60	0.53
2	Criminales	.25	.062	.44	.57
3	Arecibo below Lago	----	----	----	----
4	Upper Tanamá	.89	.25	1.37	.65
5	Upper Manatí	3.50	.84	13.40	.26
6	Upper Cibuco	.48	?	1.30	.37
7	Mavilla	.55	?	1.31	.42
8	Unibón	.23	?	.52	.44
9	Cialitos	.52	.07	1.33	.39
10	Upper Guajataca	.094	.008	.21	.44
		Basins in limestone terrane [1]			
11	Guajataca to Lago	----	----	----	----
12	Guajataca to mouth	0.50	0.13	1.35	0.37
13	Lower Camuy	1.25	.54	4.46	.28
14	Lower Tanamá	1.05	.27	1.81	.58
15	Lower Arecibo	2.15	----	.07	30.00
16	Lower Manatí	2.00	.77	4.65	.43
17	Lower Cibuco	.94	.28	4.48	.21
18	Lajas	.18	.023	.75	.24
19	Quebrada de los Cedros	0	0	----	0
20	South Canals	.002	----	.07	.03
21	Caño Tiburones	2.45	2.0?	3.06	.80
22	Laguna Tortuguero	.55	.30	.74	.75

[1] For basins that begin in volcanic terrane, discharge is the difference between total downstream flow minus upstream flow. Other data refer to limestone portion of basin only. Location of sites is shown on plate 1.

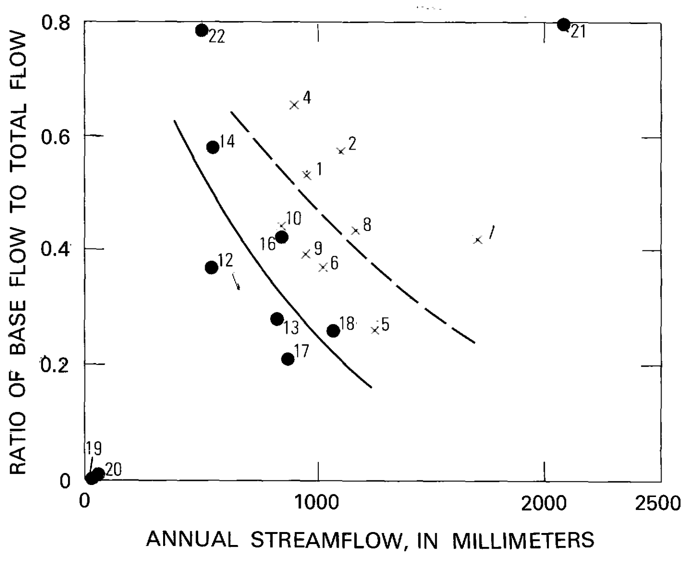

FIGURE 35.—Ratio of base flow to total flow versus discharge per unit area. Data from tables 2 and 3.

to the streams through the shallowest part of the saturated zone. The dye tracing results of Jordan (1970), in which a velocity of about 1.2 cm/s was calculated for water infiltrating to the Río Tanamá through shallow solution channels, confirm that such rapid circulation does occur.

One effect of this type of rapid circulation is that some of the water which infiltrates limestone terrane during a recharge event appears in the stream before "flood peak" has passed. Thus even though this water has infiltrated below land surface, it contributes to the flood peak rather than to base flow and causes the ratio of base flow to total flow to be lower than might be expected. The shallow circulation also persists, however, after passage of the flood peak, and thus also contributes to the base flow of the stream. As a result the total base flow is higher than the total ground-water flow as computed from head gradients in table 1; the computed flow, which is based on average long-term water levels, would not include shallow transient components. The situation forms a marked contrast to that in the volcanic basins, where infiltrating water tends to be held in storage in the weathered zone, and released slowly to the streams, generating a typical base flow recession curve, in which ground-water flow and base flow are presumably equivalent. The results are generally similar to those noted by Olmsted and Hely (1962) for the Brandywine Creek basin in Philadelphia, which flows through a gneiss-schist terrane.

It should be noted that the data for the Caño Tiburones and the Laguna Tortuguero do not fit the pattern outlined above. Base flow forms a high percentage of the total flow for these features and coincides reasonably well with the computed groundwater flow as given in table 1. The hydrologic role of these coastal discharge features differs from that of the major rivers, and neither direct runoff nor transient shallow circulation can form a major component of their discharges.

In table 3 are listed also the lowest streamflow measurements during the period 1959–70. This period includes the severe droughts of 1964 and 1965, which are rated to have frequencies of occurrence of several decades. Therefore these discharges indicate the order of the minimum flows.

DIRECT RUNOFF

The difference between total flow and base flow is generally termed the direct runoff. This terminology is retained in this report even though, as explained in the preceding paragraphs, this component of the streamflow in the limestone terrane would include a contribution from transient shallow ground-water circulation, in addition to direct overland flow. Figure 36 was obtained by plotting total direct runoff during each month for each major stream entering the limestone from the south, versus the corresponding monthly direct runoff of the same stream at its downstream gaging site, after crossing the limestone. Data points which fall below the 45° line, or equality line, on figure 36, represent instances in which the direct runoff component was smaller at the downstream site than at the upstream site. It is possible that in a few instances this effect could be caused by differences in hydrograph characteristics, through which flow classified as direct runoff at the upstream site is classified as base flow at the downstream sites. In the majority of cases, however, points falling below the equality line on figure 36 must indicate a loss in the flow across the limestone, during periods of high flow. The basins that have well-developed flood plains, the Río Cibuco and the Río Grande de Manatí, show a loss for small inflows. The Río Grande de Arecibo consistently shows a loss. For the Río Grande de Manatí and the Río Cibuco the loss may represent water taken into temporary storage by the flood plain, to be released later as base flow. For the Río Grande Arecibo valley, as already noted in the yearly water budget, a probable transbasin flow to Caño Tiburones is indicated. The large scatter of the data suggests that the network of solution channels in the limestone basins is complex and responds to rainfall in different ways under different conditions, and that the traditional methods used in hydrology of interstation correlation are unreliable for estimating the contribution from the karst. In total flow, however, a fairly reliable correlation exists between the monthly flows of the upstream and downstream sites. It must be noted, however, that the correlation is biased, statistically, because the total flow downstream includes the upstream flow.

GEOCHEMISTRY

The development of the karst arises from an interaction between a slightly acidic rainfall and the soluble limestone. It is, therefore, instructive to analyze some of the chemical and physical properties of the limestones in relation to those of rainfall and to analyze further the properties of the water after this interaction between rainfall and limestones has taken place. The background for the following discussion was obtained by a selective sampling of rocks and of water. The water was field analyzed for pH, bicarbonate, and temperature. The locations of the sample sites are shown on plate 1 and figures 37 and 38 and the data are presented in tables 4, 5, 6, and 7.

THE LIMESTONES

Some physical and chemical properties of the limestones are shown in table 4. The analyses, listed by site, are by the author and by W. H. Monroe (written commun., 1970). Whereas Monroe's data provided detailed information on the geochemistry of the rocks, the samples collected by the author were chemically analyzed only for the more important constituents. Some effort, however, was spent to obtain a measure of rock density and porosity which was unavailable from the literature. The color of the dry rock powder or the "streak" was also obtained and is expressed in units of the Munsell scale as measured from a Rock Color Chart issued by the Geological Society of America. Porosity was measured by leaving oven-dried (at 110°C) rock chips (approx 50 g) in distilled water for 72 hours and recording the amount of water absorbed by the rock. The density was calculated as the ratio of the weight of the oven-dried chips divided by their volume which was in turn measured by the water volume displaced by the water-saturated chips.

The data of table 4 show that the limestones are pure. The Lares Limestone and the Montebello Limestone Member of the Cibao Formation in the central part of the limestone belt range from 94 to 96 per-

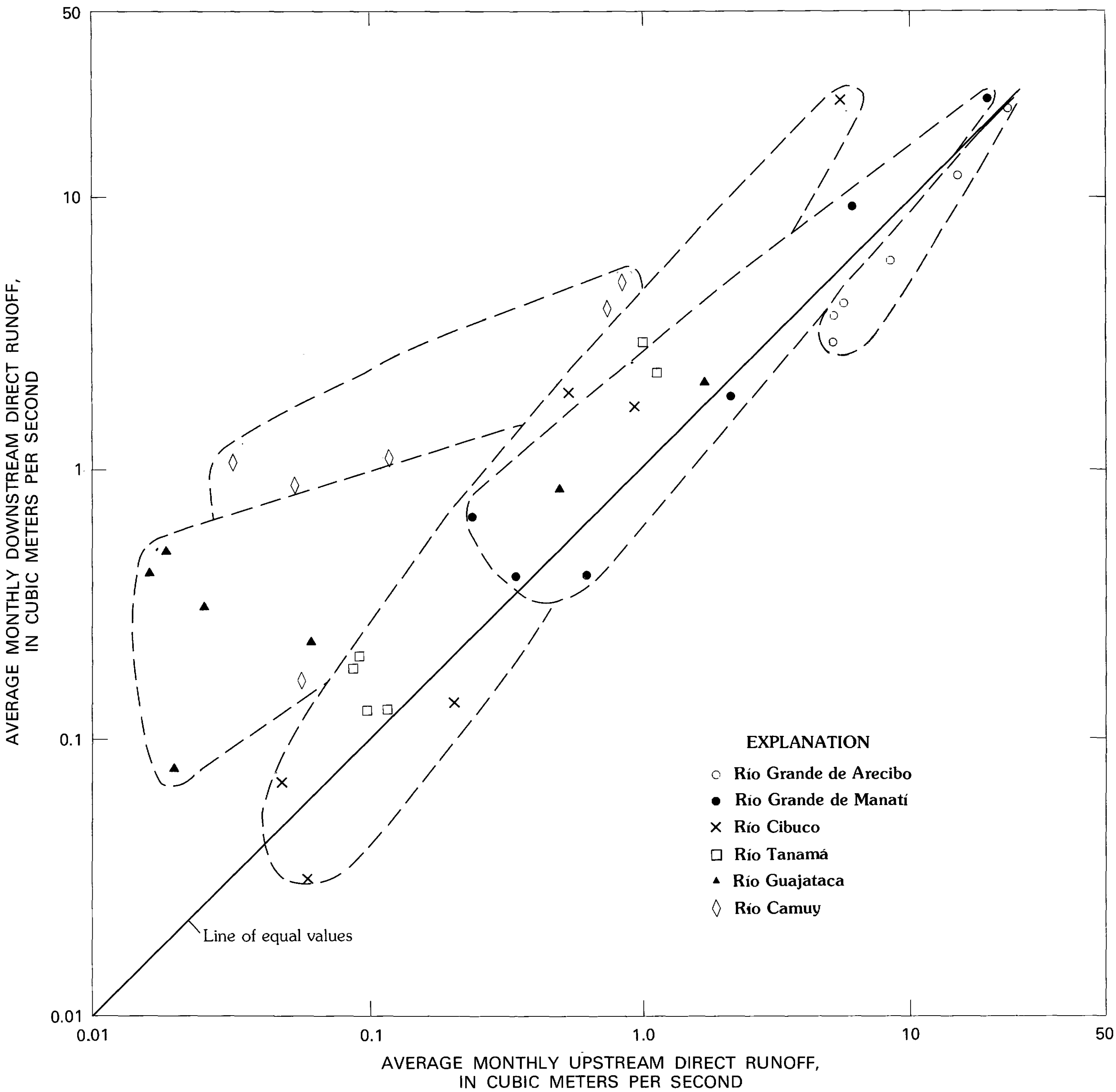

FIGURE 36.—Downstream direct runoff versus upstream direct runoff for those streams that begin in volcanic terrane and cross the limestone belt.

cent $CaCO_3$; the Aymamón Limestone ranges even higher—to 99 percent, but there is an indication from a few samples that these formations are less pure to the east and west. The Cibao Formation ranges from 59 to 91 percent $CaCO_3$, reflecting its variability as previously noted in the description of the geologic formations. The Aguada Limestone is somewhat less pure than the Aymamón and Lares, ranging from 82 to 94 percent; whereas, the Camuy Formation proves to be the most variable of all, ranging from 50 to 95 percent. The magnesium content of the limestones is generally low, less than 2 percent of $MgCO_3$, except for a few samples from the upper part of the Aymamón and the Camuy which show up to 39 percent $MgCO_3$, making these samples calcitic dolomites.

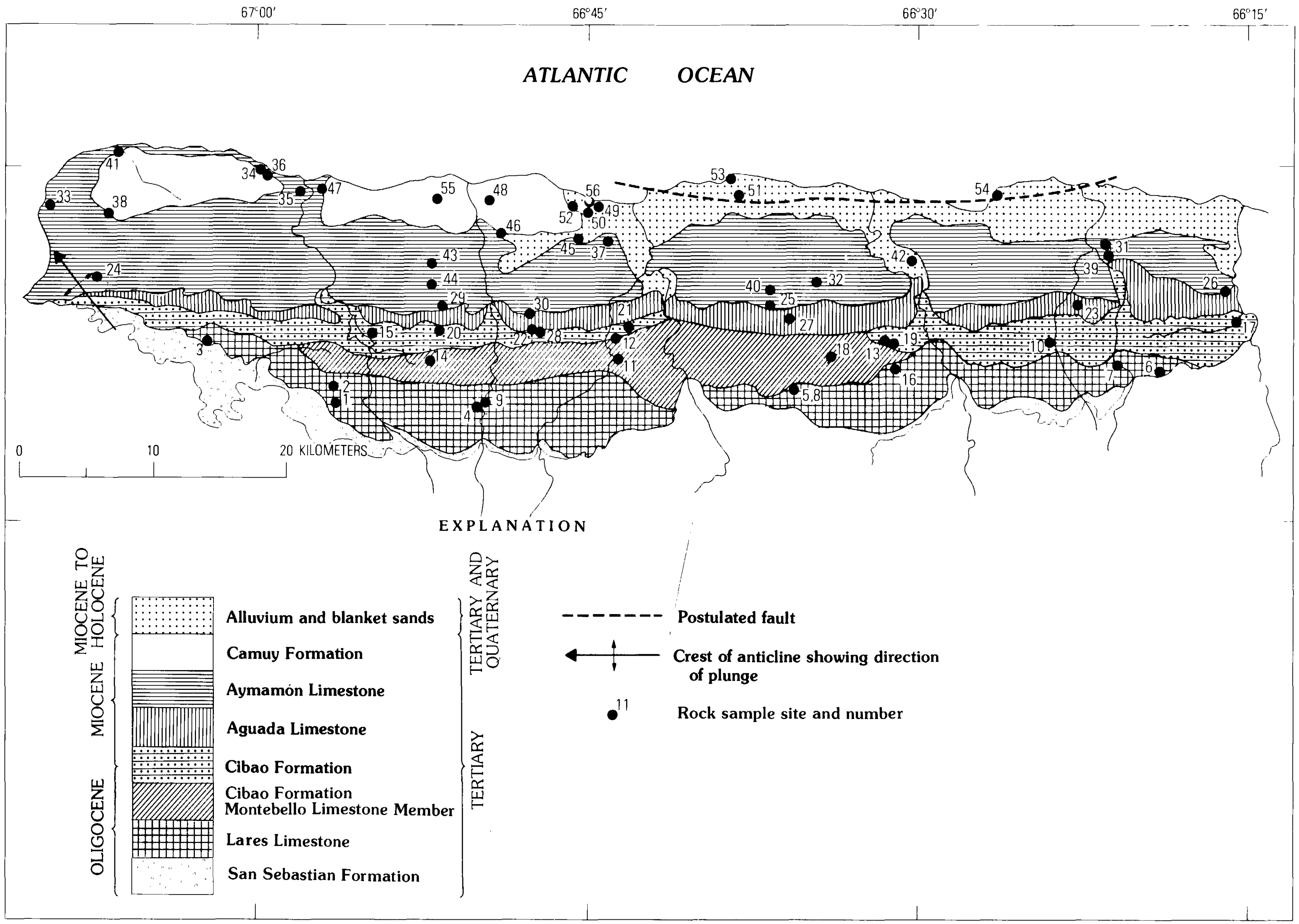

FIGURE 37.—Rock sample sites (data in table 4).

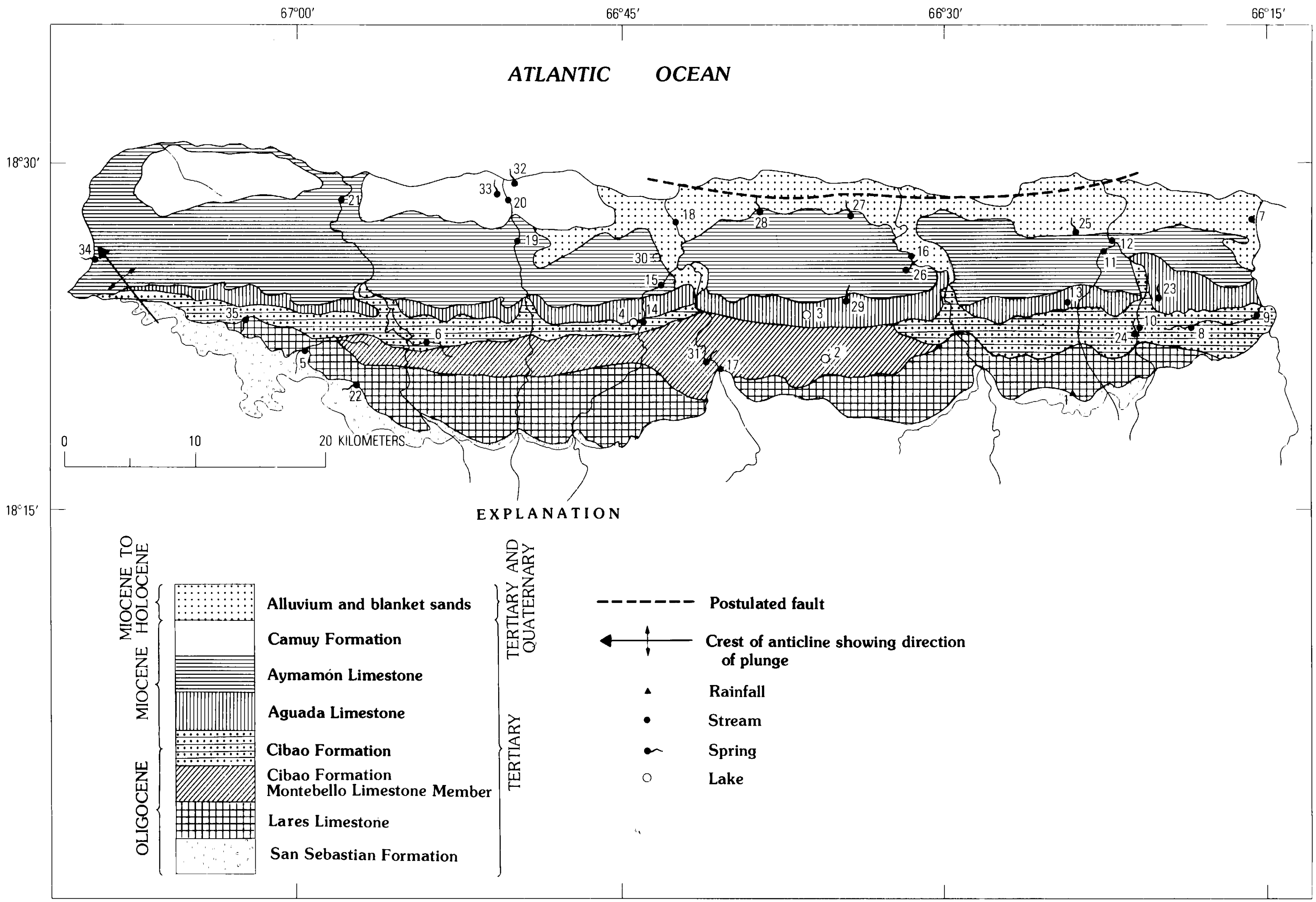

FIGURE 38.—Water sampling sites (data in table 5).

TABLE 4.—*Chemical and physical data of north coast limestone*

[Location is shown in fig. 37. Items in parentheses are from W. H. Monroe (written commun., 1970). Values of silica which are set in italics are from the relation of fig. 39]

No.	Geologic unit	Data, in percent						Porosity	Bulk density (g/cm^3)	Powder color (dry), Munsell scale[1]
		SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	Insoluble residue			
(1)	Lares Limestone	6.4	2.7	2.3	83.8	2.5	---	--	---	---------
(2)	do	1.2	.5	0	94.3	1.9	---	--	---	---------
(3)	do	16.9	5.1	2.2	68.7	3.3	---	--	---	---------
(4)	do	.3	.1	0	97.0	.8	---	--	---	---------
(5)	do	.6	.2	.1	95.4	.6	---	--	---	---------
6	do	*24*	--	2.8	60	2.5	34.7	.32	1.39	10 *YR* 6/4
7	do	*1.5*	--	.1	95	1.1	1.9	.16	1.48	10 *YR* 8/2
8	do	*.9*	--	0	97	.8	1.1	.19	1.37	5 *Y* 9/1
9	do	*2.0*	--	.2	94	1.2	2.5	.15	1.98	10 *YR* 8/2
(10)	Cibao Formation	4.0	1.2	1.0	88.7	1.7	---	--	---	---------
(11)	Montebello Limestone Member.	.1	.1	0	97.0	.8	.5	--	---	---------
(12)	do	.2	.1	.1	97.8	.8	.7	--	---	---------
(13)	Quebrada Arenas Limestone Member.	.4	.3	.2	96.5	.6	.8	--	---	---------
(14)	Cibao Formation	3.4	1.0	.4	91.4	1.9	---	--	---	---------
(15)	do	12.3	4.5	1.6	74.8	2.1	---	--	---	---------
(16)	do	8.6	2.8	1.1	83.8	.8	10.0	--	---	---------
17	do	*5.1*	--	.8	90	1.9	6.3	.17	1.73	10 *YR* 8/2
18	Montebello Limestone Member.	*.5*	--	.1	96	.6	.6	.30	1.54	5 *Y* 9/1
19	Cibao Formation	*17*	--	.8	76	.7	20.6	.12	1.98	10 *YR* 7.5/4
20	do	*29*	--	1.4	59	1.3	35.9	--	1.10	5 *Y* 7/4
21	Aguada Limestone.	6.6	1.2	.6	89.2	.6	7.5	--	---	---------
(22)	do	4.0	2.7	.9	88.8	1.0	---	--	---	---------
(23)	do	1.2	.7	.2	93.6	.4	1.3	--	---	---------
(24)	do	4.4	2.8	1.1	86.5	.8	---	--	---	---------
(25)	do	7.2	2.0	.3	88.4	.6	9.0	--	---	---------
26	do	*9.8*	--	.3	84	.8	11.9	.16	1.81	10 *YR* 7/5
27	do	*12*	--	.6	82	1.0	14.3	.11	2.13	10 *YR* 8/2
28	do	*2.6*	--	1.9	93	.7	3.2	.03	2.53	10 *YR* 5.5/3
29	do	*6.7*	--	1.0	87	.9	8.2	.04	2.16	10 *YR* 8/4
30	do	*1.7*	--	.6	95	.6	2.1	.09	2.22	10 *YR* 6.5/2
(31)	Aymamón Limestone.	.0	0	0	98.8	.2	---	--	---	---------
(32)	do	.5	.3	.1	97.5	.6	.8	--	---	---------
(33)	do	.5	.2	0	61.6	34.5	---	--	---	---------
(34)	do	.7	.6	0	61.2	35.5	---	--	---	---------
(35)	do	.5	.4	0	57.7	38.9	---	--	---	---------
(36)	do	.7	.3	0	62.7	34.3	---	--	---	---------
(37)	do	.1	.1	0	97.8	1.0	.3	--	---	---------
(38)	do	.8	.4	0	95.5	.6	---	--	---	---------
39	do	*.4*	--	.1	97	.6	.5	.18	1.95	*N* 9
40	do	*2.5*	--	.4	94	.8	3.1	.06	1.38	5 *YR* 8/4
41	do	*9.5*	--	1.3	84	1.9	11.7	.17	1.59	10 *YR* 7/6
42	do	*0*	--	.2	99	.7	0	.13	1.88	5 *Y* 9/1
43	do	*.9*	--	.2	96	.6	1.1	.28	1.63	10 *YR* 8/4
44	do	*0*	--	.1	99	.7	0	.18	1.86	10 *R* 8/2
45	do	*.2*	--	.2	98	.9	.3	.21	1.59	10 *YR* 8/4
(46)	Camuy Formation	8.3	3.0	3.7	79.6	1.5	---	--	---	---------
(47)	do	3.4	.8	.3	55.5	36.0	---	--	---	---------
(48)	do	2.2	.6	.3	93.6	.8	---	--	---	---------
(49)	do	10.6	1.7	1.3	82.2	.8	12.7	--	---	---------
(50)	do	31.7	4.2	1.9	57.0	1.0	39.5	--	---	---------
(51)	do	9.2	2.0	.9	84.8	1.0	11.3	--	---	---------
(52)	do	7.0	1.2	.6	88.8	1.0	7.7	--	---	---------
(53)	do	2.4	.6	.5	94.8	1.5	2.9	--	---	---------
(54)	do	*1.9*	--	.4	---	40.0	2.3	.26	1.23	5 *Y* 8/1
(55)	do	*21*	--	.2	70	.9	26.4	.24	1.67	5 *YR* 9/1
(56)	do	*38*	--	.5	50	.8	46.2	.18	1.93	10 *YR* 7/3

[1] See Goddard and others (1948).

TABLE 5.—*Miscellaneous chemical and physical data on water from north coast limestone*

[Data in milligrams per liter except temperature in degrees Celsius, and specific conductance in micromhos per centimeter at 25°C. Location of sites is shown in fig. 38. Number in parentheses are acidified samples]

	Temperature, °C	SiO_2	Ca		Mg		Na	K	HCO_3 Laboratory	HCO_3 Field	SO_4	Cl	NO_3	Dissolved solids	Specific conductance	pH Laboratory	pH Field
1. Rainfall, average at Morovis.	---	--	1.2	-----	.6	-----	--	--	4.7	---	1.8	4.5	.5	18	----	6.1	--
2. Lago near Montaña.	25	2.1	4.2	(4.9)	1.0	(.9)	2.6	3.5	17	17	0.8	5.5	.7	29	53	6.1	6.3
3. Lago near Alianza.	26	3.8	22	(22.8)	1.1	(.9)	4.3	4.0	66	67	2.6	9.8	.8	81	155	6.7	6.7
4. Lago at Esperanza.	26.7	2.8	58	-----	1.7	-----	6.9	1.9	168	---	12.0	12.0	5.0	183	332	7.3	--
5. Río Guatemala at San Sebastián.	27	8.0	59	(59)	5.8	-----	8.1	1.2	182	181	24	13	2.4	212	364	8.0	7.4
6. Río Chiquito	23.5	5.9	88	(90)	5.2	(5.2)	5.1	.9	274	276	17	8.5	2.7	268	469	8.0	7.4
7. Ciénega Higuillar	24.5	8.7	33	(33)	10	(10.4)	32	3.8	130	181	10	57	1.3	220	419	7.4	7.2
8. Río Lajas at Hwy 823.	24	8.9	85	(93)	6.5	(7.3)	7.9	.7	268	320	14	15	4.7	275	493	7.7	7.8
9. Río Lajas at Toa Alta.	23.4	11.0	78	(81)	4.9	(5.7)	9.8	1.2	240	288	15	19	4.5	262	469	7.7	8.0
10. Río Cibuco at Hwy 647.	23.6	26	38	(41)	7.9	(8.3)	11.0	1.9	142	141	13	16	5.9	190	308	7.6	7.9
11. Río Indio at Hwy 160.	22.8	16	73	(75)	5.8	(6.9)	12	1.8	228	234	13	19	5.6	258	451	7.7	8.0
12. Río Cibuco at Hwy 2.	23.2	21	56	(58)	7.4	(7.8)	12	2.1	190	194	14	17	5.9	230	391	7.6	7.8
13. Quebrada Hicatea	---	11	119	-----	6.3	-----	14	2.8	356	---	---	----	.3	----	659	7.3	--
14. Río Tanamá near La Esperanza.	24.5	12	47	(52)	3.9	(4.3)	6.3	.7	154	158	8.0	7.0	2.3	163	279	7.6	7.3
15. Río Tanamá at Hwy 10.	22.0	18	47	(46)	3.7	(4.2)	5.9	.6	156	156	4.0	7.3	2.1	166	290	8.0	7.2
16. Río Grande de Manatí at Hwy 2.	26	23	36	(42)	7.7	(4.9)	9.8	1.3	136	146	7.0	11	2.1	166	281	7.2	7.0
17. Río Grande de Arecibo below dam.	24.5	24	21	(21)	6.0	(6.0)	10	1.4	85	78	13	10	3.3	131	197	7.2	7.0
18. Río Grande de Arecibo at Cambalache.	26	17	40	(42)	5.2	(3.9)	8.4	1.2	140	---	4.4	11	4.3	160	290	7.2	7.8
19. Río Camuy at Salto Máquina.	24	7.4	58	(64)	3.8	(3.7)	6.4	.7	184	200	10	9.0	4.1	191	333	8.0	7.6
20. Río Camuy at gaging station.	25	7.4	63	(57)	3.7	(4.1)	6.4	.9	198	191	9.4	9.8	3.4	202	361	7.8	7.6
21. Río Guajataca at gaging station.	25	4.7	56	-----	4.1	-----	7.0	1.1	184	---	11.0	9.8	1.6	186	335	7.9	--
22. Spring, Salto Collazo.	23	4.4	72	(74)	3.2	(3.2)	4.5	.8	220	---	12	8.4	1.6	215	385	7.8	7.5
23. Spring, Hwy 647 near Vega Alta.	25.3	9.4	85	(86)	3.9	(4.7)	9.3	.7	264	266	3.4	21	4.5	267	496	7.8	7.4
24. Spring, El Convento, Hwy 647.	24.5	6.6	86	(89)	6.1	(7.0)	6.4	.4	276	283	4.6	14	10	270	498	7.7	7.3
25. Spring, Comunidad El Ojo del Agua.	25.5	7.3	96	(98)	10	(9.9)	44	1.6	268	267	16	92	11	410	791	7.6	7.2
26. Spring near Manatí.	24.8	6.6	90	(92)	3.2	(3.9)	8.3	.6	278	278	2.8	15	5.1	269	498	7.8	7.3
27. Cáncora Garrochales.	28	8.9	168	(170)	34	(33.6)	241	.8	276	284	53	562	11	1,210	2,300	7.7	7.1
28. Spring north of Garrochales.	25.5	5.6	97	(100)	16	(15.6)	118	.5	266	270	29	218	13	628	1,160	7.3	7.3
29. Spring Riachuelo	24	15	89	(91)	3.8	(4.2)	6.6	.5	276	274	2.8	10	6.4	270	483	7.7	6.9
30. Spring, Central Los Caños.	25	15	83	(85)	3.9	(3.9)	10	1.1	258	257	4.0	18	12	274	483	7.5	6.7
31. Spring, Los Chorros.	23	7.4	56	(61)	2.5	(2.9)	5.6	.4	174	182	4.2	8.8	3.3	174	305	7.8	7.6
32. Spring near Hatillo.	23.5	11	77	-----	19	-----	108	11	268	---	27	190	3.7	581	1,040	7.7	--
33. Spring, Camuy at Hwy 2.	24.5	8.9	102	(109)	30	(30)	225	8.7	288	---	60	402	7.7	986	1,800	7.6	--
34. Spring in Aguadilla.	25	7.7	83	(88)	4.5	(4.6)	7.6	.9	266	264	3.2	12	12	262	469	7.7	6.8
35. Spring near San Sebastián.	26	25	119	(144)	7.3	(7.3)	11	.5	376	460	19	12	1.6	381	628	7.5	6.9

Most of the insoluble residue from the limestone samples is silica (81 percent) as is shown in figure 39. Minor amounts of aluminum and iron are present in the quantities shown in table 4. Measurable quantities of strontium and titanium and traces of other metals not listed in table 4 were also found.

The primary porosity ranges from a minimum of 0.03 for a sample from the Aguada to a high of 0.32 for a sample from the Lares. In general, the Aguada seems to be the least porous, and the Camuy the most. The densities measured are inversely related to the porosity, with the Aguada clearly denser than all other formations.

The streak of the dry powders of most samples showed very pale colors in the orange section of the color spectrum. The chalky limestones were generally white or very pale gray.

TABLE 6.—*Chemical and physical data from ground water of the north coast limestone*

[Data in milligrams per liter except temperature in degrees Celsius, specific conductance in micromhos per centimeter at 25°C, and pH]

	Well Nos.[1]	Geologic unit	Temperature °C	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	Dissolved solids	Specific conductance	pH
1.	26–24	Aymamón Limestone.	---	9.0	81	3.2	----24----		256	2.0	28	0	19	335	534	7.9
2.	27–20	Aymamón Limestone.	29	6.8	50	4.4	19	0.8	154	8.8	38	0.1	1.4	205	384	8.0
3.	26–33	Lower part of Aymamón Limestone.	---	7.0	110	3.4	12	.0	144	9.0	34	0	26	345	581	7.6
4.	24–25	Aguada Limestone	---	6.2	88	9.8	----------		302	2.1	18	.1	2.2	283	485	7.4
5.	26–55	Aguada Limestone	---	21	100	4.1	----35----		385	3.8	19	--	---	523	---	7.2
6.	24–19	Cibao Formation	---	8.5	112	12	----22----		370	4.4	39	.1	18	404	680	7.7
7.	22–31	Cibao Formation	29	4.8	103	1.7	6.2	.5	300	5.2	10	0	12	291	514	7.4
8.	22–47	Cibao Formation	24.4	7.4	88	9.8	-----3.2---		300	28	11	.2	2.3	273	667	7.8
9.	26–33	Montebello Limestone Member, artesian.	---	7.3	37	9.1	8.8	1.5	136	19	14	.1	.4	---	---	--
10.	25–33	Montebello, Limestone Member, artesian.	---	3.6	78	10	6.2	.3	272	7.2	10	--	4.5	254	458	7.9
11.	26–33	Lares, Limestone artesian.	---	16	50	52	69	5.1	310	181	30	4.2	---	560	906	7.8
12.	25–33	Lares Limestone artesian.	---	5.8	69	18	7.8	.6	284	10	12	.2	3.2	266	485	7.5

[1] Well numbers are minutes north of lat 18° for first 2 digits, and minutes west of long 66° for next 2 digits; and can be used to locate the well roughly.

TABLE 7.—*Average values of dissolved constituents and of physical properties of surface water in the north coast limestone belt*

[Data in milligrams per liter except specific conductance in micromhos per centimeter at 25°C, and pH. Note that averages shown are means of samples and are not adjusted for discharge]

	Name and location of stream[1]	Rock type	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Dissolved solids	Specific conductance	pH
1.	Guajataca at Lares (10)	Volcanic	29.8	26.5	5.8	11	1.7	114	6.0	9.0	3.6	150	230	7.5
2.	Camuy near Lares (1)	----do	21.8	13.9	5.3	7.5	1.0	57.5	17.3	6.7	1.6	103	154	7.5
3.	Criminales near Lares (2)	----do	21.9	10.2	4.5	6.5	1.0	47.5	7.8	6.7	2.7	85	121	7.2
4.	Arecibo below Dos Bocas (3)	----do	21.6	19.3	5.9	10.1	1.7	78.3	15.0	10.1	1.6	124	189	7.2
5.	Manatí at Ciales (5)	----do	27.4	21.1	8.7	11.0	1.4	102	8.4	12.2	1.9	147	230	7.5
6.	Cialitos at Ciales (9)	----do	29.9	23.7	6.5	10.2	1.4	109	3.4	10.5	2.8	142	222	7.5
7.	Cibuco below Corozal (6)	----do	33.4	25.9	10.6	14.0	2.2	124	12.4	17.2	3.8	181	290	7.6
8.	Mavilla near Morovis (7)	----do	28.9	19.5	8.7	12.2	2.6	85.7	10.9	15.3	4.8	150	234	7.7
9.	Unibón near Morovis (8)	----do	23.3	24.8	9.6	11.6	2.1	118	10.6	14.9	2.7	163	261	7.7
10.	Guajataca, below Lago (11).	Limestone and volcanics.	8.6	57.5	4.9	7.5	1.0	185	9.1	12.4	3.1	195	355	7.8
11.	Guajataca at mouth (12)	----do	7.7	58.9	5.4	6.7	1.0	190	8.9	14.0	3.9	203	368	7.9
12.	Camuy near Camuy (13)	----do	9.9	54.5	4.2	6.5	.8	175	7.6	9.4	3.4	184	327	7.9
13.	Tanamá at Charco Hondo (14).	----do	13.0	42.7	4.0	6.1	1.2	144	6.4	7.2	1.7	154	266	7.9
14.	Arecibo at Cambalache (15).	----do	21.5	30.4	5.3	8.3	1.3	114	12.2	9.6	2.8	148	233	7.5
15.	Manatí at Highway 2 (16)	----do	20.0	28.9	6.5	8.8	1.5	96.4	7.6	10.6	3.2	144	244	7.5
16.	Cibuco at San Vicente (17).	----do	21.5	49.6	8.4	12.6	2.1	170	12.4	18.2	3.1	217	373	7.8
17.	Caño Suroeste[2] (20)	Limestone	10.4	15.5	3.2	6.7	5.7	47	14	9.0	1.2	86.5	136	6.8
18.	Caño Noreste[2] (20)	----do	9.7	22.0	6.3	27.0	3.8	66	----	50	2.3	177	312	6.7
19.	Caño Tiburones[2] (21)	----do	10.3	126	69.0	498	20	80	248	910	2.6	1,880	5,320	7.3
20.	Laguna Tortuguero (22)	----do	6.9	88.2	52.1	328	11.4	140	113	721	1.0	1,440	2,680	7.8
21.	Lajas at Toa Alta (18)	----do	10.9	86.2	6.3	10.4	1.7	242	13.9	20.3	2.8	287	505	8.0

[1] Numbers in parentheses identify stations listed in tables 2 and 3.
[2] High flows.

THE WATER

RAINFALL

Chemical and physical data on the water of the study area are given in tables 5, 6 and 7. However, whereas the data of tables 5 and 6 refer mainly to once only sampling for each given site, those of table 7 on rivers are averages from about 12 samples collected at each site.

The first row of table 5 shows the averaged mineral composition of rainfall at Morovis. These data were provided by Raúl Díaz (written commun., 1970). As expected for an island, chloride salts are the main constituents in the rainfall. The average pH of the rainwater is 6.1 (slightly acidic). A sample of rainfall analyzed in the field immediately after collection showed a pH of 6.2; thus the average of 6.1 of Díaz' samples, which were kept in storage for prolonged periods prior to analysis, can be considered valid.

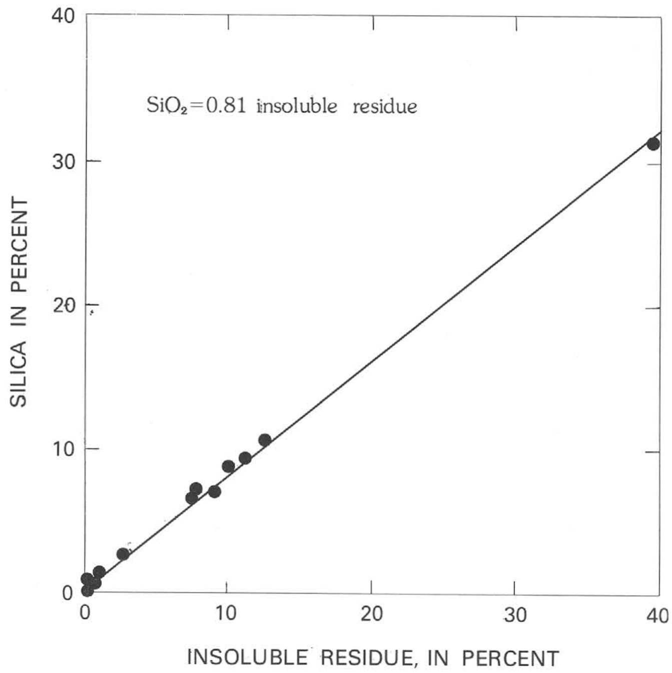

FIGURE 39.—Relation between silica and insoluble residue.

LAKES

The lake water analyses, shown in table 5, were taken from three lakes at progressively lower altitudes, and the results clearly indicate a general increase of mineral concentration. The first analysis—2, a pond resting on terra rossa receiving only direct runoff—shows a concentration similar to that of rainwater, the slight increase of some constituents, particularly calcium, being no more than a leaching of terra rossa or slight concentration from evaporation. The pH is the same; thus the capacity of this water to take limestone into solution remains unaltered. The terra rossa, as mentioned by Birot and others (1967), provides an inert medium for surface water flowing or resting on it. The samples were collected in 1970–71; the fact that these years are considered wet years lessens the possibility of general increase of mineral concentration from evaporation. Analyses 3 and 4, which are lakes that are partly spring-fed, especially 4, show a rapid increase of mineral concentration—especially, calcium.

SPRINGS

Analyses 22 to 35, table 5, are from waters which have been in contact with the limestones. Spring analyses that show sodium and chloride concentrations much larger than the rest, such as 27 and 28, are from springs which lie in the zone of diffusion between ground water and sea water. (See fig. 38.) The generally high chlorides and nitrates of all the springs and, in fact, of all waters of the north coast limestones, are not acquired from dissolution of limestone, but rather arise from the minerals introduced by the rainfall (especially the chlorides) or by residues of biological activities

There are no great differences among the waters from the various formations. The Aguada and the Cibao seem to have a larger SiO_2 content (about 10 mg/L) than the Lares and the Aymamón (about 6.7 mg/L), but the sampling can hardly be considered exhaustive. Spring 35, which flows about 100 L/h (liter per hour) has the highest SiO_2 content of all the springs sampled. This spring issues from the Cibao Formation, which has a large SiO_2 content. The source of the spring, therefore, may explain, in part, the high silica content; however, the increase in concentration could also result from direct evaporation or evapotranspiration.

The calcium content of the springs which are not in the saline zone near the coast ranges from 56 to 119 mg/L. The lowest value is for the spring shown in figure 31 which is associated with travertine deposition, whereas the high value is for spring 35 for which evaporation may be responsible for the higher-than-average calcium concentration. The average concentration of calcium in spring water seems to be about 85 mg/L.

GROUND WATER

Data on the major chemical constituents of ground water are given in table 6. The chemical analyses show that the water from the various formations is similar. The general similarity of the ground water to the spring water is also noted, and most comments about spring water apply to ground water, except that ground water has a high mineral concentration without the effect of evaporation. Of special interest are the data for the deep artesian wells, analyses 9 to 12. The fact that artesian aquifers show smaller concentrations of calcium than water-table aquifers indicates possibly precipitation of $CaCO_3$ through crystallization within the aquifer, for which there is much field evidence (figs. 40 and 41), or simply loss of $CaCO_3$ from the samples after collection (the analyses were not made with acidified samples).

RIVERS

The average composition of water from streams is shown in table 7. The data in table 7 are mainly from low flows, which are normally more concentrated than high flow, and thus the averages are

FIGURE 40.—Evidence of recrystallized limestone.

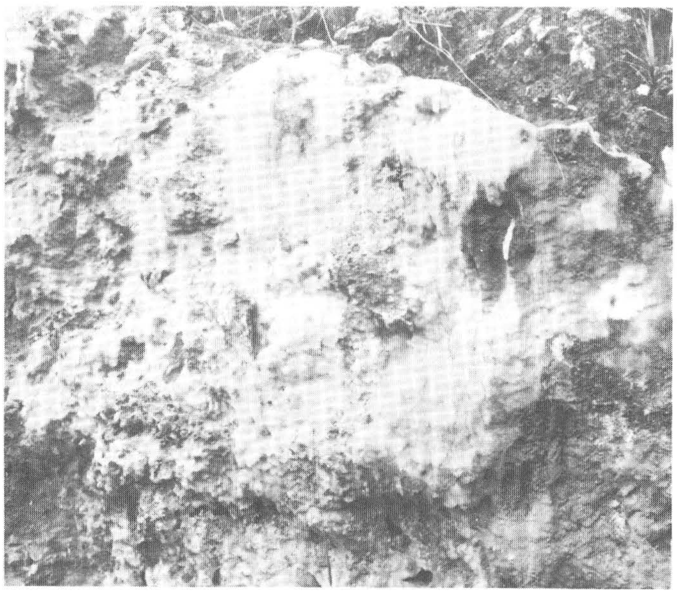

FIGURE 41.—Recrystallization of limestone (close up of fig. 40).

somewhat higher than a true average such as would be obtained from a continuous sampling that would incorporate data from more diluted high flows. Concentration of mineral constituents, as shown by the relation of $CaCO_3$ to discharge in figure 42, in the water is an inverse function of streamflow. This inverse relationship is most applicable to the streams flowing out of volcanic terrane; the limestone streams have a more nearly constant concentration. To the extent that table 7 serves as a comparison between streamflow from the volcanic terrane and that from limestone, the remark about the averages of table 7 is of little importance. It should be taken into account, however, if a comparison is made with data that are averaged relative to the flow. An example of a proper averaging of chemical constituents is shown in the rating table of figure 43 used to compute the equivalent freshwater outflow of Cãno Tiburones.

As expected, the main difference between the streamflow from the volcanic terrane and that from the limestone is the increase in concentration of calcium and, inherently, of bicarbonate, and a slight decrease of all other measured constituents. For those streams that originate in the volcanic terrane and cross the limestone belt, the decrease may be a dilution process, especially in the case of silica. The only sample valid for comparison from purely limestone terrane is from the Río Lajas (station 21 in table 7) that mainly drains the Cibao Formation which, in the Lajas basin, is an impure limestone. Assuming that no precipitation of silica takes place along the stream channel, the contribution of silica from the limestone is of the order of 10 mg/L for the Cibao Formation and perhaps for the Aguada Limestone, and of 6–7 mg/L for the Lares Limestone and Aymamón Limestone.

At the upstream volcanic terrane sites, the streams have a silica content in excess of 20 mg/L and less than half this value at the downstream sites after the streams have crossed the limestone belt. Assuming no streamflow losses through the limestone belt (as borne out by the water-budget results) and ignoring losses by evapotranspiration, one can write:

$$C_u \cdot Q_u + C_L \cdot Q_L = C_D \cdot Q_D \qquad (10)$$

where

C = concentration of silica
Q = streamflow
u,L,D = upstream, limestone, and downstream, respectively, and
$Q_L = Q_D - Q_u$

For the Río Camuy (including the Río Criminales), for example, using the water-budget data from table

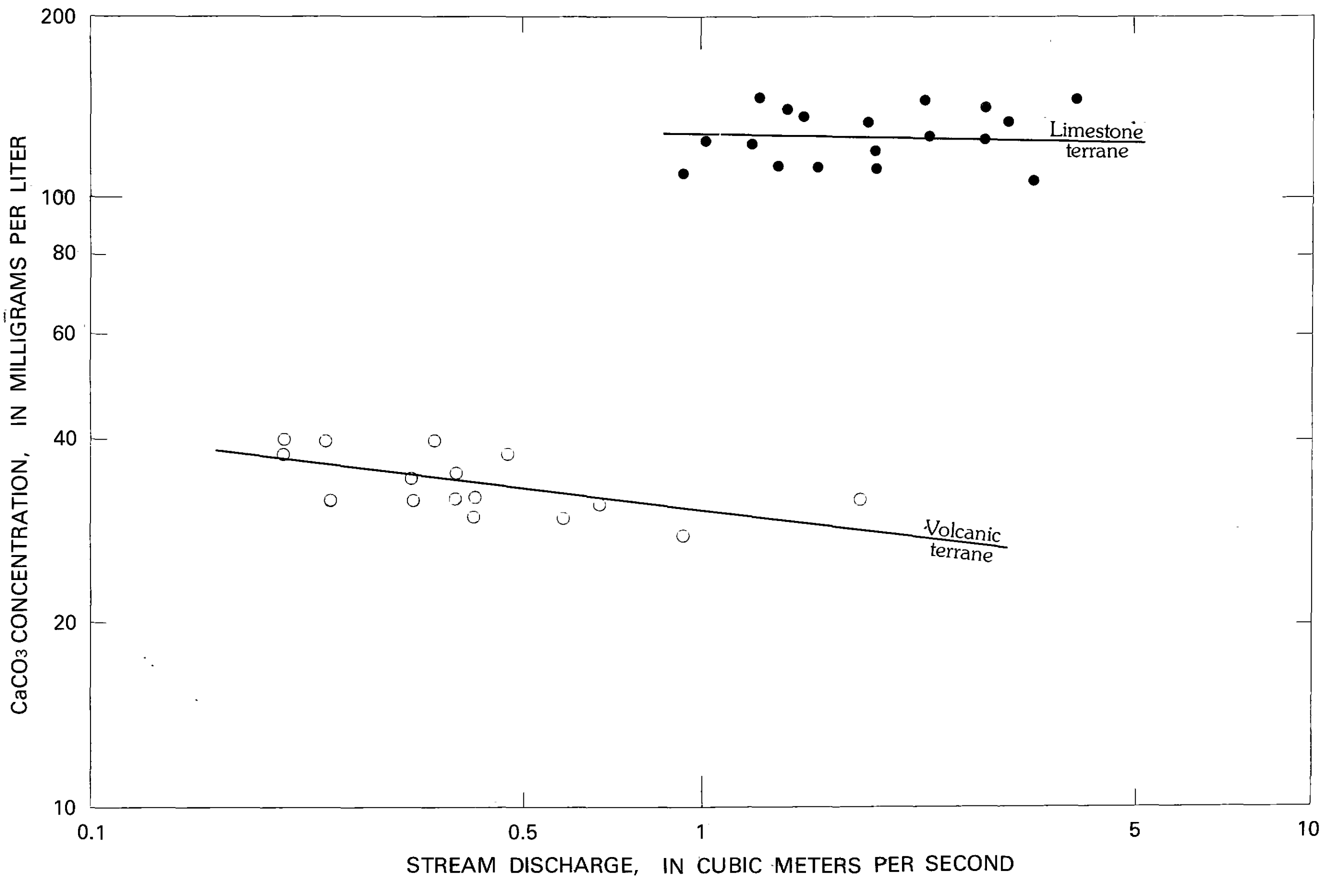

FIGURE 42.—Relation between $CaCO_3$ concentration and discharge (instantaneous values).

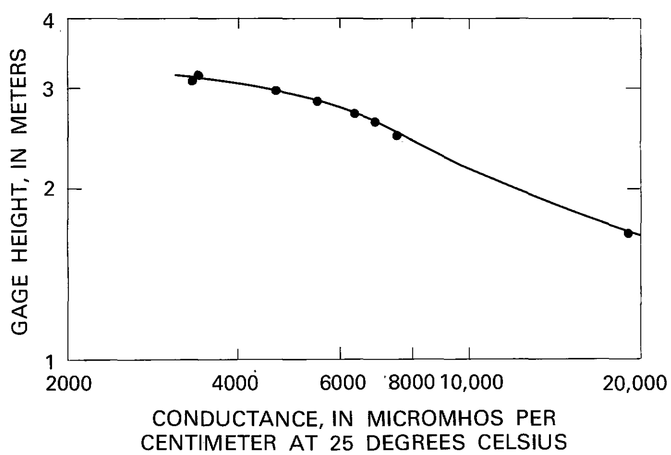

FIGURE 43.—Rating curve used to compute the equivalent freshwater discharge of Caño Tiburones.

2 converted to cubic meters per second, and the concentrations in milligrams per liter of table 7,

$$(21.8)\cdot(0.59)+(21.9)\cdot(0.33)+(X)\cdot(3.4)=(9.9)\cdot(4.3).$$

Solving for X, the silica concentration for the limestone part of the basin, gives a value of 6.6, which is about the concentration of silica found in Lares and Aymamón waters. Although more work is needed, it would seem that silica may provide a good natural tracer to compute the streamflow at the downstream end of those rivers that originate in volcanic terrane.

Samples 14, 15, and 16 are from sites on streams with substantial flood plains. Silica concentrations approach those from upstream sites in volcanic terrane, suggesting that the flood plain itself contributes silica to the water; possibly from contact with clay minerals.

THE SOLUTION PROCESS[1]

The ability of rainfall to interact with carbonate rocks is a function of the pH of the water. The potential for solution of calcium carbonate can be demonstrated by determining the chemical equilibria for rainfall which is given by

$$\frac{[H^+]\,[HCO_3^{-2}]}{[H_2CO_3]}=K\,H\,CO_3^{-2}10^{-6.4}. \qquad (11)$$

[1] The following chemical considerations are based on Garrels and Christ (1965), Back (1963), and F. Quiñones (oral commun., 1970).

where K is the equilibrium constant.
It is accepted that in the equilibria of carbonic acid in water, both CO_2 and H_2CO_3 molecules are present, but it has been customary to represent CO_2 as H_2CO_3.

The carbonate system in equilibria is represented by the relation

$$\frac{[Ca^{+2}]\ [CO_3^{-2}]}{[CaCO_3]} = KCaCO_3 = 10^{-8.3}. \qquad (12)$$

In both equations above, activities are expressed in moles per liter. For $CaCO_3$ the activity is unity. Further developing the equilibria for the constant of bicarbonate ions,

$$\frac{[H^+]\ [CO_3^{-2}]}{[HCO_3^-]} = KHCO_3 = 10^{-10.3} \qquad (13)$$

and adding the general equilibria equation for water

$$\frac{[H^+]\ [OH^-]}{[H_2O]} = 10^{-14.0} \qquad (14)$$

while taking the activity of H_2O as unity, the systems of equations can be solved as described by Garrels and Christ (1965).

To examine the influence of rainfall on the solution of the carbonate rocks, one must consider the chemical equilibria of the ions. From equation 11 we know that CO_2 and water ionize into H^+ and HCO_3^- forming H_2CO_3. From equations 11 and 12.

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{+2} + 2HCO_3^- \qquad (15)$$

which is the basic equation for the solution of $CaCO_3$. In the system, the equilibria are regulated by the CO_2 concentration; and changes in CO_2 will cause a shift of the equilibria. Taking the rainfall pH as 6.1 from table 5, or $[H^+] = 10^{-6.1}$ and substituting in equation 11

$$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{10^{-6.4}}{10^{-6.1}} = 10^{-0.3}. \qquad (16)$$

The equilibria of CO_2 is (from Garrels and Christ, 1965)

$$\frac{[H_2CO_3]}{PCO_2} = 10^{-1.47}, \qquad (17)$$

where P = partial pressure.
For a partial pressure of CO_2 in the atmosphere of the order of $10^{-3.5}$

$$[H_2CO_3] = 10^{-1.47} \times 10^{-3.5} = 10^{-5.0} \qquad (18)$$

and, substituting in equation 16

$$[HCO_3^-] = 10^{-0.3} \times 10^{-5.0} = 10^{-5.3}. \qquad (19)$$

Therefore the total amount of dissolved carbonates in rainwater would be

$$(CO_3^{-2})_{Sol} = [H_2CO_3] + [HCO_3^-] = 10^{-5.0} + 10^{-5.3} = 10^{-4.75} \qquad (20)$$

and the concentration of Ca^{+2} in equilibrium would be

$$[Ca^{+2}] = \frac{10^{-8.3}}{[CO_3]} = \frac{10^{-8.3}}{10^{-4.75}} = 10^{-3.55} \qquad (21)$$

which is equivalent to a maximum concentration of 11.2 mg/L of Ca^{+2} that can be dissolved by rainfall. Because the average concentration of calcium in rainfall from table 5 is 1.2 mg/L, we may conclude that the effective reactive ability of rainwater for calcite is almost totally available prior to the solutioning process on the limestone rocks. Once the reaction with the limestone is completed, a new equilibrium is reached. The nature of this mechanism is discussed in detail by Garrels and Christ (1965) who conclude that at a pH of 9.9 a concentration of $CaCO_3$ of 14 mg/L in the solute from the rainfall-calcite reaction will be in equilibrium —thus pointing out the low reactive capacity of rainwater. This reasoning is also followed by Birot and others (1967) who concluded that, to explain the high calcium content of some of the waters of the north coast limestone belt, additional CO_2 must be picked up from the soil by the percolating rainfall. In turn the CO_2 in the soil is obtained from the decomposition of organic acids into CO_2 and water. These are also the views first presented by Monroe (1966).

The relative importance of this enrichment in CO_2 from the breaking down of organic acids is examined by analyzing as an example the $CaCO_3$ dissolved from the Río Lajas basin which drains limestone terrane only. A mean annual base flow of about 0.1 m³/s is computed from figure 35 adjusted for the mean annual rainfall. From a concentration-discharge correlation similar to the one shown in figure 42, an average concentration of 200 mg/L of $CaCO_3$, coinciding with the low-flow field-measured sample of table 5, is obtained—an annual load from base flow of 630 tonnes per year. From the previous data for rainfall at a maximum reactive value of 28 mg/L of $CaCO_3$ (11.2 mg/L of Ca^{+2}), and 0.1 m³/s of base flow as the rainfall percolated, a total discharge load of 88 t/yr may be attributed to the effect of rainfall. If 88 t/yr $CaCO_3$ potential solution is by rainfall and 630 t/yr $CaCO_3$ is actual solution, then 542 t/yr $CaCO_3$ is derived from solution through CO_2 contributed from the soil. According to these data the enrichment in rainwater of CO_2 in the soil from the decomposition of organic acids is responsible for about 86 percent of the solution process, and the acidity of rainwater itself is responsible for 14 percent of the solution of the limestones. Birot and others (1967), from a series of samples collected during overland flow following a storm, estimated that at least three-fourths of the acidity was derived from CO_2 from the soil.

CARBONATE EQUILIBRIA

In calculating the degree to which the water of the north coast limestones is saturated with calcium carbonate, it must be realized at the outset that the computations are carried out with reference to pure calcite for which reasonable equilibrium constants are available. It is not known to what extent the computed results reflect field conditions, that is, whether the limestones depart substantially from pure components.

Back (1961) gives the two reactions

$$CaCO_3 = Ca^{+2} + CO_3^{-2} \qquad (22)$$

and

$$HCO_3^- \rightleftharpoons CO_3^{-2} + H^+ \qquad (23)$$

whose equilibrium constants are

$$K\ (CaCO_3) = \frac{[Ca^{+2}]\ [CO_3^{-2}]}{[CaCO_3]} \qquad (24)$$

and

$$K\ (HCO_3) = \frac{[CO_3^{-2}]\ [H^+]}{[HCO_3^-]} \qquad (25)$$

with $[CaCO_3] = 1$, and the basic definition of activity

$$[\ ] = m \cdot \gamma \qquad (26)$$

where m is the molality and γ is the activity coefficient. Solving for $[Ca^{+2}]$ from equation 24, inserting $[CO_3^{-2}]$ from equation 25, and making use of equation 26, one obtains

$$m\ Ca = \frac{K(CaCO_3)}{K\ (HCO_3)} \cdot \frac{1}{\gamma Ca \cdot \gamma HCO_3} \cdot \frac{[H^+]}{mHCO_3^-} \qquad (27)$$

Because interest is in the ratio of Ca (observed) to Ca (computed), equation 27 can be expressed as

$$\frac{mCa\ (obs.)}{mCa\ (comp.)} = \frac{K(HCO_3)}{K\ (CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 \cdot \frac{mCa\ (obs.)\ mHCO_3}{[H]} \qquad (28)$$

and using the symbol S (saturation) for the left hand side of the equation, and expressing molality in units of milligrams per liter and [H] as pH

$$S = \frac{1}{2.44 \cdot 10^9} \frac{K(HCO_3)}{K(CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 \frac{Ca \cdot HCO_3}{10^{-pH}} \qquad (29)$$

The ratio of the equilibrium constants and the product of the activity coefficients are a function of temperature and ionic strength, so that a function ϕ can be defined such that

$$\phi = 0.41 \frac{K(HCO_3)}{K(CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 = f(T,I) \qquad (30)$$

where

$$I = \text{ionic strength} = 1/2 \Sigma m_i z_i^2, \qquad (31)$$

where

m_i is the molality,
z_i is the charge of the ith ion in the solution, and
T is water temperature in degrees Celsius.

By keeping values of the ratio of the equilibrium constants near 1 (that is, taking out 10^{-2}) equation 29 becomes

$$S = \phi\ \ (T,I)\, Ca \cdot HCO_3 \cdot 10^{\{[pH]-11\}} \qquad (32)$$

The function $\phi(T,I)$, with the equilibrium constants and the activity coefficients taken from Back (1961), is graphed in figure 44 versus the ionic strength and temperature. With this and equation 32 one can compute the degree of saturation with respect to calcite of the water from the limestone belt.

In a discussion of the errors involved in these computations, Back (1961) states that pH, bicarbonates, and temperature must be determined in the field. The data of table 5 on pH and bicarbonates are given as determined in the laboratory and in the field, augmented by pH data from Back (1961), and the correlation between the two sets of data are shown in figure 45. The concentration of bicarbonates determined in the field is higher than the concentration of those analyzed in the laboratory by at most 20 percent (excluding one point that is 40 percent higher than the laboratory). Most are well within 10 percent of those determined in the laboratory. The pH tends to be lower in the field, especially, as expected, in tests of water from springs. Those samples that show a lower laboratory pH are not readily explainable and as it occurred to Birot and others (1967) in their sampling of karstic water, cannot be ascribed to random instrumental or operator's errors.

As is apparent from equation 32, the pH is overwhelmingly significant in the computation of satura-

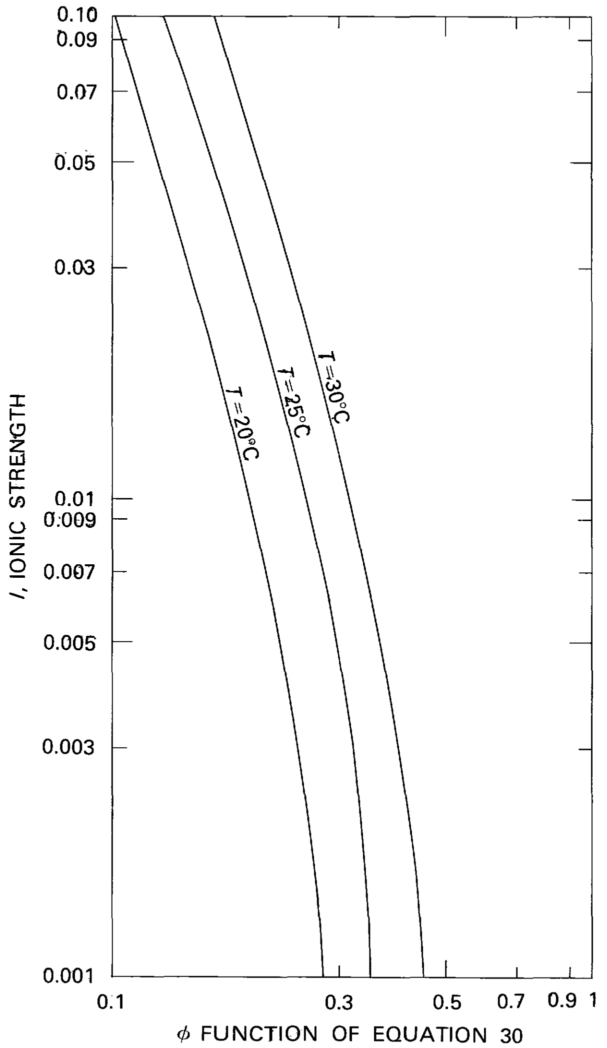

FIGURE 44.—Relation between ϕ of equation 30 and ionic strength and temperature.

tion. Further simplifications of equation 32 are possible from empirical expressions that relate the bicarbonate concentration and the ϕ function to the calcium concentration of the solution at an average temperature of 25°C. These relations are shown in figure 46, and the correlation between Ca and HCO_3 is well defined, with 95 percent of the points falling within an error band of ± 30 percent. The relationship Ca versus ionic strength shows larger scatter and it breaks down, as expected, for more concentrated water with ionic strength greater than 0.01. Still, the ϕ function of figure 44 shows that its range of values is quite restricted so that, for diluted solutions, even the approximate value of the ionic strength that can be obtained from the calcium versus ionic strength relation is sufficient to give workable values. So, by using the results of figure 46 saturation can be expressed as a function of calcium concentration and pH only as given by the equation

$$S=\phi'(\mathrm{Ca})^2\,10^{\{\mathrm{pH}-11\}} \qquad (33)$$

where ϕ' is a function of calcium concentration for a temperature of 25°C.

The expression above is graphed in figure 47 with the data of tables 5 and 6 plotted therein. Also shown as vertical lines is the deviation between the more precise saturation values computed from equation 32 and those from the empirical approximation using calcium and pH data only. The results are nearly the same except for a few of the empirical saturation values which depart somewhat from the theoretical ones. In no case is the saturation boundary crossed (that is, all the theoretically unsaturated or oversaturated samples are also from the empirical approximation). The lake samples, as previously noted, are undersaturated and only one, spring-fed, approaches saturation. At the other extreme, all the ground water (from routine well-water analyses) is either supersaturated or near saturation. For a clearer discussion the saturation ratios (exclusive of well data) are plotted in figure 48 next to the sampling points. The streams are all undersaturated before entering the limestone belt and become saturated or supersaturated before reaching their mouth. The sampling was not extensive enough to determine whether the saturation is progressively increased or decreased in a downstream direction. During a trip down the Río Guajataca, travertine was seen along the stream channel, so it is evident that some precipitation of calcium carbonate takes place. The combination of degree of saturation in relation to the stream velocity that leads to the precipitation of travertine is unknown. There is an indication that water from the Cibao Formation is more supersaturated than that of other limestone formations, but the reasons for this are not known.

RECONSTRUCTION OF THE GEOLOGIC AND HYDROLOGIC HISTORY

Paleontological evidence from the sequence of about 1,400 meters of limestone and minor sedimentary clastics that are now exposed on the north coast of Puerto Rico indicates deposition started about middle Miocene according to Gordon (1959), or middle Oligocene to middle Miocene according to most investigators, and continued possibly until middle Pliocene according to G. A. Seiglic (oral commun., 1969). Assuming that middle Miocene, middle Oligocene, and middle Pliocene correspond to

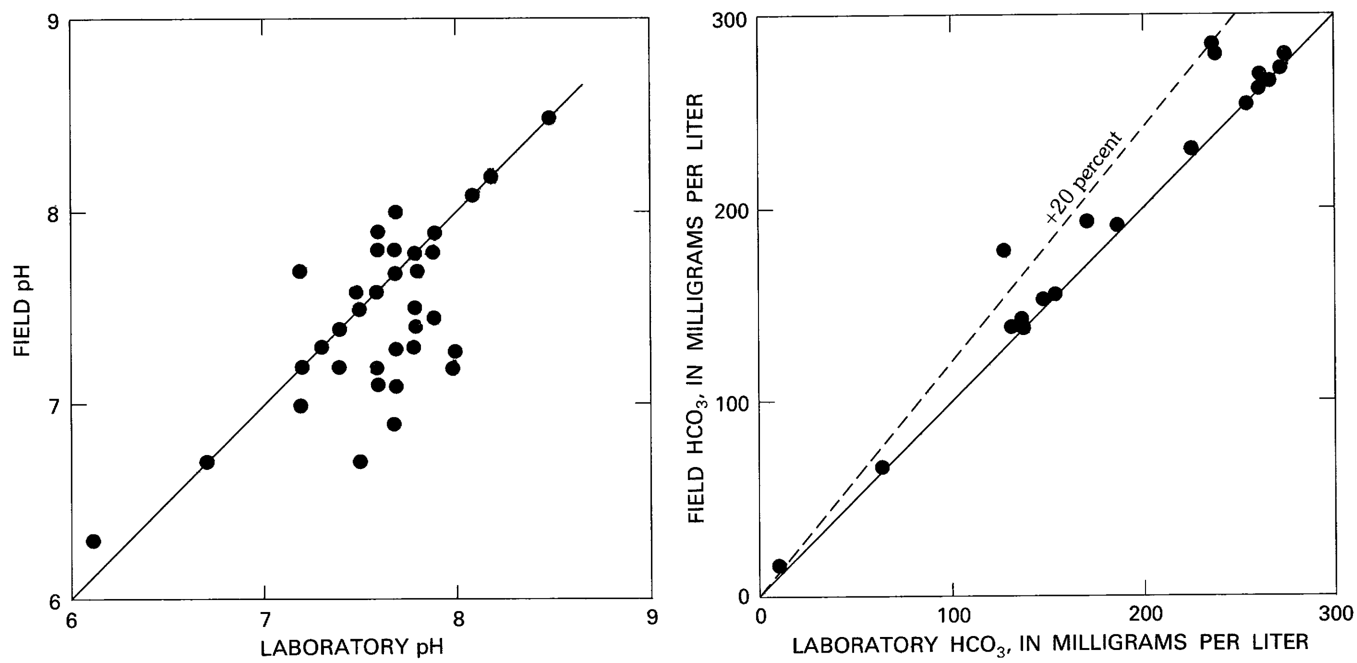

FIGURE 45.—Correlation between field and laboratory determinations of pH and bicarbonate concentration.

about 17, 32, and 5 million years ago, respectively, the rate of sedimentation would calculate to be about 0.12 mm per year (1,400 meters per 12 million years) or 0.05 mm per year (1,400 meters per 27 million years) making no adjustment for change of thickness resulting from compaction.

The rate of sedimentation based on a middle Miocene age for the oldest sediments appears to be too high if compared with maximum rates of sedimentation of 0.01 to 0.02 mm per year reported by Keunen (1950) for *Globigerina* ooze and the chalky deposits of the Paris basin. For this reason, the beginning of sedimentary deposition on the north coast of Puerto Rico is considered to be middle Oligocene in age—a view held in most of the literature. Sedimentation closed near the end of the Tertiary Period with the deposition of the Camuy Formation; the deposition of the Camuy was followed by or was contemporaneous with the arching up of the Puerto Rican platform.

On the basis of the hydrologic and geochemical data presented it is possible to determine, albeit roughly, the time when the limestones emerged from the sea and their dissolution began. Several assumptions and approximations are needed in making such an assessment:

1. The present bioclimatological conditions (vegetation cover and rainfall-evaporation) do not depart greatly from those of the past, either in quality or quantity.
2. It is possible to reconstruct the general configuration and height of the original limestone surface.
3. The physical and chemical properties of the dissolved material were not different from those measured on the material of the present surface.
4. No large vertical tectonic movement occurred, after the emergence of the limestones.
5. The lowering of the original limestone surface took place largely through the solution process.

Assumption 1 is justified by the fact that the limestone belt is presently as densely covered with vegetation as it can be and enrichment of CO_2 in the soil through the decomposition of organic matter should be at a maximum. Man's activities, with the accompanying increase of erosion and solution, are at a minimum within the general area and nearly absent in the more rugged part of the limestone belt. Therefore, the rock and water samples collected are free of or negligibly influenced by man. The rainfall-evaporation function has varied, no doubt, through geologic time. The consolidated sand dunes of the north coast bear testimony to both the lowered sea level of glacial times—hence to an increase of sand supply—and to lower rainfall (because under present rainfall conditions, vegetation grows readily nearly up to the strandline and would have trapped the sand available during periods of lower sea levels. However, glacial times would have increased the

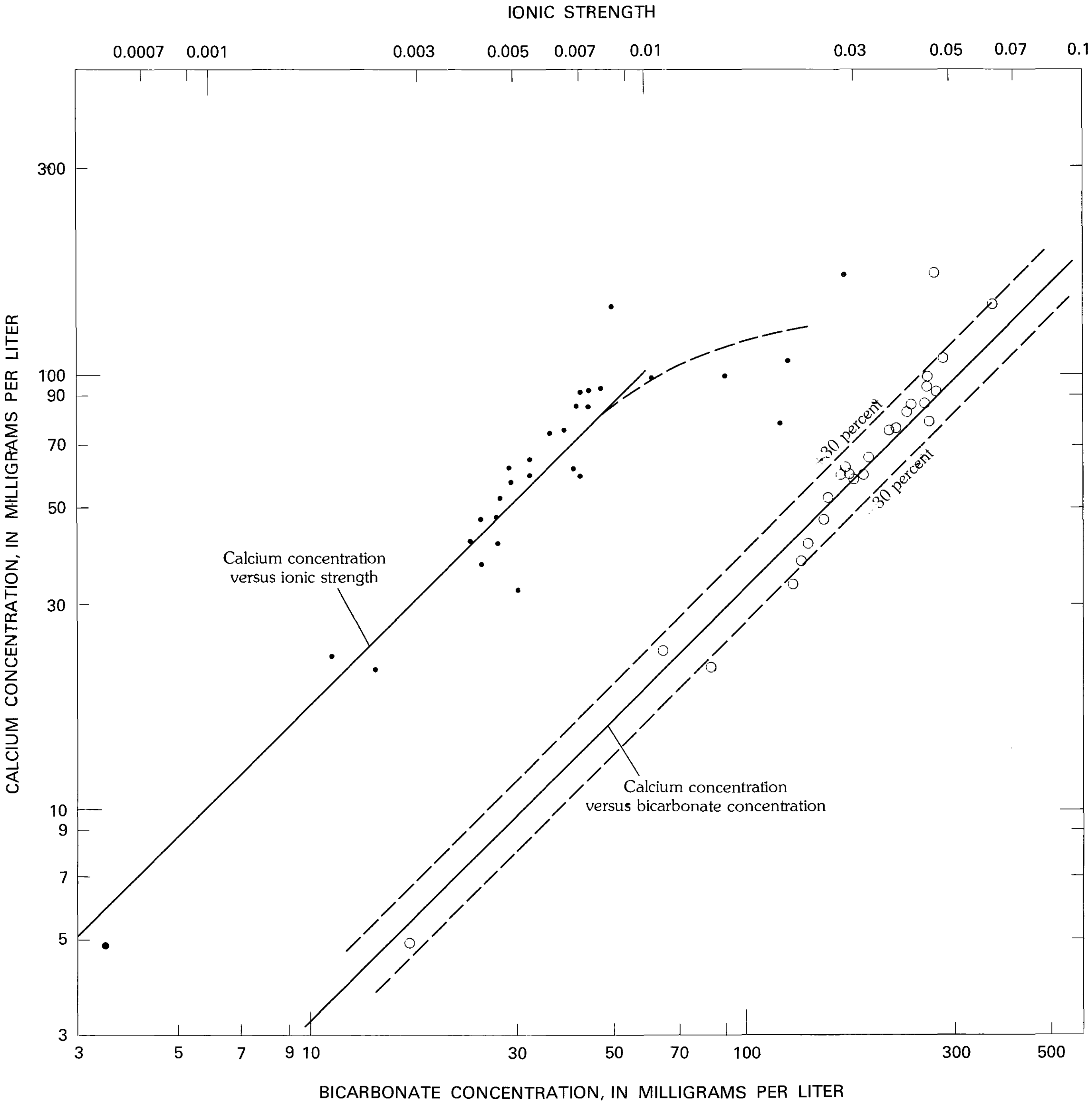

FIGURE 46.—Relation between calcium concentration and ionic strength and between calcium concentration and bicarbonate concentration.

limestone solubility through a lowering of temperature, so that some justification exists for using present rainfall-evaporation functions, and present calcium concentration values.

Assumption 2 is justified because the simple wedge structure and the uniformity of dip of the limestones permit a usable reconstruction of the height of the original surface. Of the other assumptions, 3 seems reasonable if some allowance is made for the more clastic nature of the original surface material especially toward the contact with the volcanic core; and 5 can accommodate with no great error the possible presence of an ancestral fluvial system formed on more clastic material, with lesser

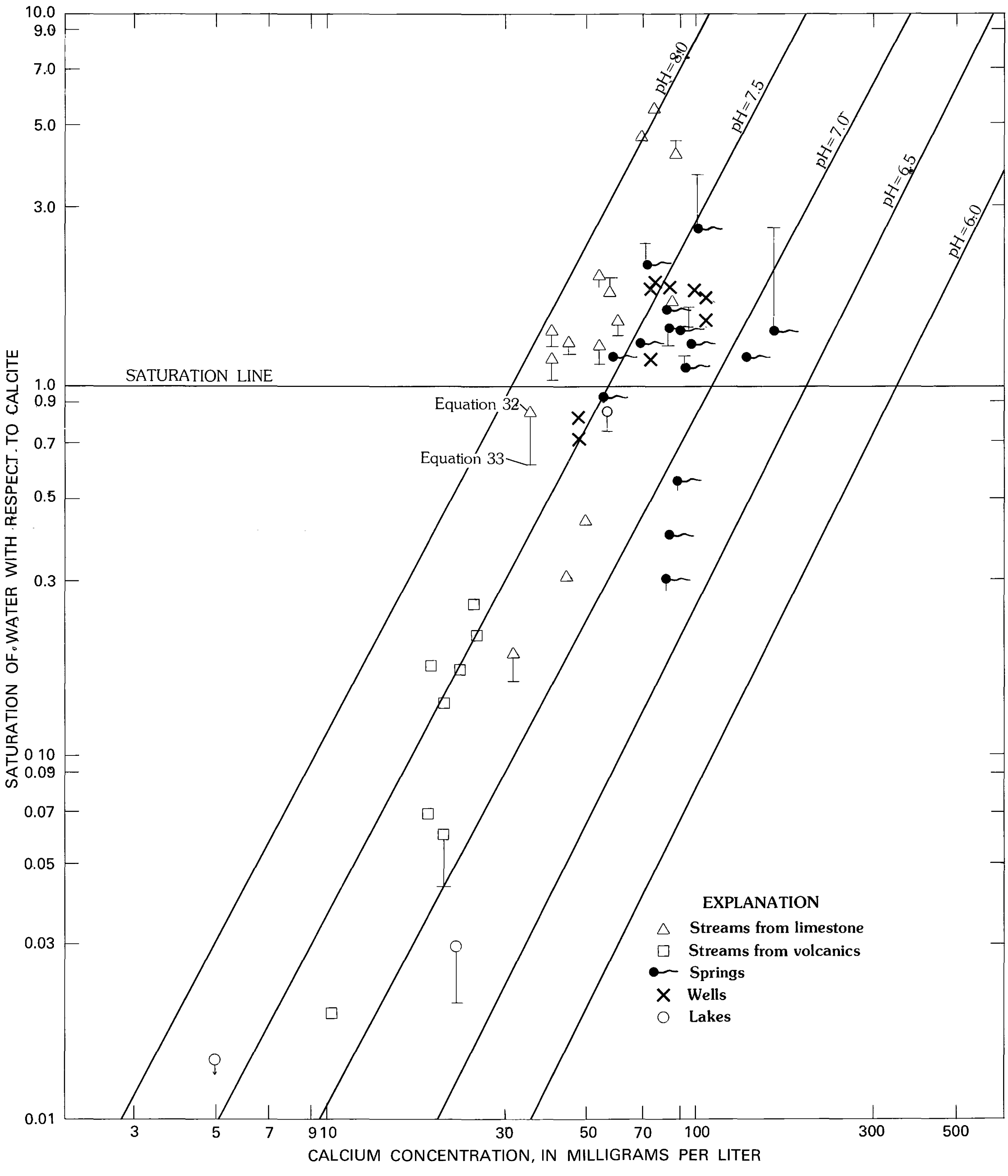

FIGURE 47.—Saturation of water with respect to calcite as a function of calcium concentration and pH. Vertical lines represent saturation values from equations 32 and 33 in text.

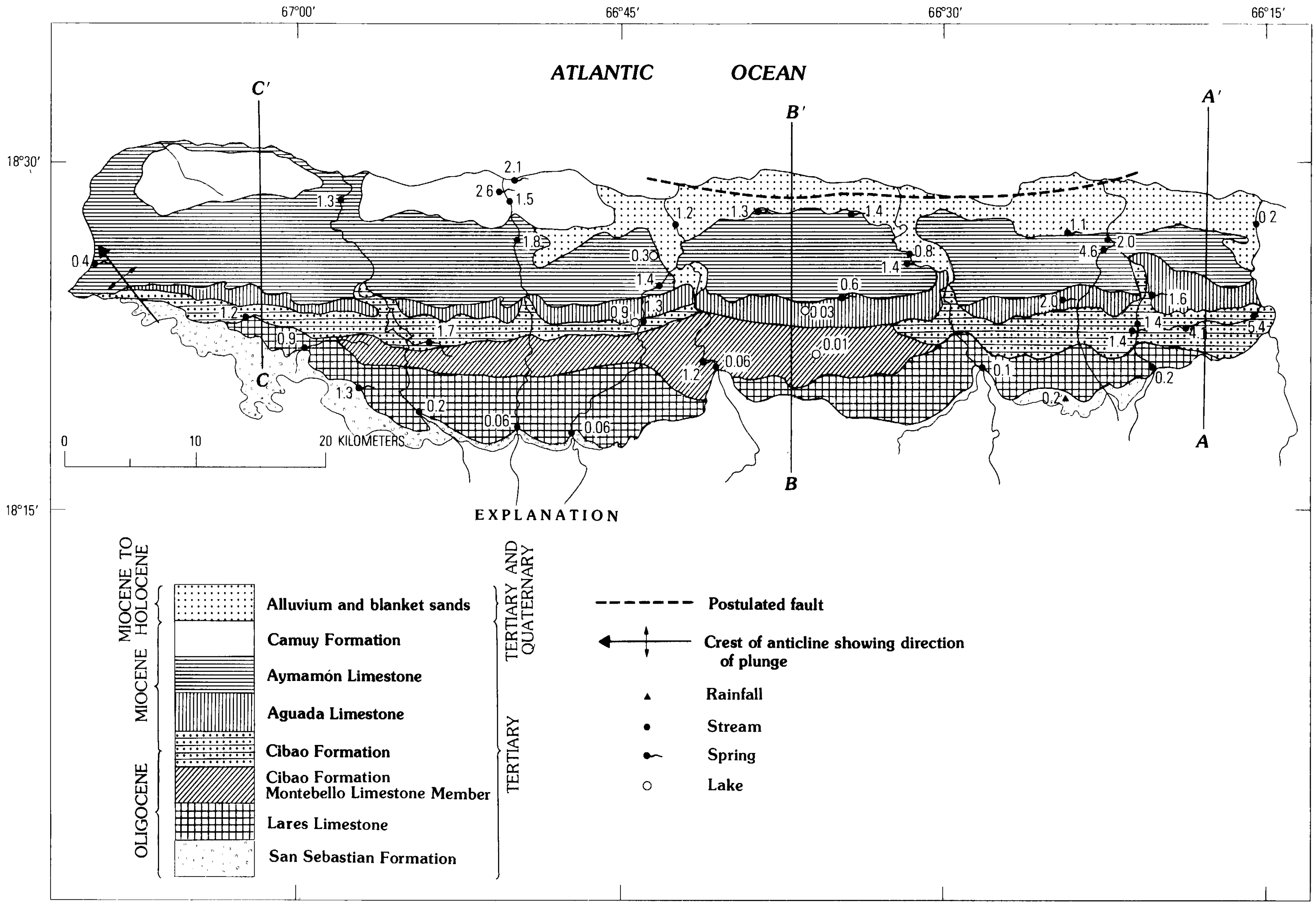

Figure 48.—Saturation ratio of waters from north coast limestone and volcanics.

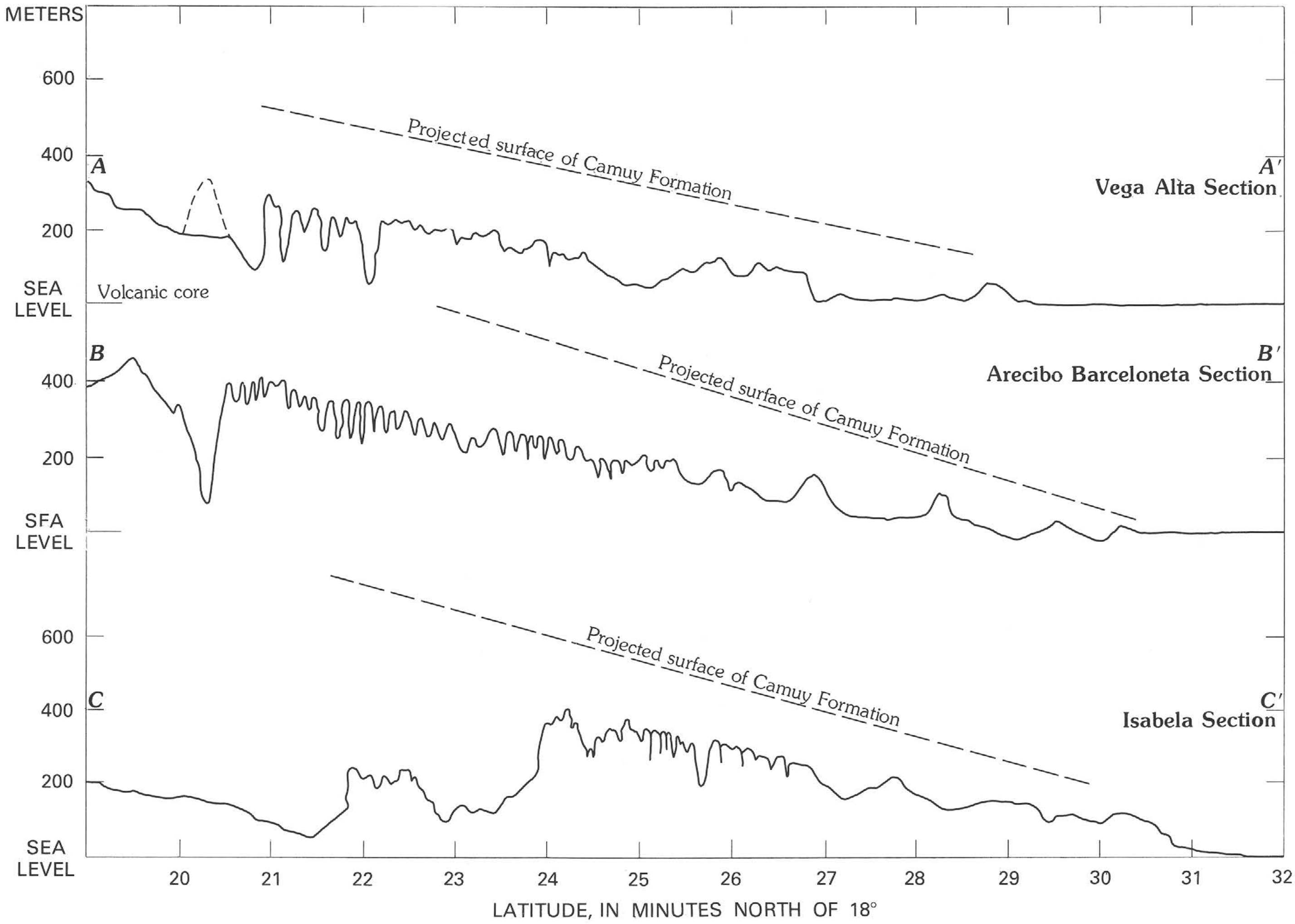

FIGURE 49.—Sections south-north through the limestone belt, with projected original surface of the Camuy Formation. (See figure 48 for location of sections.)

solution and more abrasion. No evidence is reported in the literature for or against assumption 4 other than possible tilting in Pleistocene time. The computations of the time when the limestones began to be dissolved shall be used to test this assumption.

An interpretation of profiles of the original surface is shown in figure 49 for three sections thought to be representative. The surface has been projected according to the dip of the formations and to their thinning southward as best as can be calculated from the detailed geologic maps of Monroe (1962, 1969a) and Briggs (1961), and from the few deep wells drilled in the area. The Camuy Formation is assumed to have been about 150 m thick near the coast, an estimated average based on the maximum thickness of 180 m for the Camuy given by Briggs and Akers (1965). The difference between the projected surface of the Camuy and the mean altitude of the present land surface (fig. 12) represents the amount of limestone removed since the time of emergence of the Puerto Rican platform. To compare the total volume of the calcium carbonate of the limestone removed by solution with the calcium carbonate concentrations measured in the water, the following factors are involved:

1. the calcium carbonate content.
2. the primary intergranular porosity.
3. the secondary porosity of the formation, accounting for the space between larger pieces of limestone; fractures, bedding planes or reef structures (figs. 50 and 51).

Data for 1 and 2 were obtained from table 4, and 0.1 was taken as the value of porosity for 3. Having obtained a slab thickness of pure calcium carbonate by the method just outlined, the next step was to obtain the thickness of calcium carbonate removed annually. For this, figure 23 was used together with

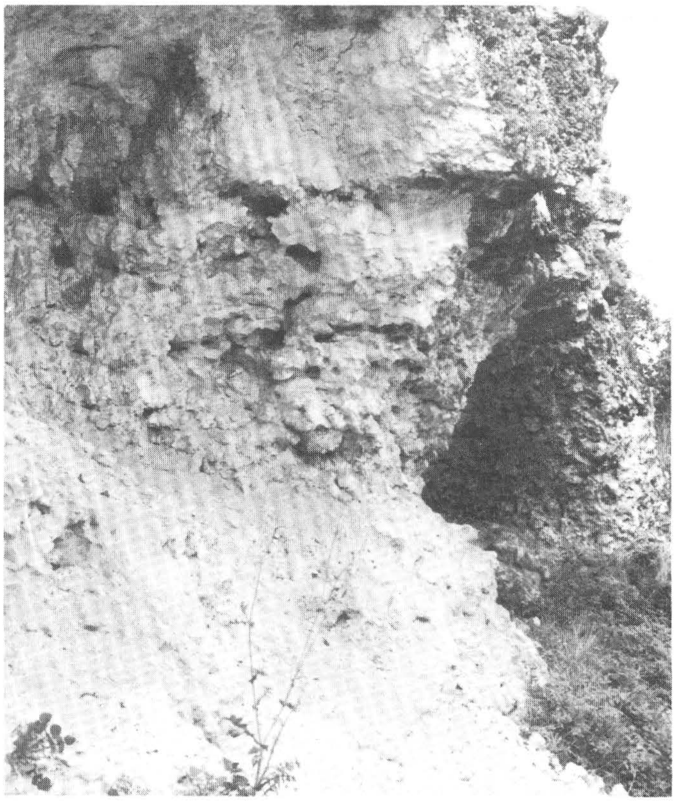

FIGURE 50.—Secondary permeability developed on chalky Aymamón Limestone. In this solution riddled limestone, water moves through much as through a sponge.

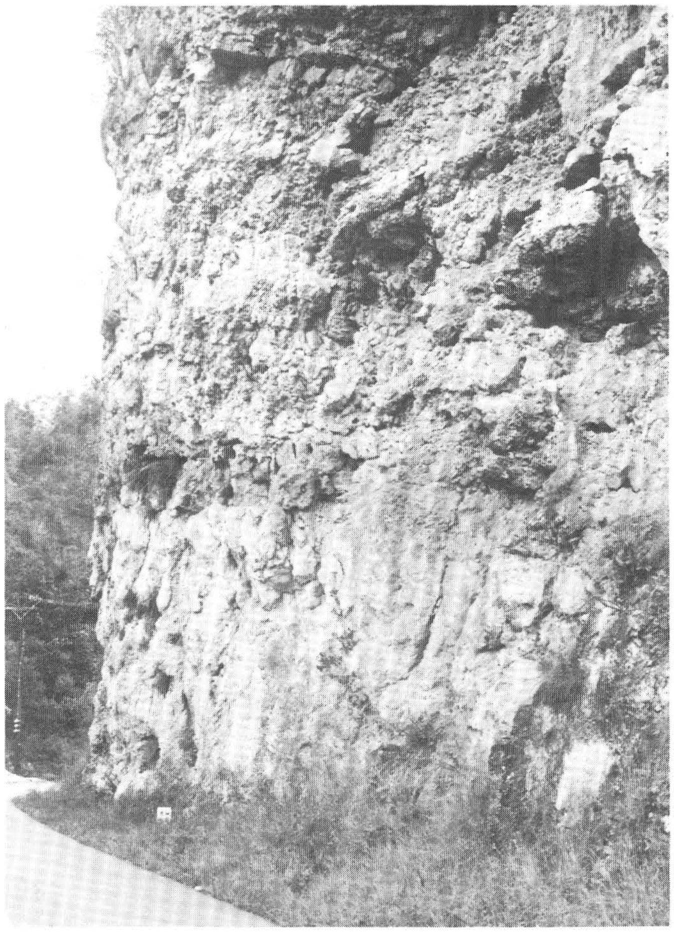

FIGURE 51.—Secondary permeability developed on Aguada Limestone. Water moves through openings between larger limestone clasts.

the average annual rainfall to compute the evapotranspiration and the subsequent discharge. The discharge is further assumed to carry an average concentration of 200 mg/L of $CaCO_3$ as obtained from the data of table 5. No adjustment was made for the $CaCO_3$ carried by rainfall—a negligible amount. An example is shown of the computations carried out for a piece of the cross section *B–B'* of figure 49 between latitude 18°22′ N. and 18°23′ N.

Altitude of original surface = 550 m
Mean altitude of present surface = 230 m
Thickness of removed slab = 320 m
Average $CaCO_3$ content = 0.85, average primary porosity = 0.15, average secondary porosity = 0.10
Thickness of equivalent $CaCO_3$ slab = $320 \times 0.85 \times 0.85 \times 0.90 = 210$ m
Average annual rainfall = 1,750 mm
Average annual evapotranspiration = 1,000 mm
Average annual outflow = 750 mm
Average concentration of $CaCO_3$ in outflow = 200 mg/L = 0.2×10^{-3} g/cm^3 = 0.074×10^{-3} (using a $CaCO_3$ density of 2.72 g/cm^3)

Average solution rate = 750 mm/yr $\times 0.074 \times 10^{-3} = 0.055$ mm/yr
Time needed to dissolve 210 m of $CaCO_3$ = 3.8 million years

This value of 3.8 million years is computed assuming only solution. Where fluvial drainage is present it is possible to compute the contribution to erosion of the abrasion process. In section *A–A'* of figure 49 between latitude 18°22′ N. and 18°23′ N. the karst surface is cut by a river. If we assume that the next 1-minute of latitude of the section immediately to the south underwent only solutioning from the same beginning time, we can write for the Vega Alta section:

Between latitude 18°21′ N. and 18°22′ N.

Solution rate × time = thickness of equivalent $CaCO_3$ slab, or 0.055 mm/yr $\times t_1 = 280$ m

Between latitude 18°22′N. and 18°23′ N.

(Solution rate + abrasion rate) × time = thickness of equivalent $CaCO_3$ slab, or
(0.055 mm/yr + abrasion rate) $t_2 = 290$ m

and, assuming that $t_1 = t_2$

$$\text{Abrasion rate} = 0.007 \text{ mm/yr}$$

and the relation between abrasion and solution rates is

$$\frac{\text{Abrasion rate}}{\text{Solution rate}} = \frac{0.007}{0.055}$$

or

$$\text{Abrasion rate} = 0.13 \text{ Solution rate.}$$

The calculations shown refer to an area where one small river has cut a canyon through the karst surface, perhaps through collapse of a former underground channel. The abrasion rate computed is probably a minimum.

The previous computations carried through in the area between latitude 18°21′ N. and 18°23′ N. of the Isabela section *C–C′* where a true fluvial system is present, give much larger results for abrasion: there

$$\frac{\text{Abrasion rate}}{\text{Solution rate}} = \frac{0.024}{0.063} = 0.38$$

or

$$\text{Abrasion rate} = 0.38 \text{ Solution rate}$$

and this can probably be considered a more significant ratio.

The solution rates and the time since solution began, computed for the three sections of figure 49, adjusted for abrasion rates where applicable, are shown in table 8. The variability in time since the onset of solution among the sections is probably due to sampling error except for the uniformly lower values of section *C–C′*. These lower values are thought to be indicative of the Pleistocene tilting and, taking an age of 3.6 to 4 million years as an average for the beginning of the erosion process or the time of emergence of the limestones, and 2.6 to 3.0 million years as the apparent age of the most seaward part of the Isabela section, the tilting can be dated as the difference in the two times, or about 1 million years ago.

Birot and others (1967) compute 2 million years as the time needed to erode a circular doline 100 m deep, and this is the same order of time computed here for an equivalent thickness of limestone.

The author's view is that tectonic movements have been responsible for the high Pleistocene terraces and eolianities described by Monroe (1968a) and Kaye (1959), but these investigators prefer eustatic movements (changes in sea level) as the explanation.

HISTORICAL DEVELOPMENT OF THE PUERTO RICAN KARST

According to the computations of the previous section, about 4 million years ago the north coast of Puerto Rico completed its emergence from the sea and the dissolution of the limestones began (it had probably started earlier near the contact of the limestones with the volcanic mountain core). A view of the area as it might have looked about 3.8 million years ago is shown in figure 53.

The drainage in the limestone belt in the west near the contact with the volcanics is assumed to have been southward to the ancestral Río Culebrinas, which was cutting a deep canyon at the volcanics-limestones contact. Subterranean drainage in a slight northwesterly direction is assumed to have been taken by all the rivers west of the city of Arecibo. All the rivers from the city of Arecibo east are presumed to have cut through the limestone belt by this time (fig. 52). It is further assumed that a mature karst existed in the east and that an incipient karst was forming in the west.

TABLE 8.—*Solution rates (in millimeters per year) and times (in million years) since solution began*

Latitude	Sections in figure 49					
	A–A′		*B–B′*		*C–C′*	
	Solution rate (mm per yr)	Time since solution began	Solution rate (mm per yr)	Time since solution began	Solution rate (mm per yr)	Time since solution began
18°29′	----	--	----	--	0.028	2.6
28′	----	--	----	--	.032	3.0
27′	----	--	0.035	4.0	.035	3.0
26′	0.035	3.7	.040	3.7	.042	3.3
25′	.040	3.2	.040	4.1	.049	3.4
24′	.040	3.8	.045	4.2	.052	3.6
23′	.045	3.5	.050	3.8	.056	[1] 3.6
22′	.050	[1] 3.5	.055	3.8	.063	[1] 3.6
21′	.055	3.1	.060	4.0	.063	[1] 3.6
20′	----	--	.060	4.0	----	--

[1] Adjusted for abrasion.

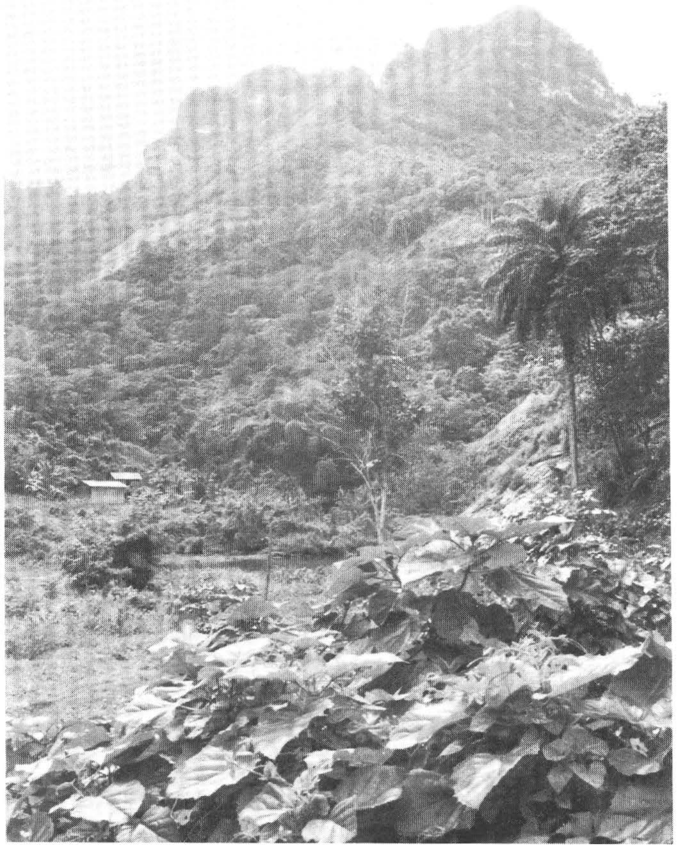

FIGURE 52.—Limestone knobs left as residuals on top of volcanic rocks by downcutting of the Río Grande de Arecibo.

Solution presumably continued to about 1 million years ago; during the process geomorphic development led to capture of part of the south-draining karst by the Río Guajataca, development of part of the Ríos Camuy and Tanamá, and the development of flood plains in the eastern rivers. At that time the karst between the Río de la Plata and the Río Grande de Arecibo is thought to have entered its final phase, characterized by the formation of mogotes covered by blanket sands weathered in situ or carried northward from higher altitudes. In the west, cockpit karst developed in the permeable formations, and a fluvial system formed on the more impermeable rocks.

About a million years ago tectonic activity raised the north coast limestones in the northwest and tilted eastward the entire Puerto Rican platform. The rise and tilt brought about a shift in the direction of drainage, as is interpreted from figure 54, a series of histograms of stream channel orientation for the various limestone formations. Qualitatively, attention is called to the multipeaked distribution of all the flow directions and to the flow directions

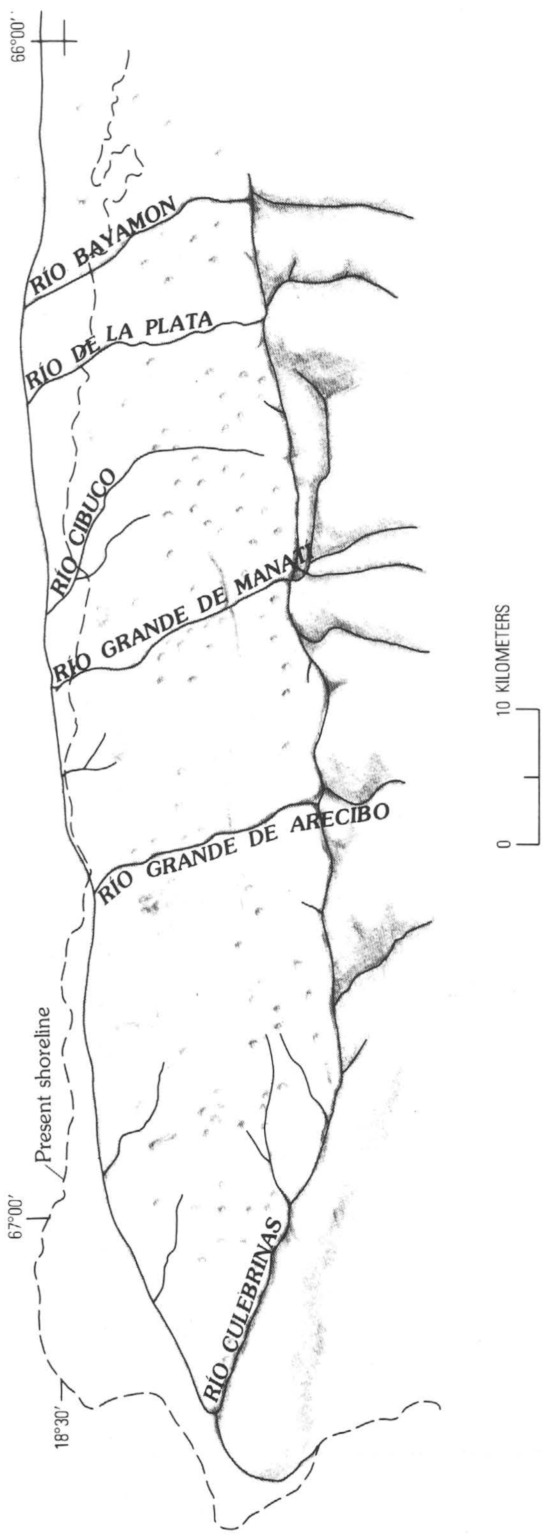

FIGURE 53.—A view of the north coast belt 3.8 million years ago.

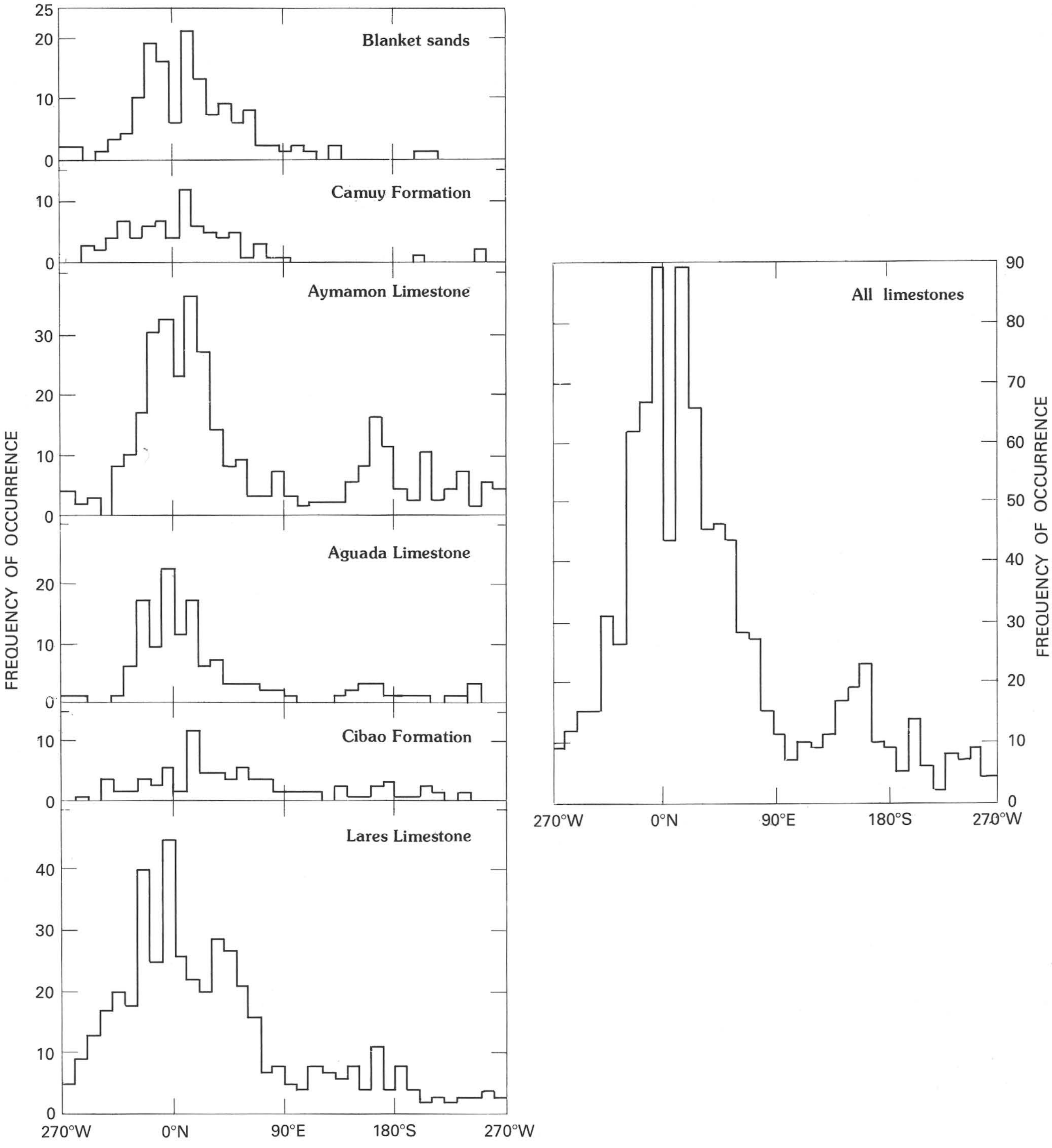

FIGURE 54.—Distribution of stream channel orientations in the north coast limestones.

of those formations exhibiting clearly multipeaked distribution .The main western peak in these cases (modal values of about $-10°$ or $350°$, is interpreted as a fossil drainage direction from pre-tilt times. Two formations are either single peaked (assuming that the ups and downs of the histograms are due to sampling errors) or weakly multipeaked: (1) the Camuy, which is the youngest, most lithologically variable, and most seaward formation, and (2) the Cibao, which is a formation that has a clearly developed fluvial system. The lack of a predominant peak in the histogram to show a preferential direction west of north is inferred to indicate that the abrasion process has erased the evidence of the vestigial drainage direction still present in the other formations. In the purer limestones the solution process has etched in depth the former paths of flow. It should also be noted in figure 54, that all mean values of the distributions would only indicate an orientation of stream channels in an eastward direction and thus fail to disclose the admittedly subjective assignment of some drainage to a westward direction as just discussed. The tilt of the Puerto Rican platform is also taken to have affected the directional pattern of subterranean drainage, leading to development of springs mainly on the west side of rivers, especially in the western part of the belt. The coastal swampy area east of Arecibo is also ascribed to the tilt, as is the raised shoreline west of Arecibo.

FACTORS OF KARSTIFICATION

The north coast Puerto Rican karst, with its peculiar landscape called "lunar" by Monroe (1968b) and, with Gallic sagacity, "á mamelons" by Birot and others (1967), is notably different from the classic karst of Yugoslavia: there are no uvalas (depressions 1 to 10 kilometers in diameter), no poljes, and karren or lapiez are scarce. Perhaps some forms of mogote karst are a local equivalent of the uvalas and poljes; certainly they do not look the same. Birot and others (1967) find it difficult to explain the differences of this karst from that of other areas, particularly that of the temperate zone. In a search for explanations temperate zone karst investigators suggest climatic differences, though they admit to having no final answer. Monroe, (1966) as already discussed, favors, lithologic and stratigraphic differences to explain the various landforms of the Puerto Rican karst; he has not yet compared this karst to that of other places. Traditionally, of course, climate, percentage of $CaCO_3$ in the rocks, and the regional structure have been set forth as the cause and, in particular, since most investigators of karst have been European, fracturing has invariably been suggested as the primary condition for the beginning of the karst. The Puerto Rican limestones of the north coast, however, are not obviously fractured as the European limestones are. Jointing is inconspicuous as can be seen from the photographs shown so far, including one (fig. 55) taken on a cut in the Lares Formation. There are, to be sure, open spaces between the larger pieces of limestone, through which water can percolate and even create vertical caves (fig. 56), but there are no vertical shafts or obvious fractures. The absence of joints, however, does not keep water from infiltrating; on the contrary it does so quite readily, much as it does in fine alluvial material or through soil, and even if the limestones had no void space between the larger clasts, water could infiltrate through the primary openings of the rocks. (See table 4.) The development of the karst only requires that water infiltrate—no significance is attached to the manner in which infiltration takes place.

Presently the limestones are being preferentially dissolved under the blanket sands because of the existence of the hardened limestone shell covering the mogotes, as explained by Monroe (1966). However, on a larger scale it may be argued, and Birot and others (1967) tacitly assume it, that there are regional fractures and joints such that dolines are formed at the intersection of the fracture planes and mogotes are formed in the area between the fractures. This view deserves testing, as clearly then there should be a preferential arrangement of

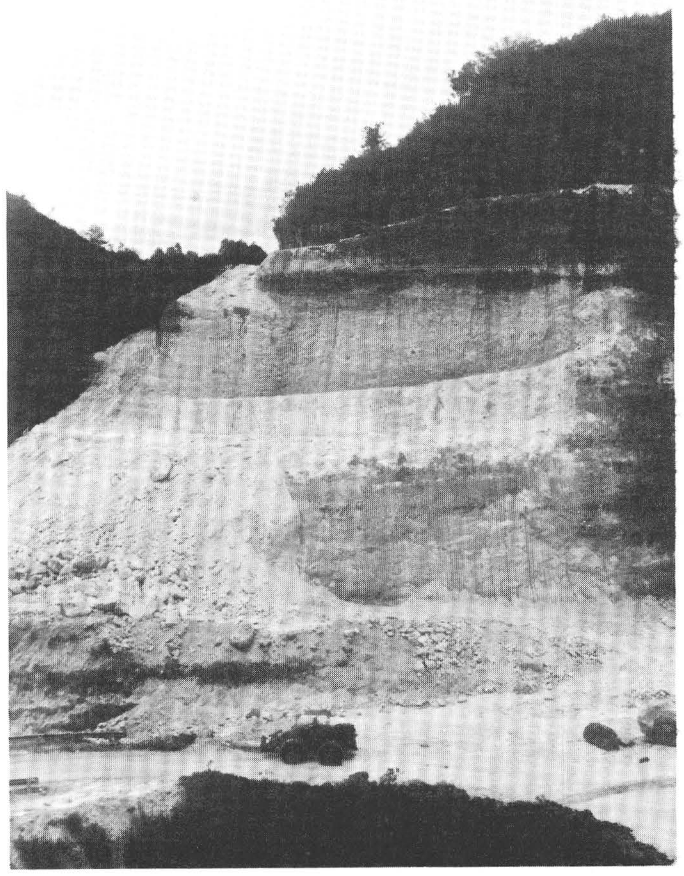

FIGURE 55.—A cut through a mogote of Lares Limestone. Note the absence of fracturing. (Photograph by Rafael Dacosta).

FIGURE 56.—Small cave in Aguada Limestone. Water percolates much as through soil layers—no fracturing.

dolines in some direction. A qualitative test of this interpretation is demonstrated in figure 57, which shows a random arrangement of dolines (drawn from a table of random numbers), two actual examples from the north coast karst, and an assumed geometrical arrangement of dolines. A distribution of orientations can be obtained by counting the number of dots recorded within a plastic strip (about 2.5 cm wide) superimposed and rotated on the various arrangements of dots of figure 57. Using six strips orientations and assuming equal count per orientation, valid intuitively for a random arrangement, a chi-square test can be used.

The results of this test, shown in table 9, indicate that dolines are located randomly within the space of the two sampled areas. As expected, the geometrical arrangement of dolines tested to be nonrandom. Therefore, it is concluded that water infiltrates through no preferential path and that dolines are randomly distributed. The flow directions that show preferential orientation at the scale of the entire belt resulted from the topographic gradient and were not the result of jointing or fracturing. (See Williams (1965), p. 67–80.)

Leopold and Langbein (1962) have investigated the development of river drainage networks and have derived by random walks river networks quite similar, at least on a gross scale, to the real ones. It appears that an equivalent condition is present in the karst of Puerto Rico through random arrangement of solutional features. If this is so then, it is not the "classical" European karst that we should look to for a more clear understanding of the beginning of karst development, and certainly it should not be taken as the standard to which other karsts are to be compared. The karst of the north coast of Puerto Rico, showing as it does, all degrees and shades of karstification, from the incipient stage forming on the raised platform of the northwest to the completed denudation of the northwestern coastal flats, offers a vast field of profitable investigation on its own. And because this karst appears to be the product of random solution on a structurally simple wedge and on relatively young unfractured limestones which, at places, seem to have the consistency of freshly deposited material (fig. 58), it may be regarded as the sequence of erosional stages which the limestone terrane goes through when newly emerged from the sea.

The question of rock hardness or density and fracturing is thought to be of crucial importance for determining the type of karst features that will develop on a carbonate-rock terrane. There are, for example, among the Cretaceous and older Tertiary limestones of Puerto Rico (fig. 1), areas where the rocks are fractured and indurated; in these areas the similarity (on a small scale) to the European karst becomes more apparent, for both karsts contain lapie fields and funnel-shaped dolines. Clearly the different morphologies cannot be explained by climatic differences because the climate where the Cretaceous and older Tertiary limestones are located is nearly the same as that of the north coast limestones. Even the dismissal of a lack of an extensive karst development on the limestone belt of the south coast because of an arid climate, may be erroneous as Moussa (1969) points out. Nonetheless one would expect climate to exert some influence on karst development and on its morphology in that the rate at which rock solution takes place, other things being equal, depends in part on the amount of net precipitation coming in contact with the limestones. Furthermore soils and vegetation are thicker and more abundant in humid than in arid areas and thus there is a better opportunity for the

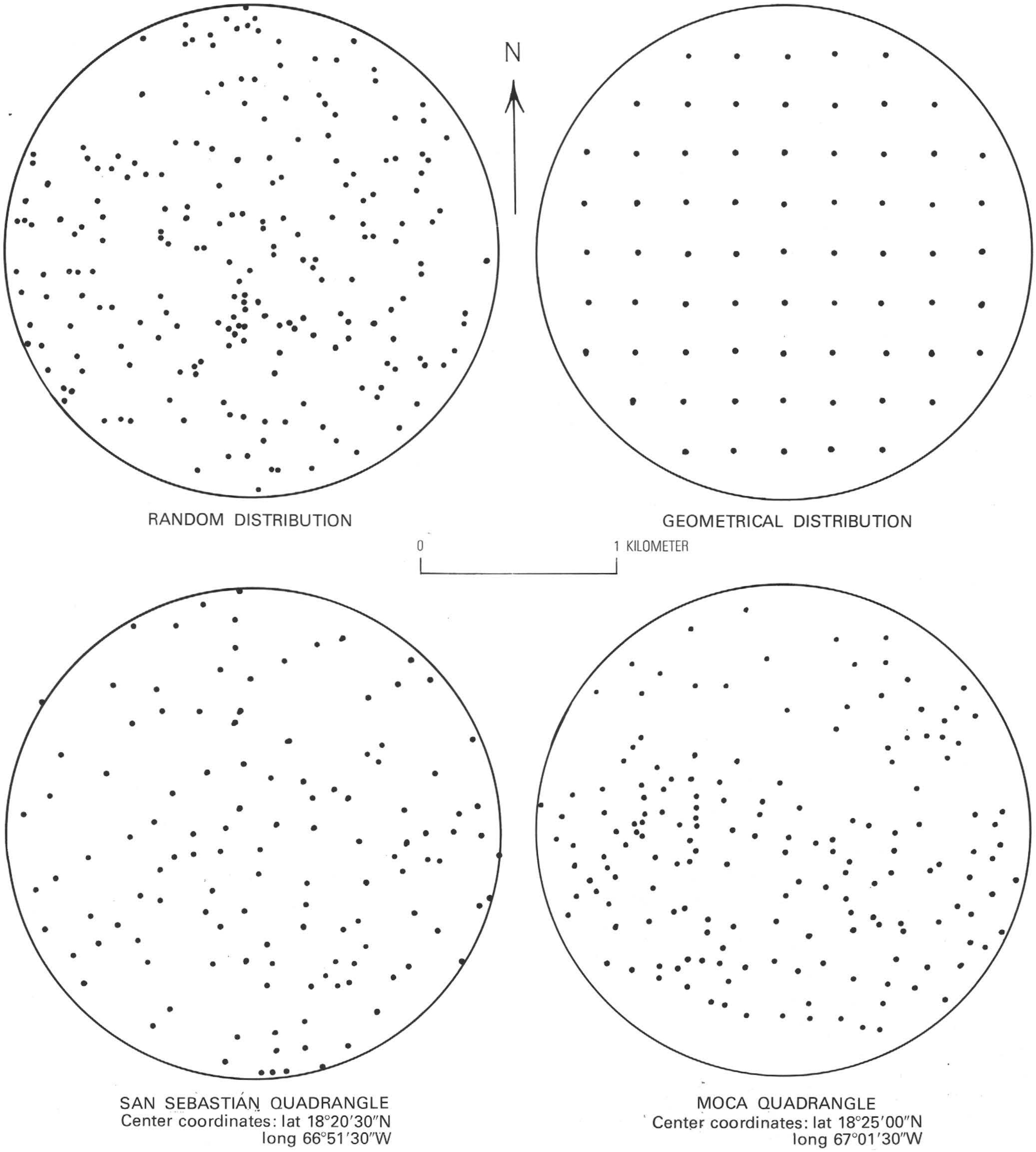

FIGURE 57.—Spatial distribution of dolines.

development of organic acids which contribute significantly to the solution process.

Clearly the $CaCO_3$ content of the rocks determines the threshold between the formation of a karst or a fluvial drainage (for example, the lithology of the Cibao Formation). Given that the limestones are sufficiently pure as to be readily dissolved by acidic water, it is thought that the two primary factors which determine the karst morphology at a given stage in time are vertical and lateral rock

TABLE 9.—*Chi-square test of doline orientation*
[Areal distribution shown in figure 57]

Orientation, degrees	Observed frequency, in percent				Theoretical frequency, in percent
	Random dolines	Grid-alined dolines	Actual dolines		
0–180	12	25	11	22	16.7
30–210	20	12	14	14	16.7
60–240	10	12	18	19	16.7
90–270	22	25	23	19	16.7
120–300	19	12	20	11	16.7
150–330	17	12	14	16	16.7
χ^2(5df)	6.67	13.54	5.95	4.73	---

permeability (either primary or from fracturing) and the primary porosity or rock density. Climate, lacking proof to the contrary, is tentatively placed at a lower level of importance.

SUMMARY AND CONCLUSIONS

The north coast limestone area of Puerto Rico is underlain by a sequence of six formations which range in age from middle Oligocene to middle Miocene (or as young as middle Pliocene(?)). These formations from oldest to youngest are known as San Sebastián Formation, Lares Limestone, Cibao Formation, Aguada and Aymamón Limestones, and Camuy Formation. All the formations, except for the first, which is mainly a claystone and the third which is a mixture of marl, chalk, sand, and clay, are nearly pure limestones. Little structural deformation is shown by the formations, and this broad mass of rocks can be described as forming a homocline gently inclined to the north.

All degrees of karst development can be found on the limestone surfaces except for the San Sebastián Formation and parts of the Cibao Formation; these two formations have developed a dendritic fluvial drainage. The surface and subsurface paths taken by precipitation falling on the karst are different from those found in fluvial drainage basins and even in alluvial ground-water provinces. In terms of the water balance, however, most of the

FIGURE 58.—The limestone is so soft, in places, that a knife is sufficient for this modern sculptor. Montebello Limestone Member of Cibao Formation at entrance of Arecibo Astronomical Observatory. (Photograph by Rafael Dacosta).

rainfall on the karst can be accounted for by streamflow or lagoonal discharge, when consideration is given to losses by evapotranspiration.

The climatic factors which condition this discharge are:

1. Average rainfall ranging from 1,550 mm on the coast to 2,300 mm at the higher elevations, or 1,800 mm as an overall average.
2. Incoming total solar radiation (direct plus diffuse sky), expressed as about 4,000 mm of evaporated water for cloudless sky or about 2,900 mm under the average cloud cover; resulting in an average potential evapotranspiration of about 1,500 mm.

For the average climatic conditions, the actual evapotranspiration is about 1,100 mm and the discharge is about 650 mm. The discharge may follow surface or subsurface paths whose pattern is controlled by the karst development. In the impure Cibao Formation and in the northwestern part of the Lares Limestone area, discharge is predominantly by surface drainage with subsequent infiltration in the karst of the Aguada Limestone, where the Cibao dips under it. Elsewhere in the karst the discharge is subsurface partly as transient tributary flow to those rivers alined in the general direction of the ground-water flow (south to north) and partly as saturated flow in the areas between the rivers.

The ground-water flow is under water-table conditions in the Aymamón and Aguada Limestones; discharge occurs in a strip near the coastline along a freshwater–seawater interface created by the difference in density between freshwater and seawater. East of Arecibo, much of the ground water discharges landward of the shoreline, in springs, lakes, and swamps, and is dissipated by evapotranspiration or by surface outflow to the sea. The direct discharge to the sea in this area probably emerges uniformly (rather than through springs) through the seabed and diffuses into the sea. West of Arecibo, and in increasing amounts toward Aguadilla, however, the ground-water discharge appears to be predominantly on the seaward side of the shoreline and may emerge in places as spring flow through the sea bottom.

In the downdip parts of the Montebello Limestone between Arecibo and Mantatí, the ground-water flow is under artesian conditions, confined by low-permeability layers of massive limestone and by certain nearly impermeable sections of the Cibao. The artesian flow emerges through submarine outflow areas at an unkown distance from the coast and possibly, in part, through the fault proposed by Briggs (1961) into the swampy areas of Caño Tiburones and Laguna Tortuguero.

There is an indication that the lateral permeability of the aquifer decreases exponentially with stratigraphic depth, ranging in value from about 1 cm/sec for the upper part of the Aymamón Limestone to 10^{-4} cm/sec for the basal Lares. No data are available for the vertical permeability although it can be inferred that it must be high because the water table is but a few meters above sea level in certain parts of the upper part of the Aymamón where the altitude of the land surface is more than 100 meters.

The water table is extremely flat in the most seaward Aymamón thus reflecting its high permeability. The increase in water-table gradient through the Aguada is ascribed to its relatively low lateral permeability and to the effect of the underlying impermeable Cibao. In the Cibao and the Lares the water table is again quite flat, possibly indicating that lateral flow through the water-table zone is less significant than downdip flow into the artesian system.

Streamflow from the volcanic terrane south of the limestones is increased during rainy periods by contribution from the karst, mainly by shallow transient subsurface flow through solution channels. The base-flow component of streamflow is less in basins in limestone than in volcanic terrane. On an annual basis, water-budget results indicate, however, that the flow of the rivers, after they have traversed the limestone belt, is about the same as it would have been had they continued flowing on volcanic terrane.

The flood plain provides a dampening effect on the storm runoff, absorbing part of the floodflow through bank storage, and releasing it later as base flow. However, one flood plain, the Río Grande de Arecibo, seems to be responsible for an overall apparent loss of flow. This loss is probably flow that bypasses this basin to emerge as spring flow in Caño Tiburones.

It is not possible to define a unique drainage area for that portion of the limestone belt that is drained by Caño Tiburones and the Río Grande de Arecibo because the base flow of Caño Tiburones is almost all ground-water flow from much of the belt to the south, whereas its direct runoff is from the area of the Caño itself. The best interpretation that can be made of the flow pattern and associated drainage areas of the north coast limestones is shown in figure 59.

The overwhelming effect of the limestones on the chemical quality of the water is to increase its bicarbonate and, therefore, its calcium concentration. Silica content in the limestone water is less than half (6–10 versus 15–30 mg/L) that found in the waters from the volcanic terrane.

The acidity of rainfall is insufficient to explain the measured quantity of $CaCO_3$ in the limestone water, and it is calculated that as much as 86 percent of the limestone solution takes place mainly through the enrichment of rainwater with CO_2 by the decomposition of organic material in the soil. Except for the water of lakes resting on terra rossa, most limestone waters are saturated or supersaturated with respect to calcite. Some of this calcite is probably reprecipitated as is evidenced by the crystalline limestone and the stalactitic deposits seen in most roadcuts. On the average, about 0.047 mm per year of $CaCO_3$ is discharged with the water flowing out of the limestones. Accordingly, the average land-denudation rate from solution is about 0.070 mm per year. Scant evidence indicates that abrasion in fluvial systems contributes about another 40 percent to the calculated denudation rate based on solution only.

A span of about 4 million years is computed as the time it would take present denudation rates to reduce a reconstructed original limestone surface to the present land surface. It is inferred, therefore, that the limestones of the north coast of Puerto Rico emerged from the sea about 4 million years ago. Some lower computed ages for the northwestern part of the limestone belt are thought to be indicative of later emergence related to the eastern tilting of the Puerto Rican platform as reported in the literature. By difference between the computed lower ages (about 3 million years ago) and the average, this eastern tilting of the Puerto Rican platform is considered to have occurred about 1 million years ago.

Geomorphic data on orientation of river courses indicate that the present drainage pattern, oriented slightly to the east and in accord with the topographic slope, is superimposed on a vestigial pattern slightly oriented to the west. These drainage patterns are thought to be supporting evidence for the tilting, as is the fact that karstic springs are most prevalent on the west side of river valleys.

An analysis of orientation and distribution of sinkholes reveals no preferred orientation. Thus surface solution is inferred to take place as an areally random process. The absence of preferred

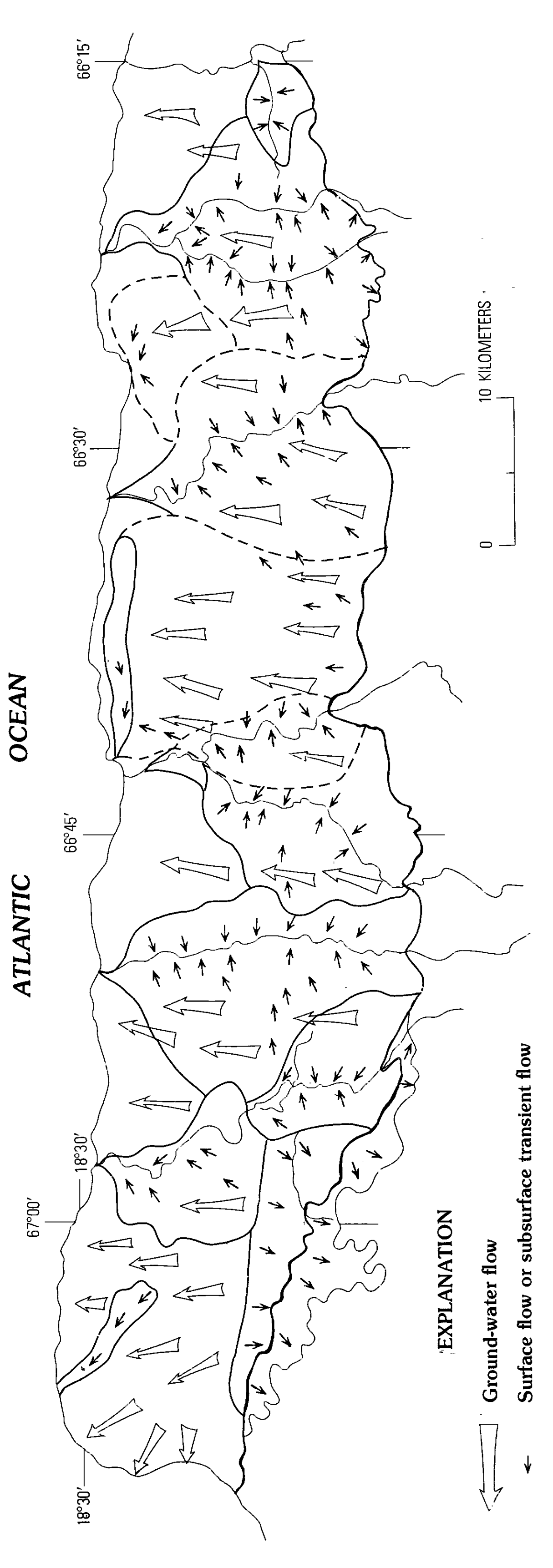

FIGURE 59.—Flow patterns and drainage areas of the north coast limestones.

orientation is taken to imply that large scale limestone joints are rare or absent.

Consideration of the processes that form the surface features of karst on soluble, unjointed, and unfractured limestones in Puerto Rico indicates that the primary controls are the distribution of lateral and vertical permeability and the primary porosity of the rocks. Climate is considered to be of lesser importance.

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By Jesús Rodríguez-Martínez

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Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
mile (mi)	1.609	kilometer
square foot (ft^2)	929.0	square centimeter
square mile (mi^2)	2.590	square kilometer

Temperature: Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = 1.8 x °C + 32

Transmissivity: the standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [($ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form of this unit, foot squared per day (ft^2/d), is used for convenience.

Abbreviated water-quality units used in this report:

mg/L milligrams per liter
µS/cm microsiemens per centimeter at 25 degrees Celsius

Acronyms used in this report:

MSL Mean Sea Level
USGS U.S. Geological Survey

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Abstract

The North Coast Limestone aquifer system of Puerto Rico is composed of three regional hydrogeologic units: an upper aquifer that contains an underlying saltwater zone near the coast, a middle confining unit, and a lower aquifer. The upper aquifer is unconfined, except in coastal areas where it is locally confined by fine-grained surficial deposits. The upper aquifer is mostly absent in the Río Piedras area of northeastern Puerto Rico. The confining unit is composed of calcareous claystone, marl, chalky and silicified limestone, and locally clayey fine-grained sandstone. Test hole data indicate that the confining unit is locally leaky in the San Juan metropolitan area. An artesian zone of limited areal extent exists within the middle confining unit, in the central part of the study area. The lower aquifer mostly contains ground water under confined conditions except in the outcrop areas, where it is unconfined. The lower aquifer is thickest and most transmissive in the north-central part of the study area. Water in the lower aquifer is fresh throughout much of the area, but is brackish in some areas near San Juan and Guaynabo.

West of the Río Grande de Arecibo, the extent of the lower aquifer is uncertain. Data are insufficient to determine whether or not the existing multiple water-bearing units in this area are an extension of the more productive lower aquifer in the Manatí to Arecibo area. Zones of moderate permeability exist within small lenses of volcanic conglomerate and sandstone of the San Sebastián Formation, but in general this formation is not a productive aquifer.

Transmissivity values for the upper aquifer range from 200 to more than 280,000 feet squared per day. The transmissivity values for the upper aquifer generally are highest in the area between the Río de la Plata and Río Grande de Arecibo, where transmissivity values have been reported to exceed 100,000 feet squared per day in six locations. Transmissivity estimates for the lower aquifer are highest in north central Puerto Rico, where the Lares Limestone and the Montebello Limestone Member of the Cibao Formation have transmissivities as high as 500 and 3,600 feet squared per day, respectively.

INTRODUCTION

The North Coast Limestone aquifer system is an important source of ground water in Puerto Rico. It consists of a highly karstified carbonate platform sequence of middle Tertiary age and extends eastward 85 miles (mi) from Rincón, in western Puerto Rico, to Loíza in northeastern Puerto Rico (fig. 1).

This aquifer system is composed of three main hydrogeologic units: an upper aquifer and a lower aquifer, separated by a confining unit of variable thickness (Giusti, 1978). Although the upper aquifer has been developed extensively in some areas, relatively little is known about the aquifer system, particularly the lower aquifer. To gain a better understanding of this regional aquifer system, the U.S. Geological Survey (USGS), in cooperation with the Commonwealth of Puerto Rico Department of Natural and Environmental Resources, conducted a study of the hydrogeology of the North Coast Limestone aquifer system from 1983 to 1988.

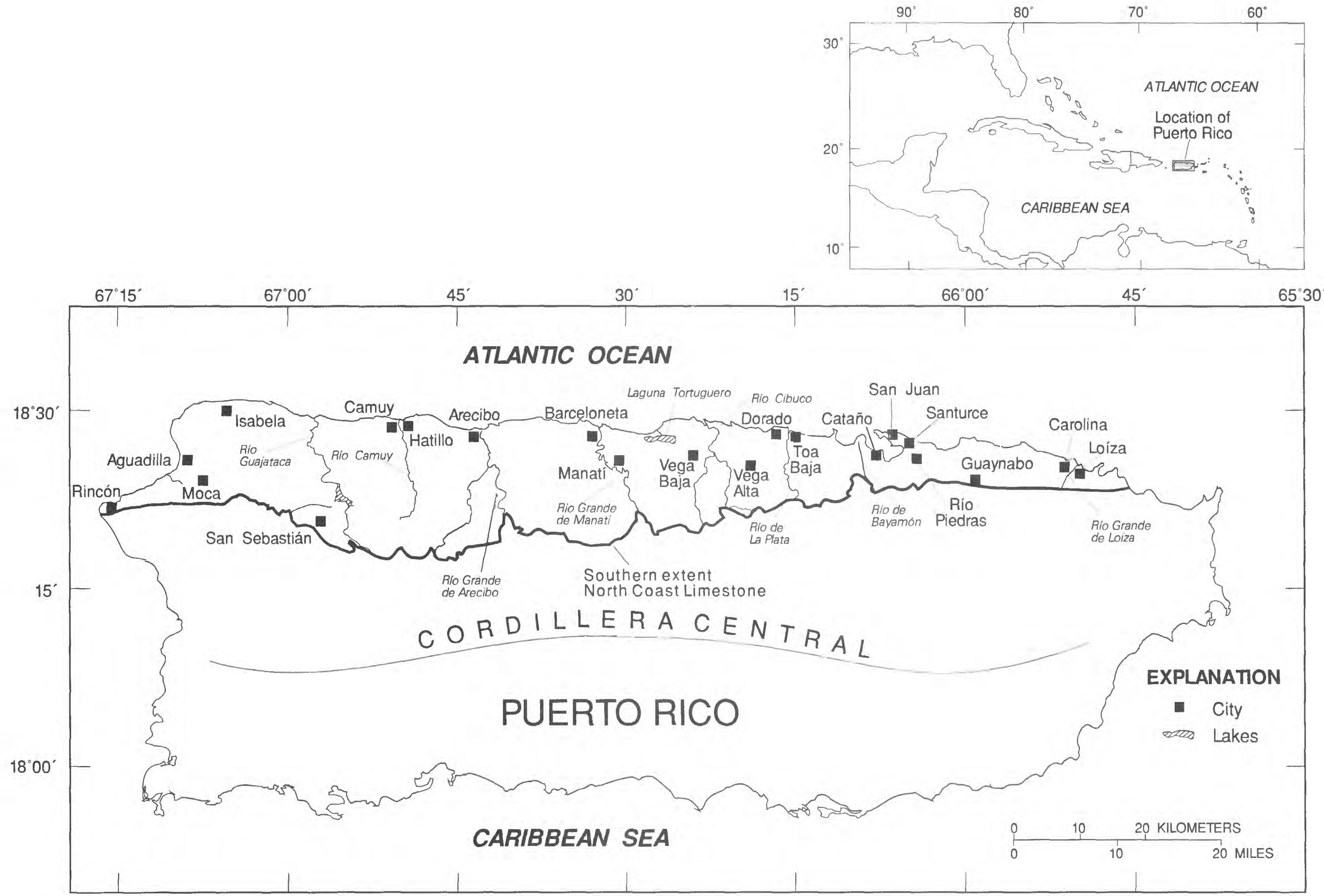

Figure 1. Areal extent of the North Coast Limestone of Puerto Rico.

Purpose and Scope

The purpose of this report is to describe the regional hydrogeologic units and the hydrogeologic framework of the North Coast Limestone aquifer system. The regional aquifers and confining units have been mapped on the basis of relative permeability and hydraulic continuity of geologic materials penetrated by a series of deep test wells and test holes drilled during the study (fig. 2). Lithologic, geophysical, and hydraulic data for the test wells and test holes and from other wells in the area were also used to prepare a series of hydrogeologic sections showing the variations in the lithology and thickness of the main hydrogeologic units in the study area. These hydrogeologic sections are presented in this report, along with maps showing the distribution of estimated ranges of transmissivity for the major aquifers in the North Coast Limestone.

Geographic Setting

The North Coast Limestone of Puerto Rico underlies about 700 mi^2 in the northern one-third of Puerto Rico and extends eastward from Rincón in the western part of the island to Loíza (fig. 1), a distance of about 85 mi. The North Coast Limestone extends from the Atlantic Ocean southward to a central east-west ridge that is part of the Cordillera Central Mountain Region. The outcrop area of North Coast Limestone is approximately 11 mi wide near Camuy and narrows to 2.25 mi near San Juan.

The North Coast Limestone is drained by eight major rivers that originate in the mountainous volcanic terrane to the south. These rivers flow predominantly north to the Atlantic Ocean.

The surface exposure sequence of middle Tertiary age is characterized by tropical karst topography. In the northwestern part of Puerto Rico, the karst topography is characterized by high relief and deeply entrenched river channels or rivers with subterranean courses in some areas. In the north-central part of the island, the land surface is characterized by numerous karst features including sinkholes and limestone hills (mogotes). In this part of the island, dissolution processes generally are still very active in the intermogotal areas. The karst topography in the eastern part of the island, which includes the municipalities of San Juan and Loíza, is in an older stage of development. There, the karst development is characterized by low topographic relief with little or no active dissolution of limestone, and by surface, rather than underground drainage (Monroe, 1976).

Previous Hydrogeologic Studies

The first study of the North Coast Limestone was conducted by McGuinness (1948), as part of a general reconnaissance of the ground-water resources of Puerto Rico. Subsequent hydrogeologic studies in the North Coast Limestone, prior to 1973, are summarized by Giusti (1978). In his report, Giusti discussed the hydrogeology of the North Coast Limestone karst, placing emphasis on the upper aquifer. Since 1973, a series of hydrologic investigations in parts of the North Coast Limestone have been carried out by the USGS in cooperation with various agencies of the Commonwealth of Puerto Rico (Anderson, 1976; Gómez-Gómez, 1984; Torres-González and Wolansky, 1984; Torres-González, 1985a and 1985b; Quiñones-Aponte, 1986; Gómez-Gómez and Torres-Sierra, 1988). None of these studies, however, described the hydrogeologic framework of the lower part of the aquifer system in detail.

Method of Study

The geologic and hydrogeologic framework of Puerto Rico's North Coast Limestone belt is based largely on core and hydrologic data collected from 15 deep test wells, mostly drilled to depths exceeding 1,500 ft (fig. 2 and table 1), and on lithologic as well as hydrologic data from three other existing wells. These deep test wells were drilled as part of a cooperative Commonwealth of Puerto Rico-USGS investigation to evaluate the water-resources potential and to map the extent of an artesian limestone aquifer of northern Puerto Rico. Cores were collected using a reverse-air dual tube drilling method that can be used to collect continuous core samples of 10-cm diameter. Limestone core samples considered

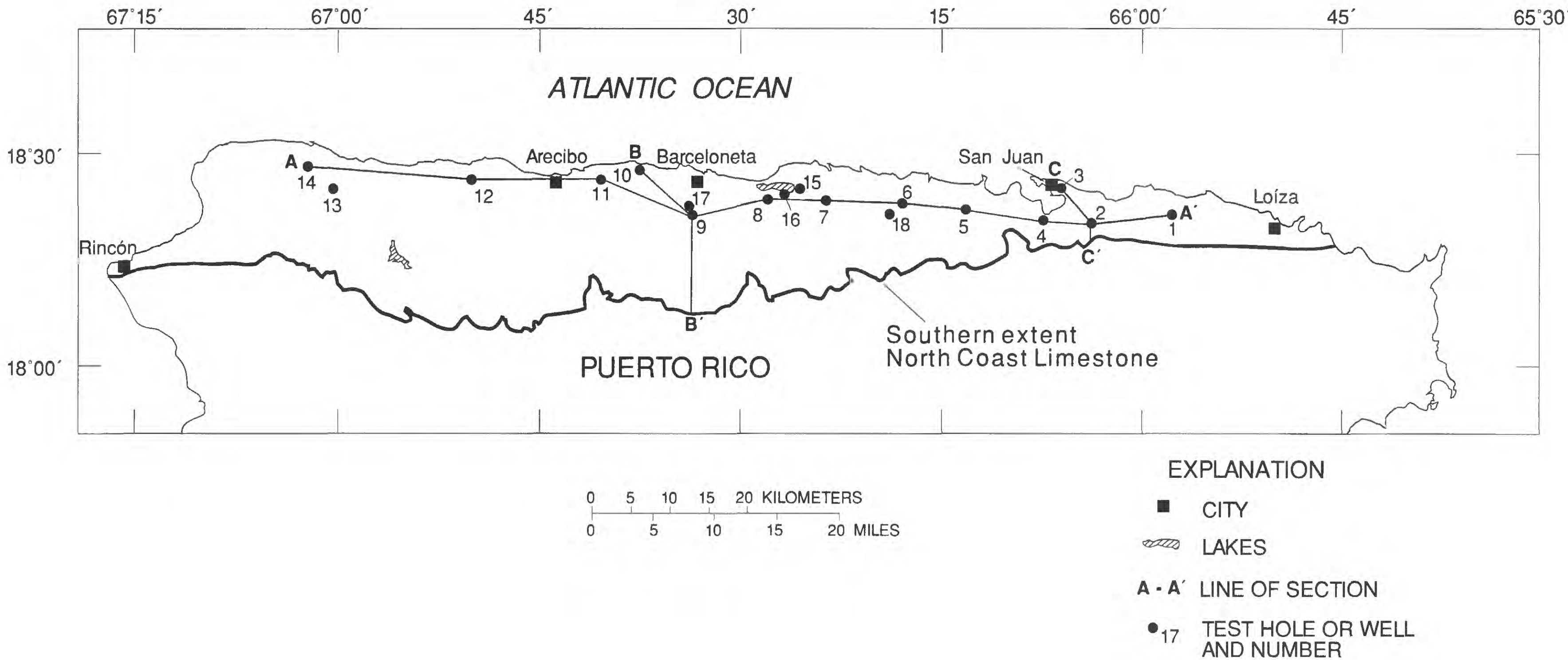

Figure 2. Location of test wells, test holes, and lines of section within the extent of the North Coast Limestone of Puerto Rico (the location and description of the test holes and wells are shown in table 1).

Table 1. Location and description of test holes, test wells, and supply wells in the study area used in this report
[--, indicates no data available; °, degrees; ', minutes; ", seconds]

Test well or hole number in figure 2	Location in figure 1	Local well or hole designation	Latitude	Longitude	Casing depth below land surface (feet)	Total depth below land surface (feet)
1	Loíza	NC-12	18°26'44"	65°55'31"	--	1,450
2	Río Piedras	NC-3	18°24'32"	66°02'33"	--	375
3	Santurce	NC-15	18°26'37"	66°04'22"	--	1,268
4	Guaynabo	NC-1	18°25'33"	66°06'45"	--	635
5	Toa Baja	NC-13	18°26'30"	66°12'23"	--	1,506
6	Dorado	NC-2	18°27'01"	66°18'22"	--	2,128
7	Vega Baja	NC-9	18°27'35"	66°23'43"	--	1,725
8	Interaquifer System (Manatí)	[1]IAS-1	18°27'32"	66°28'13"	--	2,700
9	Cruce Dávila (Barceloneta)	[2]NC-5	18°25'38"	66°34'12"	1,750	2,564
10	Islote, Arecibo	[3]CPR-4	18°29'29"	66°36'13"	--	6,934
11	Santana, Arecibo	--	18°27'01"	66°38'58"	--	1,520
12	Hatillo	NC-6	18°27'57"	66°49'26"	--	2,574
13	Isabela	NC-7	18°28'05"	67°02'58"	--	760
14	Isabela	NC-11	18°29'19"	67°03'13"	--	2,120
15	Manatí	NC-14	18°27'43"	66°25'22"	--	1,898
16	Manatí	NC-4	18°26'33"	66°26'26"	--	1,837
17	Barceloneta	NC-10	18°26'05"	66°34'44"	--	1,516
18	Vega Alta	NC-8	18°25'18"	66°19'43"	--	1,736

[1] Test hole drilled as part of the Interaquifer Project (C. Conde, U.S. Geological Survey, written commun., 1990).

[2] Test well drilled as part of the North Coast Limestone study and used as an observation well completed in the lower confined aquifer.

[3] Oil test well.

representative of a certain bed, or sequence of beds, were selected, slabbed and thin sectioned for study at the University of New Orleans. Analyses included the study of carbonate rock texture, porosity, fossil content, bedding, and identification of other possible depositional and diagenetic features.

The geologic framework for major rock units that lie buried in the subsurface (Ward and others, 1991) serves as the physical basis for the hydrogeologic framework described in this report. Major hydrogeologic units of the North Coast Limestone aquifer system were separated on the basis of relative permeability and hydraulic continuity. Field data from these 18 test wells and existing wells were used to compile maps that show the distribution of transmissivity within major aquifers and the position of the freshwater-saltwater interface. These data also were used to prepare hydrogeologic sections that show the thickness of the freshwater lens contained within the upper aquifer.

A chloride concentration of 500 milligrams per liter (mg/L) was used to delineate the boundary between the saltwater and freshwater zones of the upper aquifer. This concentration represents slightly saline water. Because of the absence of data on chloride concentrations in certain areas of the north coast, both surface resistivity and borehole geophysical data obtained from the test holes drilled for this study and from existing wells were also used in the delineation of the saltwater zone. The mixing zone of freshwater and saltwater where chloride concentrations exceed 500 mg/L is considered part of the saltwater zone in this report.

GEOLOGIC SETTING

The stratigraphic nomenclature of the middle Tertiary age sequence of rocks of the North Coast Limestone belt used in earlier USGS reports is that proposed by Monroe (1980). In a more recent study, Seiglie and Moussa (1984) proposed a somewhat different stratigraphic nomenclature that is based on paleontologic and lithologic data collected from two water wells in the Manatí area of north central Puerto Rico (fig. 3). However, the nomenclature of Monroe (1980) is largely used in this report because it is based on stratigraphic observations made along the entire north coast of Puerto Rico. One exception is reference to the mudstone unit of Seiglie and Moussa (1984) that occurs only in the subsurface.

A thick sequence of platform carbonates and minor clastics ranging in age from middle Oligocene to Miocene, constitute the sequence of middle Tertiary age rocks of the North Coast Limestone belt (fig. 4). These rock units make up a homoclinal sequence that dips gently northward (Monroe, 1980; Meyerhoff and others, 1983) at an average dip of three to four degrees; the dip ranges from two degrees near the coast to six or seven degrees where these rocks lie in contact with the volcanic core of Puerto Rico (Monroe, 1980). Local faulting and fracturing may be responsible for the apparent alignment of geomorphic features of the province, such as limestone hills (mogotes), sinkholes, and straight rivers segments (Meyerhoff and others, 1983).

The sequence of formations of late-middle Tertiary age of the North Coast Limestone is the product of several minor and major regressions and transgressions of the sea that occurred between Oligocene and Miocene time (Seiglie and Moussa, 1984). A variety of depositional environments are represented in the late Tertiary age sequence: fluvial, coastal marginal marine, and open-marine conditions (Seiglie and Moussa, 1984). Fore-reef and outer-shelf environments, indicative of deep-water conditions, are only locally represented (Seiglie and Moussa, 1984; Hartley, 1989; Scharlach, 1990).

A generalized east-west geologic section showing the major rock units of the north coast province is shown in figure 5. In ascending order these units are: the San Sebastián Formation, the Lares Limestone, the Mucarabones Sand, the Cibao Formation, the Aguada Limestone, the Aymamón Limestone, and the Camuy Limestone. The San Sebastián Formation consists of coastal and fluvial clastics, marginal marine clay, and inner platform limestone. The Lares Limestone consists of mid-platform, and minor inner- and outer-platform carbonate rocks. The Mucarabones Sand, which is in part chronostratigraphically equivalent to the Lares Limestone and the lower part of the Cibao Formation, consists of marginal marine quartz sand and minor fluvial clastics. The Cibao Formation is separated into the Montebello Limestone Member, an unnamed mudstone unit of Seiglie and Moussa (1984) and an unnamed upper part. The Montebello Limestone Member, the Río Indio Limestone Member, and the Quebrada Arenas Limestone Member consists of mid-platform limestones. The Río Indio Limestone and the Quebrada Arenas Limestone Members are made-up of inner and mid-platform carbonates containing terrigenous material. The mudstone unit consists of deep-water claystone and marl, and the uppermost part of the Cibao Formation consists of claystone, marl, and limestone containing terrigenous material. The Aguada Limestone is composed of inner- to middle-platform carbonates. The Aymamón Limestone is a mid-platform coral-rich limestone; and the Camuy Formation, the youngest unit, is mostly an inner platform chalk but locally includes minor terrigenous material.

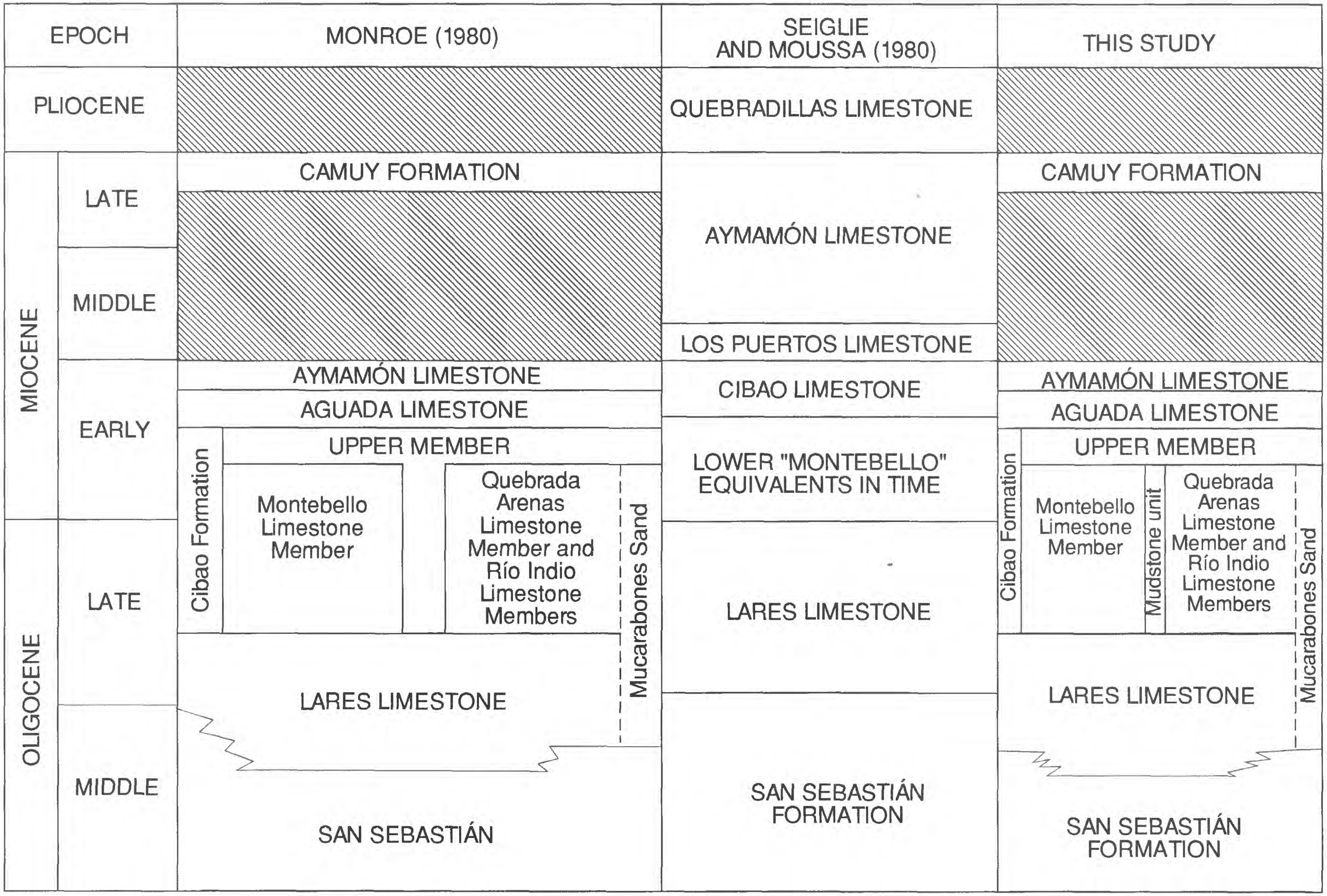

Figure 3. Stratigraphic nomenclature sequence of middle Tertiary age of the North Coast Limestone of Puerto Rico.

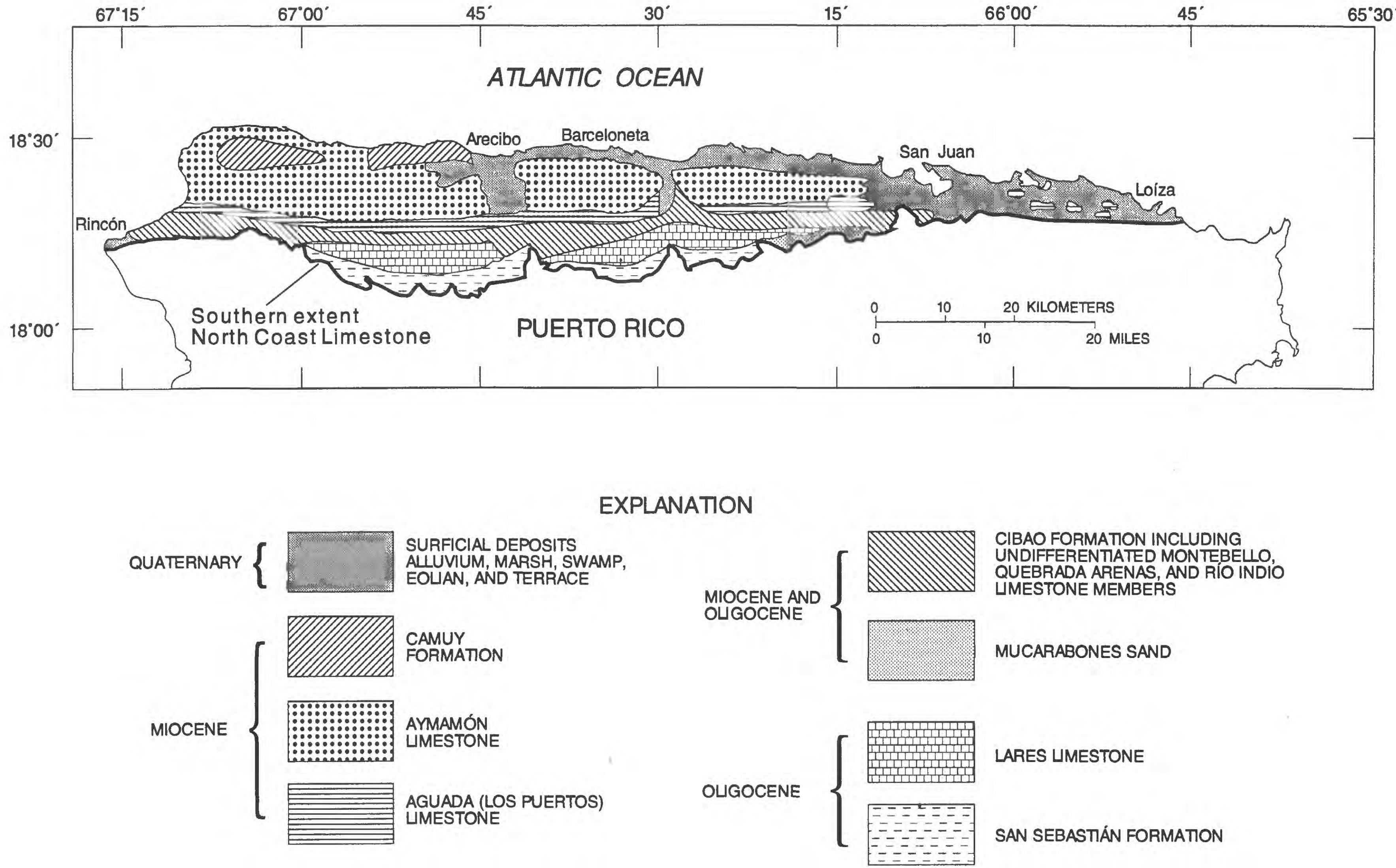

Figure 4. Generalized geologic map of the North Coast Limestone belt of Puerto Rico (modified from Monroe, 1980).

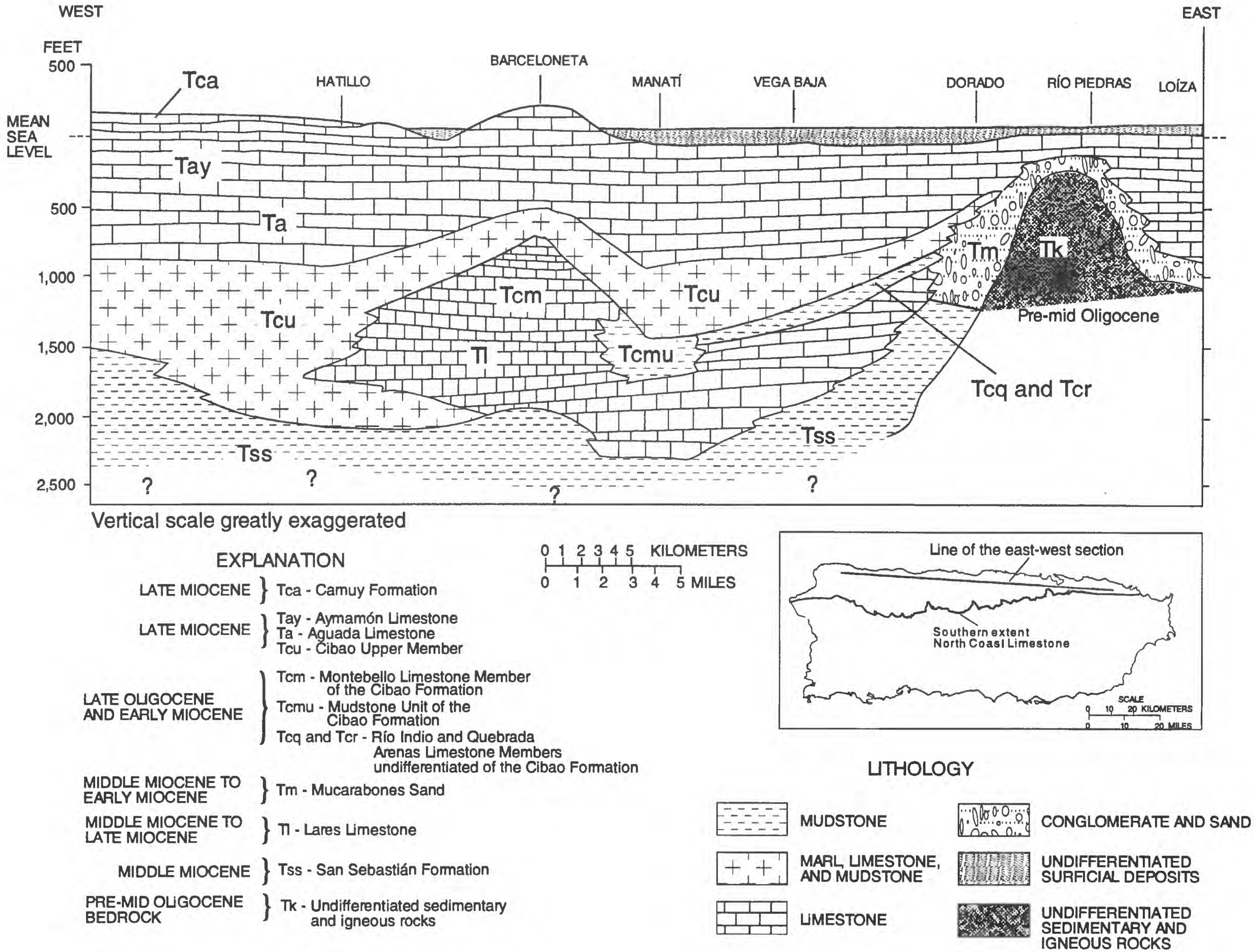

Figure 5. Generalized east-west geologic section sequence of middle Tertiary age of the North Coast Limestone belt of Puerto Rico.

Underlying basement rocks consist of Late Cretaceous and early Tertiary volcaniclastics (siltstone, sandstone, breccia, and conglomerate), minor limestone and minor amounts of igneous intrusive rocks (Monroe, 1980; Meyerhoff and others, 1983). Geophysical and geological evidence indicate that a number of structural highs have compartmentalized the middle Tertiary basin into a series of sub-basins (Meyerhoff and others, 1983; fig. 6). The vertical and lateral relations between the various sedimentary formations observed in the lower part sequence of middle Tertiary age; the San Sebastián Formation, the Lares Limestone, and the Cibao Formation seem to be controlled by the presence of these sub-basins (Meyerhoff and others, 1983; Hartley, 1989). The sedimentary facies of the Aguada (Los Puertos) and Aymamón Limestones and the Camuy Formation do not seem to be controlled by these sub-basins.

REGIONAL HYDROGEOLOGIC UNITS

The North Coast Limestone aquifer system is divided into three regional hydrogeologic units: an upper aquifer containing a basal saltwater zone in the coastal region, an intervening confining unit, and a lower aquifer. A local artesian zone also has been identified within the confining unit in some areas. The upper aquifer, which includes the freshwater part and the underlying saltwater zone near the coast, the confining unit, and the lower aquifer are discussed in the following sections.

Upper Aquifer

The upper aquifer mainly consists of the Aymamón Limestone and underlying Aguada (Los Puertos) Limestone, however, in some areas the upper aquifer also includes the uppermost permeable beds of the upper member of the Cibao Formation and overlying permeable surficial deposits (fig. 7). The upper aquifer contains water under unconfined conditions, except in coastal areas where it is locally confined by overlying silty and clayey surficial deposits. The upper aquifer contains a basal saltwater zone in much of the coastal areas of northern Puerto Rico (figs. 7 and 8).

The thickness of the upper aquifer along section A-A' (fig. 7) ranges from about 450 ft in the Arecibo and Barceloneta area to about 1,075 ft in the Isabela area to the west and about 925 ft near Manatí to the east. East of Vega Baja it decreases to about 650 ft in the Toa Baja area. The upper aquifer is absent in some parts of the Río Piedras area. In the San Juan metropolitan area, the upper aquifer where locally present, is thin and well yields are small. The Aymamón and the Aguada (Los Puertos) Limestones have been extensively eroded by karstification east of Toa Baja, and many of the thin erosional remnants have little hydrologic importance. In the area of Loíza, the upper aquifer is present as a continuous unit and has a thickness of about 750 ft.

The base of the upper aquifer is primarily defined by the uppermost strata of terrestrial clastics and argillaceous limestone of the upper member of the Cibao Formation. However, in the Hatillo-Isabela area the base of the upper aquifer seems to coincide with the lower boundary of the karstic zone located in the Aguada Limestone where this geologic unit is characterized by a significant decrease in porosity and increase in the clayey content of the rocks.

The freshwater zone on section A-A' of the upper aquifer is thickest in the area between the Río Grande de Arecibo and Río Grande de Manatí with a maximum thickness of about 500 ft (fig. 7). The freshwater part in the coastal zones of the San Juan metropolitan and Loíza areas is either absent or present with a thickness that does not exceed 30 ft. In the Guaynabo area, along section A-A', the upper aquifer is mostly brackish and saline. In north-south sections B-B' and C-C', the maximum thickness of the freshwater zone is greatest in the interstream areas of the southern extent of the freshwater-saltwater interface (figs. 8 and 9).

The freshwater zone of the upper aquifer is underlain by a basal zone of saltwater along the coast. The landward extent of this saltwater zone is not known for the entire north coast, but is about 6 mi in the Barceloneta area (fig. 8). In the Santurce-San Juan area, the landward extent could be about 3 mi (fig. 9). The position of the

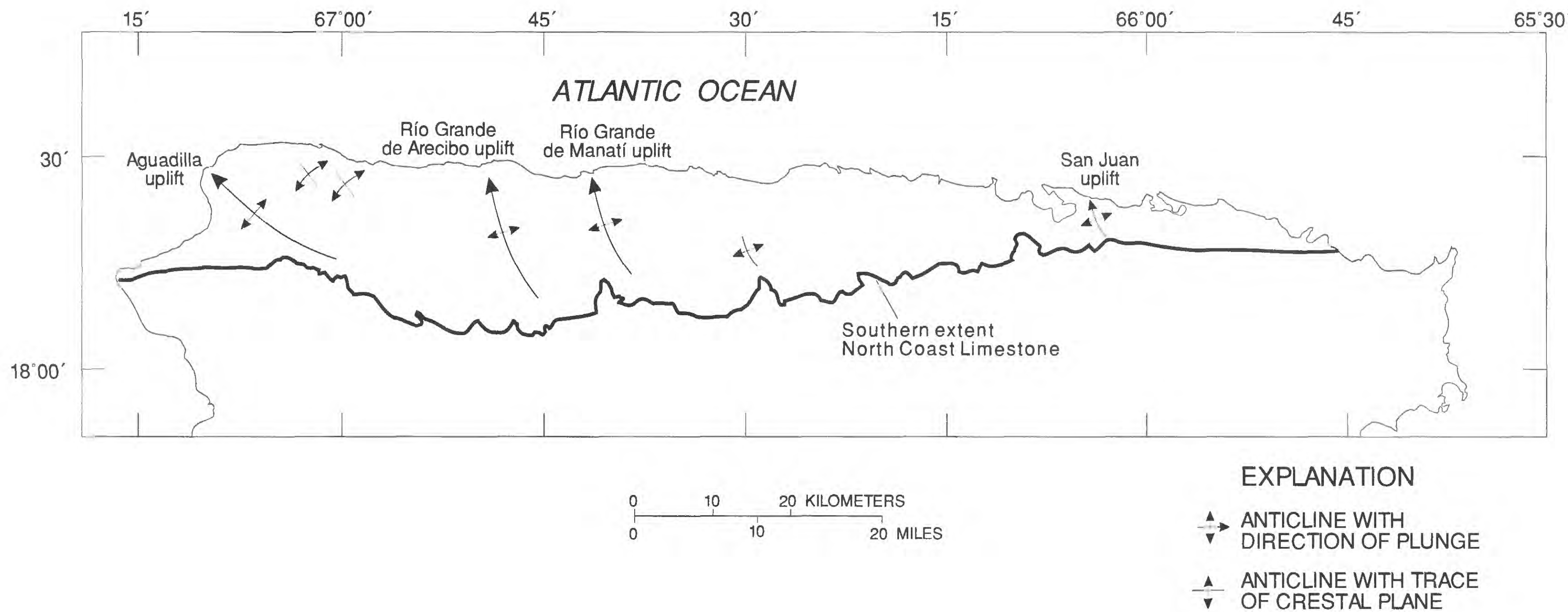

Figure 6. Major structural features of the North Coast Limestone belt of Puerto Rico (modified from Meyerhoff and others, 1983).

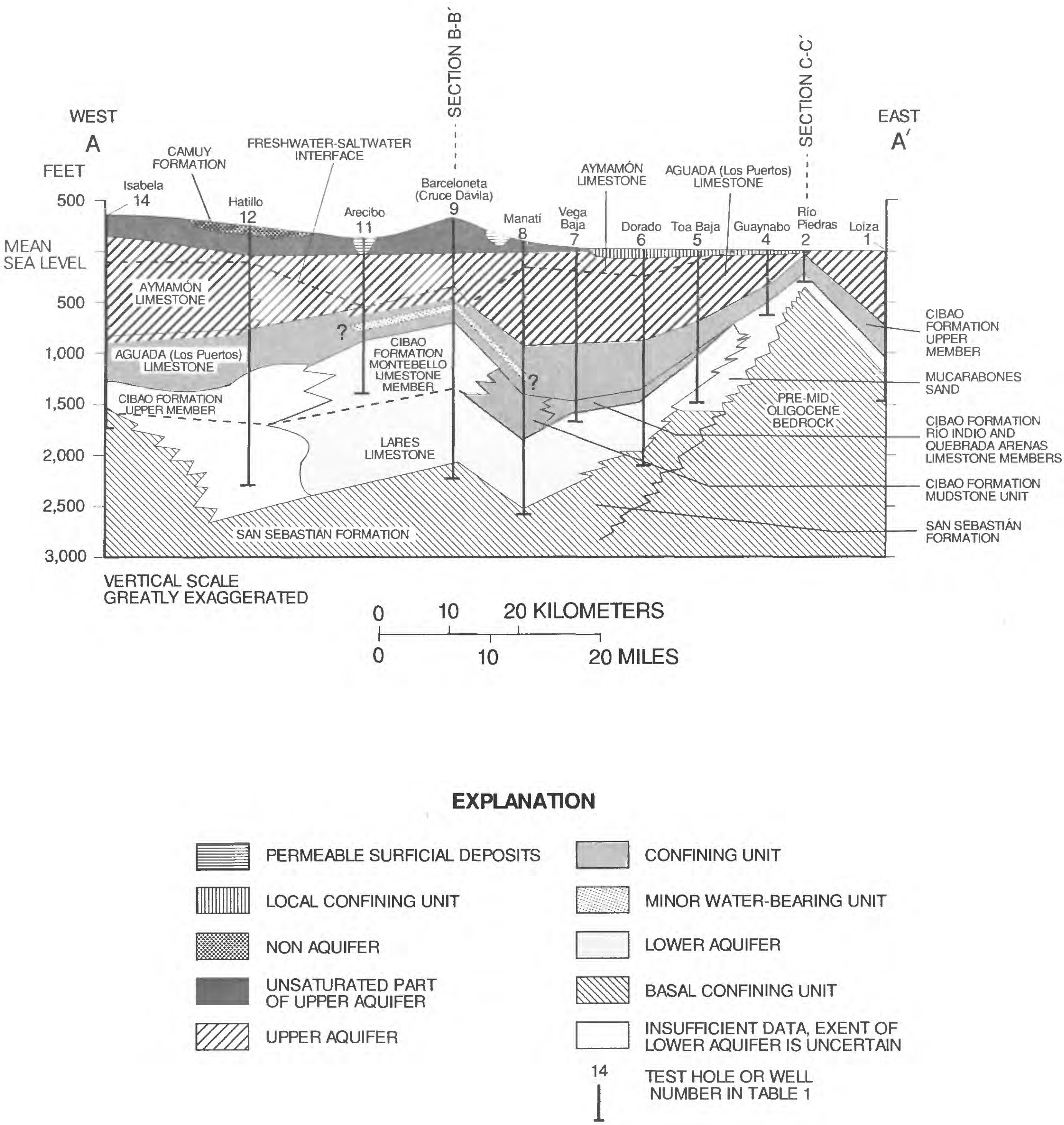

Figure 7. Hydrogeologic section A-A' (section line shown in figure 1).

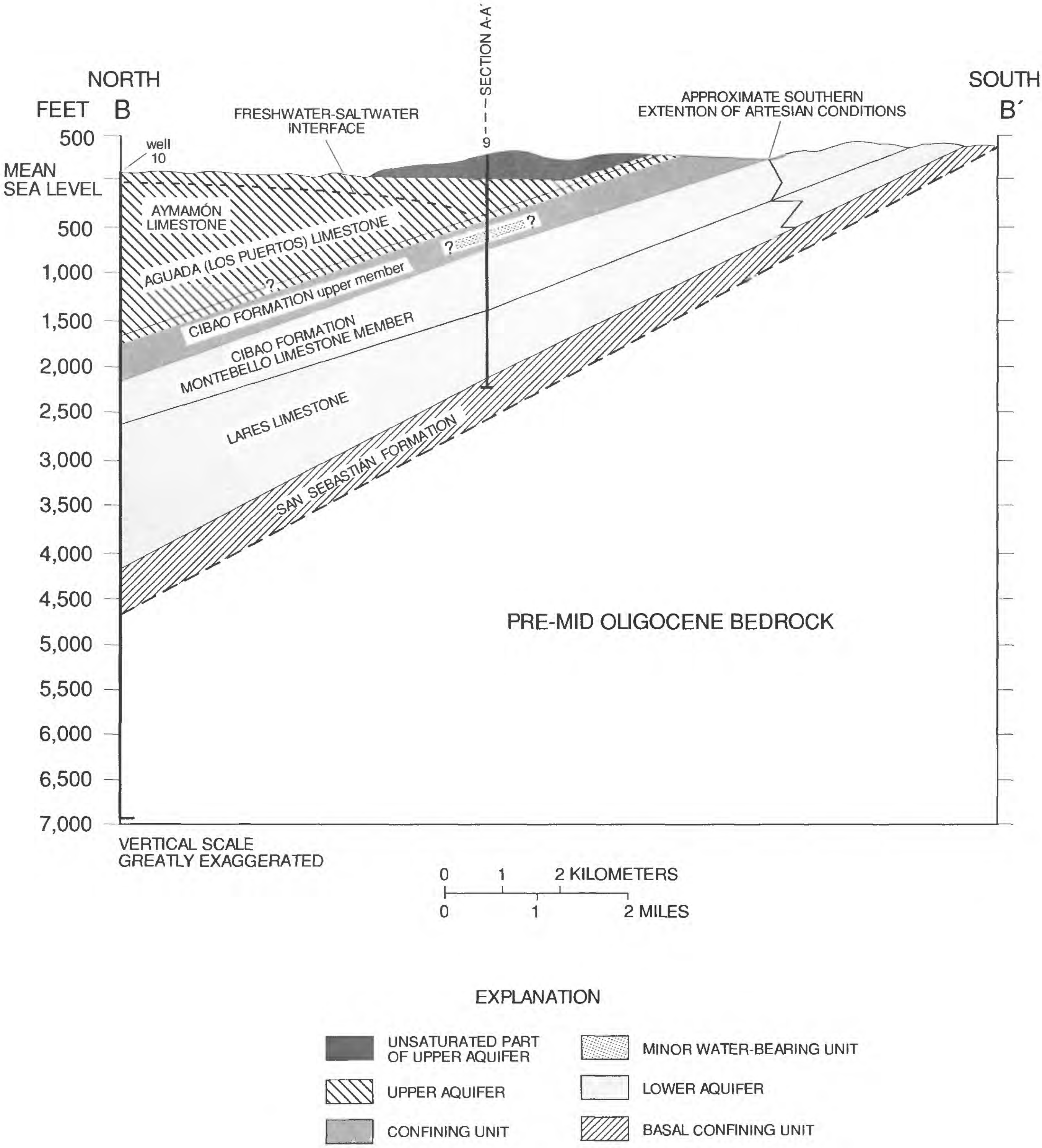

Figure 8. Hydrogeologic section B-B' (section line shown in figure 2).

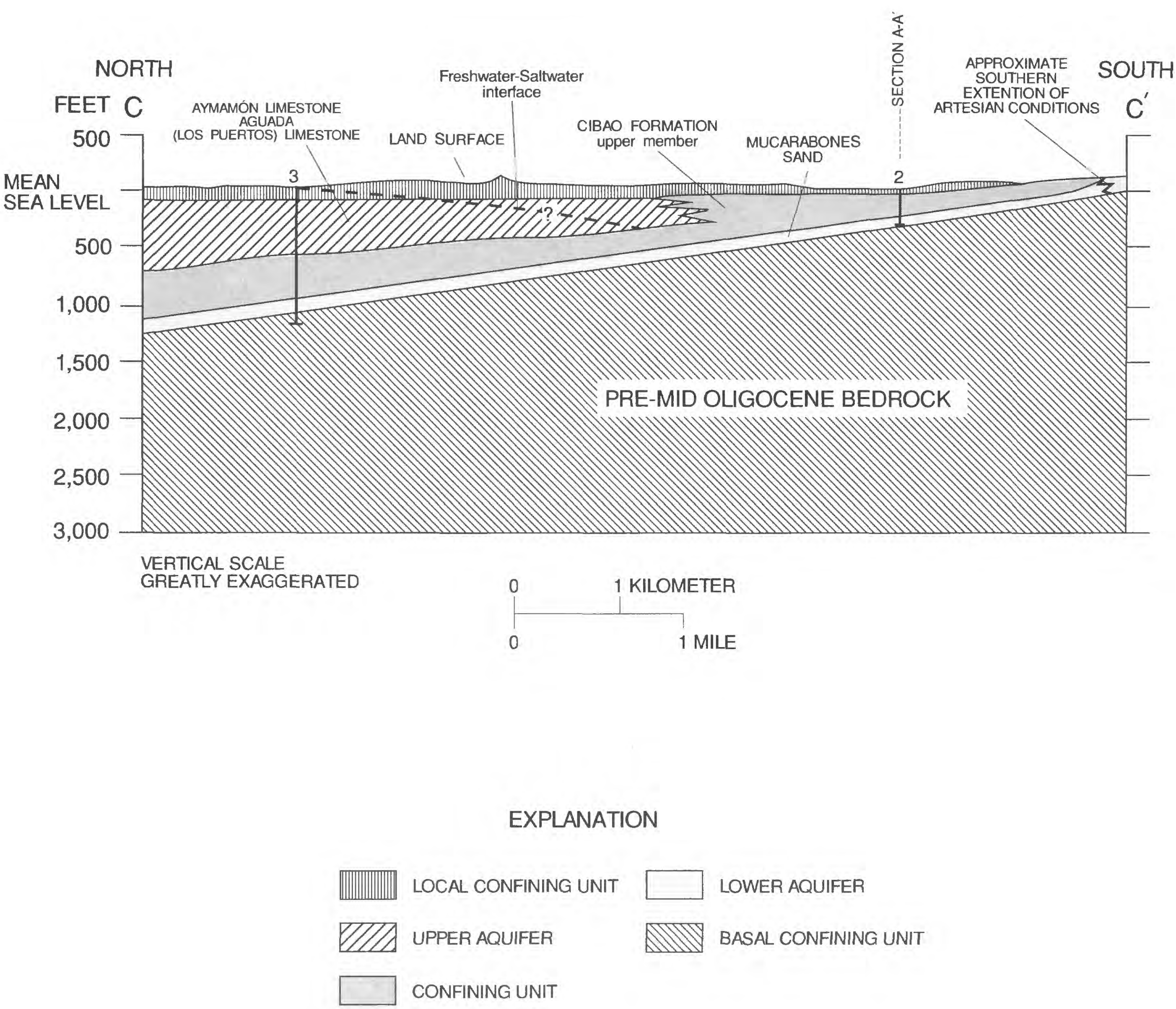

Figure 9. Hydrogeologic section C-C' (section line shown in figure 2).

freshwater-saltwater interface (fig. 10) is a function of the hydraulic properties of the aquifer, the effects of pumping, and large rivers that function as drains.

The most permeable of the geologic units that constitute the upper aquifer is the Aymamón Limestone (Giusti, 1978). The estimated hydraulic conductivity of this geologic unit ranges from 57 to 570 ft/day (Giusti, 1978). The hydraulic conductivity within the Aymamón Limestone generally diminishes with depth. The decrease in hydraulic conductivity is probably related to a maximum effective depth to which karstification will occur within the aquifer. Because hydraulic conductivity can vary with depth, use of site specific values of hydraulic conductivities to determine the transmissivity of the upper aquifer is not appropriate. Transmissivity values determined from aquifer tests or specific capacity data reflect the vertical variations in hydraulic conductivity and are used in this report to describe the regional transmissive properties of the freshwater zone of the upper aquifer. In some localities, site specific values of transmissivity may not be in good agreement with regional transmissivity, because locally transmissivity can reflect the irregular distribution of cavernous porosity.

The areal distribution of transmissivity in the freshwater zone of the upper aquifer is controlled, in part, by the depositional environment, diagenesis, and fractures in the Aymamón and Aguada (Los Puertos) Limestones. Another factor controlling transmissivity is the thickness of the freshwater lens.

Transmissivity estimates are available in most areas underlain by the freshwater zone of the upper aquifer. Estimates are sparse, however, for the areas east of the Río de La Plata and west of the Río Camuy. The transmissivity and hydraulic conductivity of the aquifer are not well documented for these areas. Available transmissivity estimates for the freshwater zone of the upper aquifer range from 200 to more than 280,000 ft^2/d (F. Gómez-Gómez and S. Torres-González, U.S. Geological Survey, written commun., 1990; fig. 11).

The maximum transmissivity of the freshwater zone of the upper aquifer (more than 280,000 ft^2/d) is in the area between the Río Grande de Arecibo and the Río de La Plata, where the transmissivity of this zone is reported to exceed 100,000 ft^2/d at six locations in this area. These high transmissivity values probably are the result of the cavernous porosity and enhanced dissolution along bedding planes, joints, and fractures. Also in this area the Aymamón Limestone is mostly a grainstone-packstone and coral boundstone and has as much as 25 percent total porosity (Hartley, 1989; Scharlach, 1990). Locally, the transmissivity of minor water-bearing units underlying the San Juan metropolitan area range from 200 ft^2/d (Rullán well) to 500 ft^2/d (Banco de Ponce well) (I. Padilla, U.S. Geological Survey, written commun., 1990).

Confining Unit

Although the upper member of the Cibao Formation is the principal rock-stratigraphic unit of the middle confining unit, the upper boundary of the confining unit does not always coincide with its top. For example, the uppermost part of the Cibao Formation is reef limestone (wackestone-packstone) in the Barceloneta and Arecibo areas (test wells 9 and 11, respectively). In these areas, the upper part of the upper member of the Cibao Formation is considered part of the upper aquifer (figs. 7 and 8).

The areal and vertical extent of the confining unit are well known in the Arecibo to Manatí area, but are less precisely known east and west of this area. The confining unit gradually thickens east of Barceloneta (fig. 7). Between Manatí (test well 8) and Vega Baja (test hole 7), the confining unit consists of the upper member of the Cibao Formation, the underlying Quebrada Arenas and Río Indio Limestone Members, and the mudstone unit. In this area, the confining unit ranges in thickness from 250 ft at test well 9 in Barceloneta to about 925 ft at test well 8 in Manatí. At test hole 6 near Dorado, the confining unit includes the Río Indio Limestone and the Quebrada Arenas Limestone Members and the upper member of the Cibao Formation and is about 600 ft thick. The confining unit is about 225 ft at test hole 2 near Río Piedras east of Dorado.

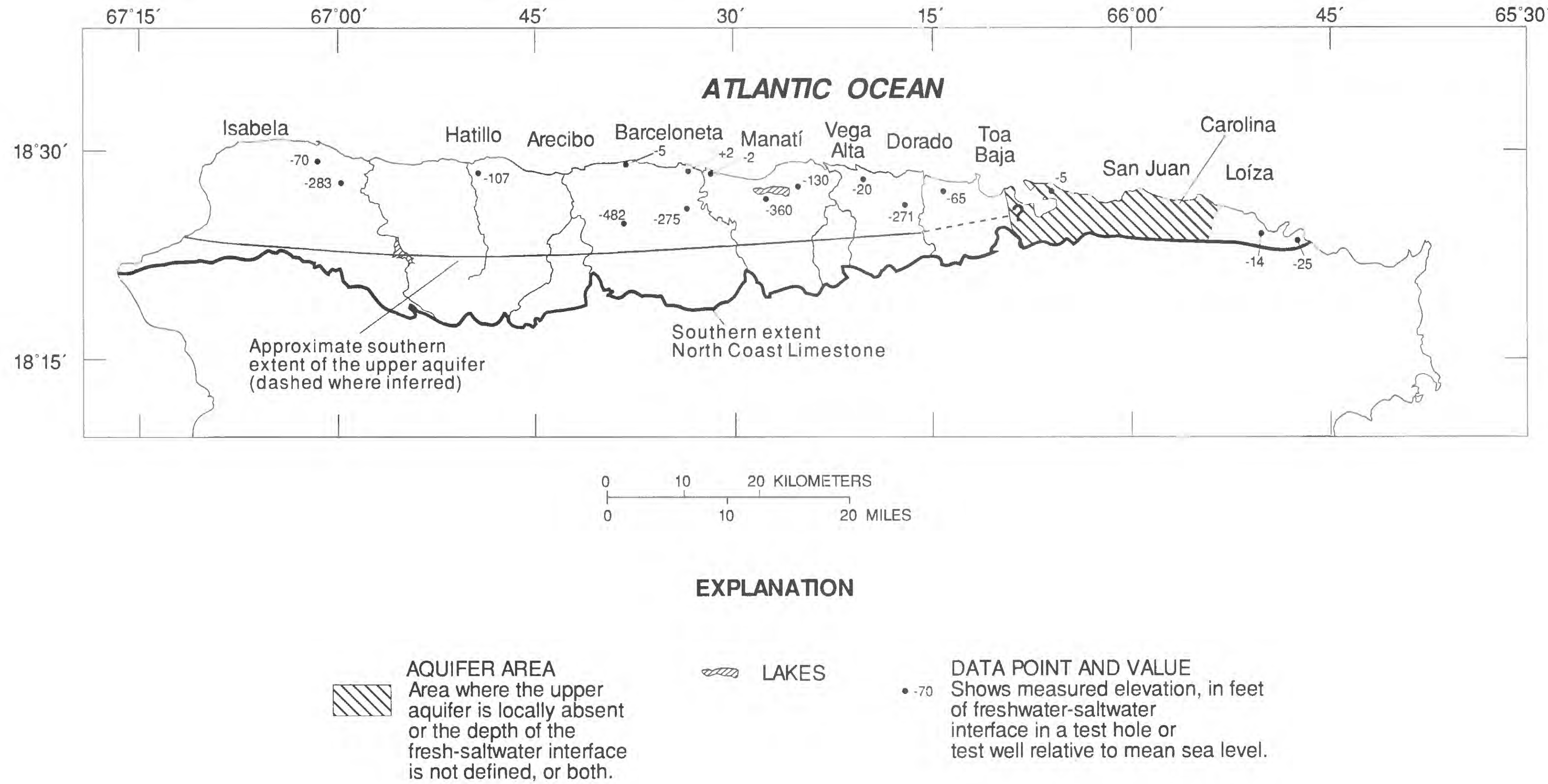

Figure 10. Elevation of the regional freshwater-saltwater interface in the upper aquifer.

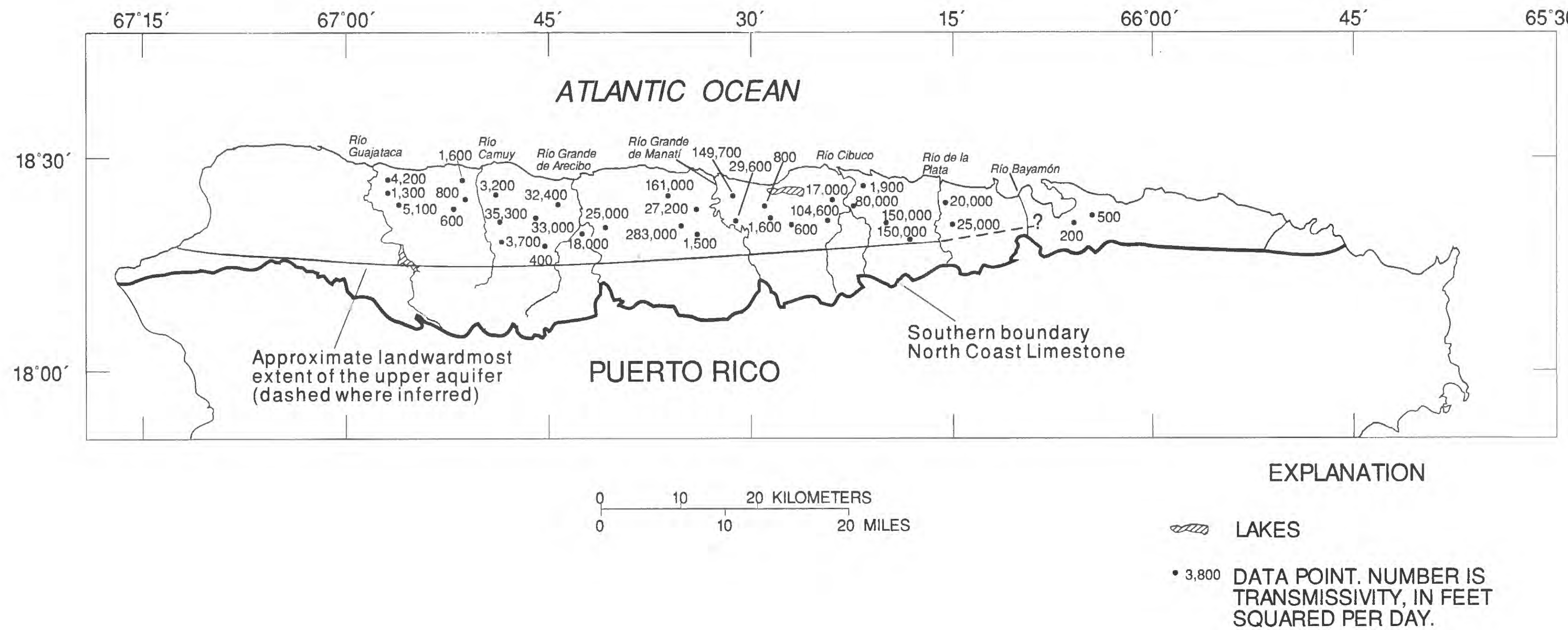

Figure 11. Estimates of transmissivity for the freshwater zone of the upper aquifer F. Gómez-Gómez, U.S. Geological Survey, written commun., 1992.

Hydrologic and lithologic data collected at test holes 3 and 4 indicate the probable leaky nature of the confining unit in the easternmost part of the North Coast Limestone aquifer system. In these test holes, the variations of specific conductance and water level (head) with depth, as well as the lithologic nonhomogeneity of the confining unit, indicate possible upward movement of water from the lower aquifer into the upper aquifer (Rodríguez-Martínez and others, 1991).

An artesian water-bearing zone of local extent exists within the confining unit near water well 11 in Arecibo, observation well 9, and test well 8 south of Manatí (fig. 7). This local water-bearing zone consists mostly of coral-bearing wackestones and packstones and is about 50-ft thick.

Lower Aquifer

The lower aquifer of the North Coast Limestone was first identified in 1968, when two disposal wells were drilled in the Cruce Dávila area of Barceloneta (Giusti, 1978). The aquifer contains water under artesian pressure throughout the area where it is overlain by the middle confining unit. Where the aquifer crops out, in the recharge areas near the southernmost outcrop belt of the mid-Tertiary sequence, however, the lower aquifer contains water under water-table conditions.

The lithology of the lower aquifer is most homogeneous in the area between Arecibo and Manatí. In that area, the aquifer consists of the Lares Limestone and the Montebello Limestone Member of the Cibao Formation (figs. 7 and 8). Core samples collected from observation well 9 indicate that the aquifer consists of skeletal wackestone-packstone and packstone-grainstone that were deposited in a carbonate middle platform environment. The Lares Limestone is generally much finer-grained than the Montebello Limestone Member of the Cibao Formation. The hydraulic conductivity of the lower aquifer, particularly the Montebello Limestone Member, is greater in the Arecibo to Manatí area than elsewhere in the study area. No hydraulic separation between the two limestone units was observed in the Arecibo to Manatí area.

West of Río Grande de Arecibo, the extent of the lower aquifer is uncertain. The terrigenous character of the Lares Limestone in the Hatillo and Isabela areas and the increased stratigraphic complexity of the Cibao Formation west of Arecibo, suggest that multiple confining and water-bearing strata of unknown areal and vertical extent exist in this area. Because only 3 out of the 18 test holes and wells used in this study were drilled west of Río Grande de Arecibo, it is not known if these water-bearing strata are an extension of the more productive lower aquifer in the Manatí to Arecibo area. Zones of moderate permeability are known to exist locally in the westernmost part of the mid-Tertiary age sequence within small lenses of volcanic conglomerates and sandstones of the San Sebastián Formation, but in general, this formation is not a good aquifer.

In the area between Manatí and Dorado, the lower aquifer is composed solely of the Lares Limestone (fig. 7). The Lares Limestone in this area is a moderately to highly terrigenous and mostly fine-grained wackestone-packstone, which is predominantly argillaceous at its base (Scharlach, 1990). The Montebello Limestone Member of the Cibao Formation grades by facies change to an age-equivalent calcareous mudstone, marl, and a highly argillaceous wackestone unit in the area between Manatí and Vega Baja. In this area, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation are more argillaceous and silty than in their outcrop areas, and consequently, are part of the confining unit (Scharlach, 1990). The Quebrada Arenas and the Río Indio Limestone Members are, in part, stratigraphically equivalent to the Montebello Limestone Member that exists to the west. East of Toa Baja, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation grade by facies change to the Mucarabones Sand. East of Toa Baja, the lower aquifer includes rocks that are part of the Mucarabones Sand (fig. 7). In this area, the Lares Limestone gradually thins and grades to the Mucarabones Sand, a calcareous marine sandstone with local lenses of volcanic conglomerate (Scharlach, 1990). The lower aquifer also includes permeable units in the upper part of the San Sebastián Formation, in and near the area where the San Sebastián Formation crops out.

In the area of San Juan and Guaynabo (test hole 4) and Río Piedras (test hole 2), the lower aquifer is composed mostly of the Mucarabones Sand (figs. 7 and 9). The Mucarabones Sand in this area consists of sandstone and gravel of terrestrial origin. In San Juan and to the east, the water in the lower aquifer is brackish in some areas.

Transmissivity estimates for the lower aquifer are available from only a few aquifer tests and specific capacity tests (fig. 12). In the Río Grande de Arecibo to Río Grande de Manatí area, the transmissivities of the Lares Limestone at two sites were 150 and 500 ft^2/d (fig. 12). Transmissivity values for the Lares Limestone in other areas range from 20 to 330 ft^2/d (fig. 12). Reported transmissivity values for the Mucarabones Sand, which is stratigraphically equivalent to the Lares Limestone in the San Juan metropolitan area, range from 850 to 1,000 ft^2/d (Anderson, 1976). The transmissivity of the Montebello Limestone Member is highest in the Río Grande de Arecibo to the Río Grande de Manatí area, where it ranges from 625 to 3,600 ft^2/d (fig. 12). West of the Río Grande de Arecibo, the reported transmissivity of the Montebello Limestone Member ranges from 370 to 680 ft^2/d. In this area, the unit becomes increasingly chalky and is similar in lithology to the upper member of the Cibao Formation.

SUMMARY

The hydrogeology of the North Coast Limestone aquifer system was studied by the U.S. Geological Survey in cooperation with the Commonwealth of Puerto Rico Department of Natural and Environmental Resources during 1983 to 1988. During this study, 15 deep test holes and wells were drilled into bedded carbonate and clastics deposits of middle Oligocene to Miocene age that underlie the north coast of Puerto Rico. Lithologic cores collected from these test holes and test wells were analyzed to describe the stratigraphic and hydrogeologic framework of the area. Data from three other existing water wells collected during previous studies also were used in the delineation of the regional hydrogeologic units.

An upper aquifer, a lower aquifer, and a middle confining unit constitute the hydrogeologic units of the North Coast Limestone aquifer system. The upper aquifer consists mainly of the Aymamón Limestone and the Aguada (Los Puertos) Limestone and locally includes part of the upper member of the underlying Cibao Formation and the overlying alluvium. This upper aquifer is present along much of the north coast of Puerto Rico, but is largely absent in the Río Piedras area. A saltwater zone underlies the freshwater zone of the upper aquifer in the coastal region. The upper aquifer contains water under water-table conditions, except in the coastal region where it is locally confined by overlying fine-grained material. The extent of the lower aquifer west of Arecibo is uncertain. It is not known if the existing multiple water-bearing units west of Arecibo are an extension of the more productive aquifer in the Arecibo to Manatí area.

The confining unit consists of the upper member, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation, and the mudstone unit. The confining unit generally consists of low permeability rocks; however, in an area that extends from Manatí to Arecibo it locally contains a water-bearing zone that is under artesian conditions. Data from test holes 3 and 4 indicate that the confining unit possibly is leaky in the San Juan metropolitan area and that water from the lower aquifer is moving into the upper aquifer in that area.

The lower aquifer is composed of the Lares Limestone, the Montebello Limestone Member of the Cibao Formation, and the outcrop areas and shallow facies of the San Sebastián Formation. The lower aquifer is thickest and most transmissive in the north-central part of the study area. West of the Río Grande de Arecibo, the extent of the lower aquifer is not known. Multiple water-bearing units and intervening confining units of limited extent exist in the Hatillo to Isabela area but it is not known if these water-bearing units are extensions of the lower artesian aquifer in the Manatí to

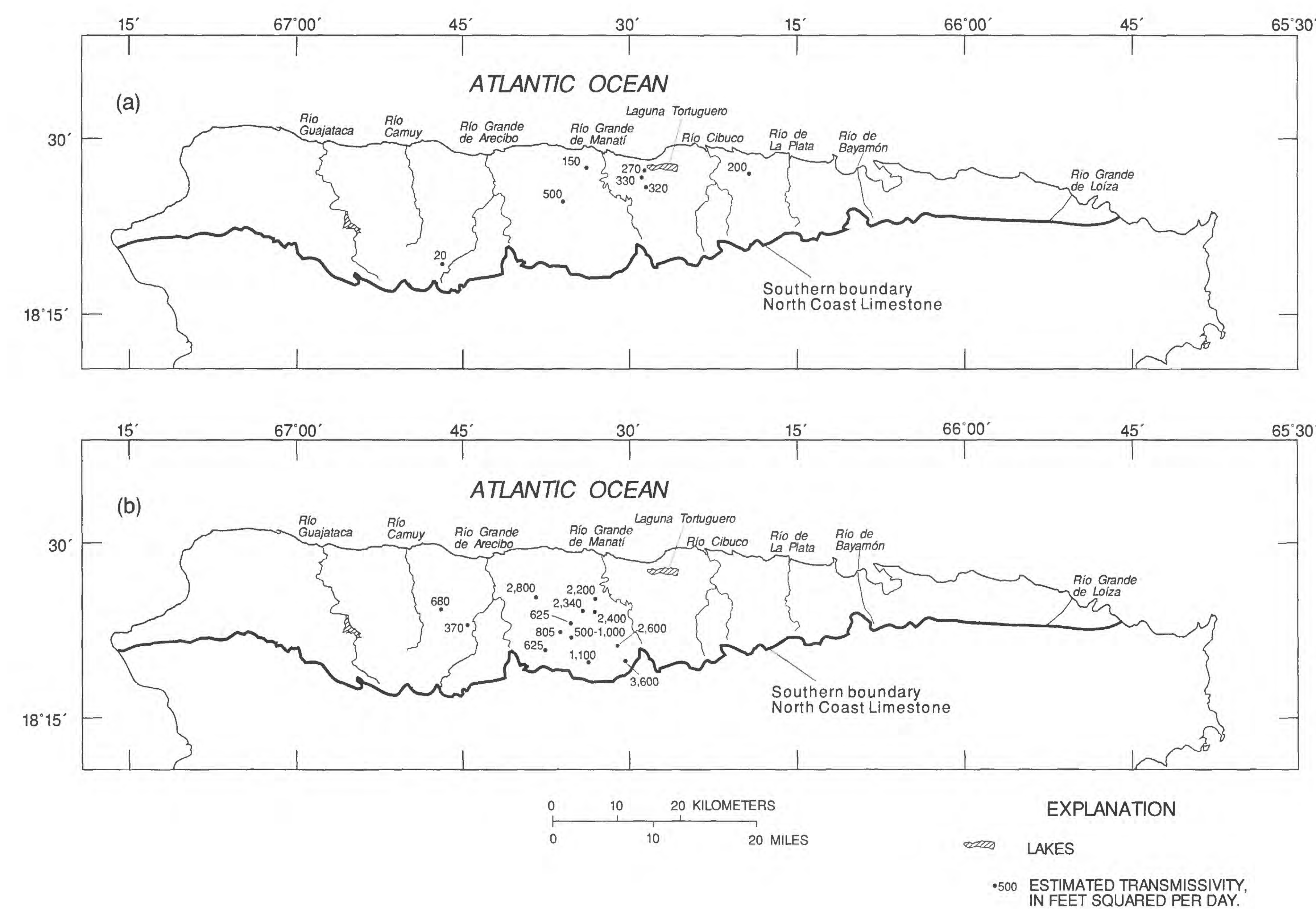

Figure 12. Estimated transmissivity for the lower aquifer in the North Coast Limestone aquifer system of Puerto Rico: (a) the Lares Limestone and (b) the Montebello Limestone Member of the Cibao Formation (F. Gómez-Gómez, U.S. Geological Survey, written commun., 1991).

Arecibo area. In an area that extends from Manatí to Dorado, the lower aquifer is composed of rocks that are part of the Lares Limestone. In the area of Toa Baja and further east, the limestone rocks that make up the lower aquifer grade by facies change to the more terrigenous Mucarabones Sand. East of Toa Baja the lower aquifer consists of the Mucarabones and contains water that ranges from fresh to brackish.

The transmissivity values for the freshwater zone of the upper aquifer are highest in the Río Grande de Arecibo to the Río de La Plata area. Transmissivities values for the upper aquifer exceed 100,000 ft^2/d in six locations in this area and have been reported to exceed 280,000 ft^2/d at one site near Barceloneta. Locally, the transmissivity values of minor water-bearing units within the upper aquifer underlying the San Juan metropolitan area range from 200 to 500 ft^2/d. In the lower aquifer, the Lares Limestone has transmissivity values of 150 and 500 ft^2/d at two sites in the Río Grande de Arecibo to the Río Grande de Manatí area. In other areas the transmissivity values for the Lares Limestone range from 20 to 330 ft^2/d. The estimated transmissivity of the Mucarabones Sand in the San Juan metropolitan area ranges from 850 to 1,000 ft^2/d. The transmissivity values of the Montebello Limestone Member of the Cibao Formation are highest in the Río Grande de Arecibo to Río Grande de Manatí area and range from 625 to 3,600 ft^2/d. West of the Río Grande de Arecibo transmissivity data for the Montebello Limestone Member are sparse, but values at two sites were 370 and 680 ft^2/d.

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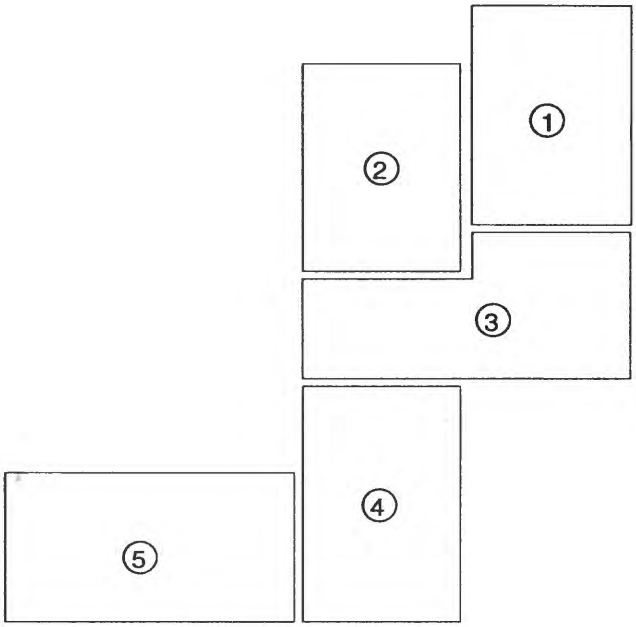
HYDROGEOLOGY OF THE NORTH COAST LIMESTONE AQUIFER SYSTEM OF PUERTO RICO

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4249

Prepared in cooperation with the PUERTO RICO DEPARTMENT OF NATURAL RESOURCES



PHOTOS USED ON COVER

1) Cueva Clara de Empalme - one of the entrances to the Río Camuy Cave System, Puerto Rico. (Photo by Arturo Torres-González, USGS)

2) Areal view of the Río Tanamá Canyon and the Arecibo Ionospheric Radiotelescope in the central karst region of Puerto Rico. (Photo by Ramón A. Carrasquillo-Nieves, USGS)

3) View of Laguna Tortuguero on the north coast near Manatí, Puerto Rico. (Photo by Ramón A. Carrasquillo-Nieves, USGS)

4) Explorers floating down the Río Tanamá in the north central karst region of Puerto Rico. (Photo by Arturo Torres-González, USGS)

5) Intermogotal area in the north coast karst limestone belt of Puerto Rico. (Photo by Arturo Torres-González, USGS)

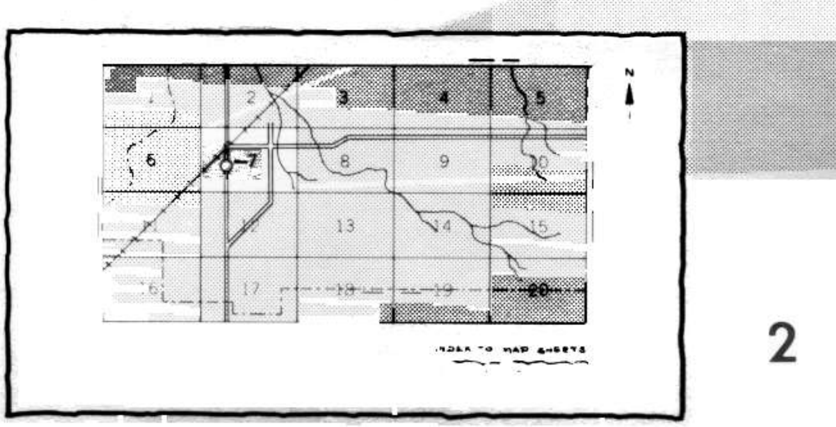
SOIL SURVEY OF

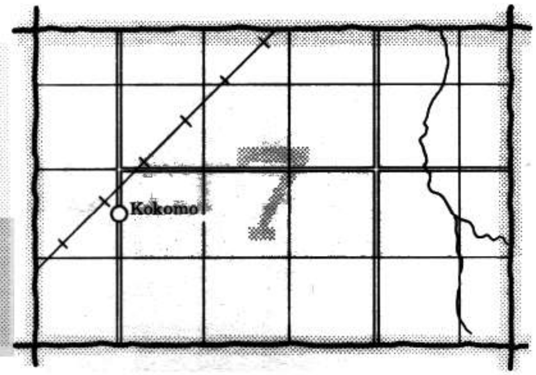
San Juan Area of Puerto Rico

United States Department of Agriculture
Soil Conservation Service
In cooperation with
University of Puerto Rico
Agricultural Experiment Station

HOW TO USE

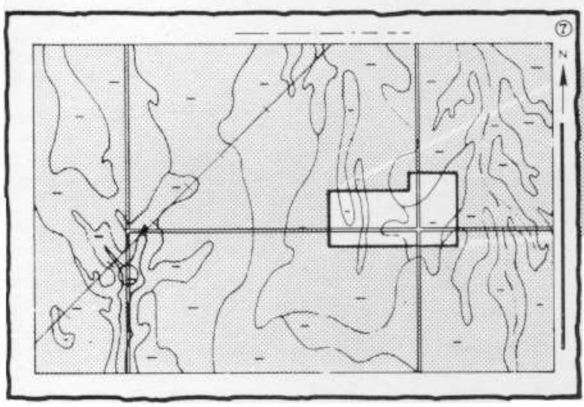
1. Locate your area of interest on the "Index to Map Sheets" (the last page of this publication).

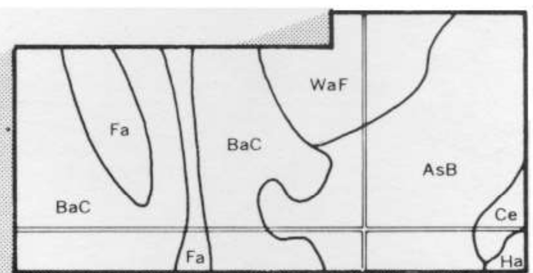




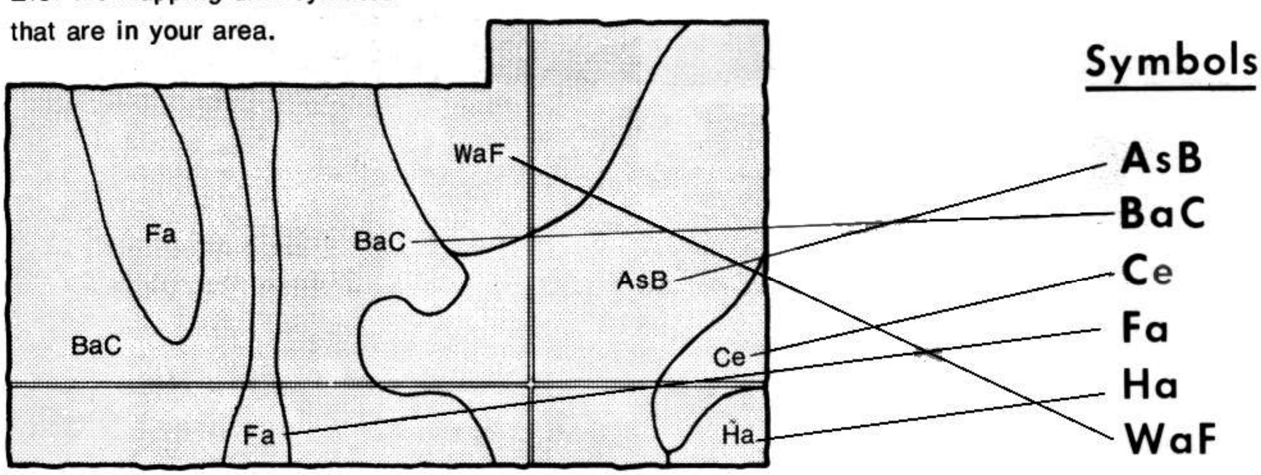
2 Note the number of the map sheet and turn to that sheet.

3. Locate your area of interest on the map sheet.



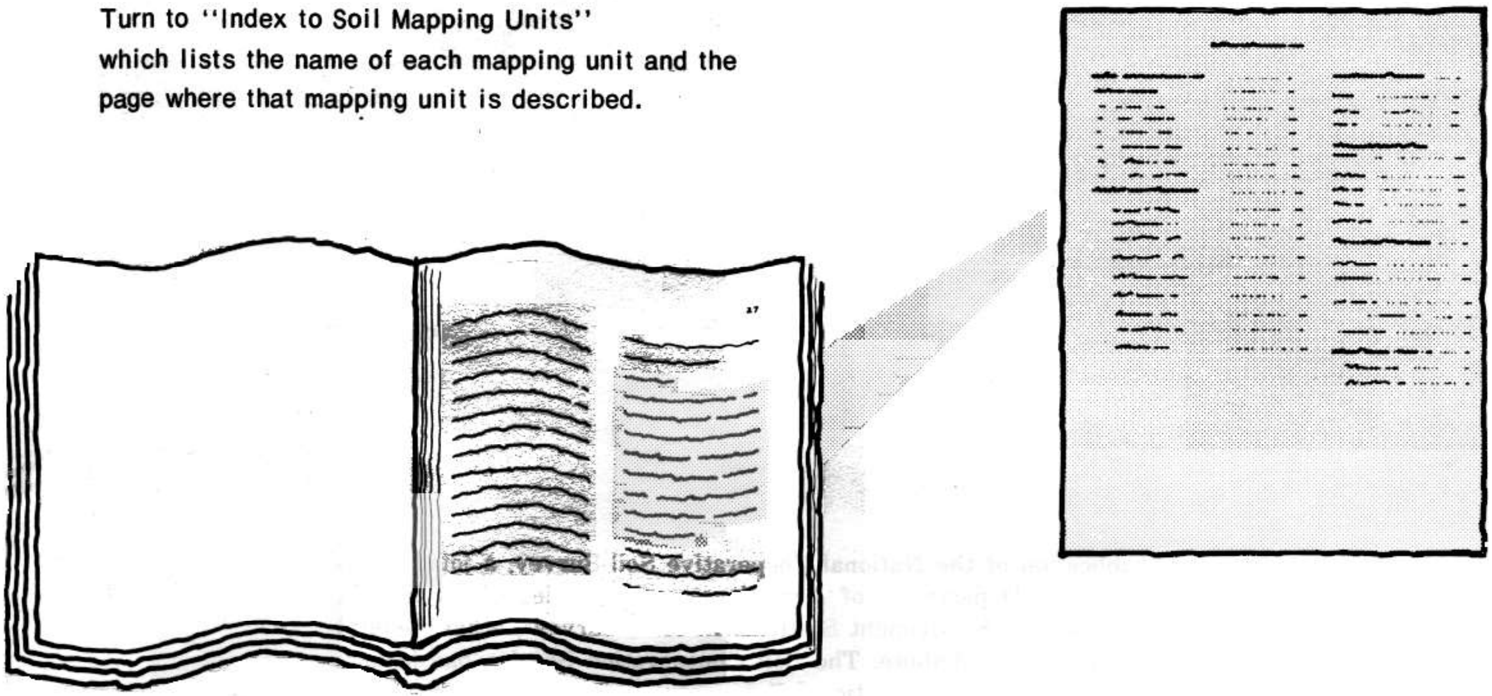


4 List the mapping unit symbols that are in your area.

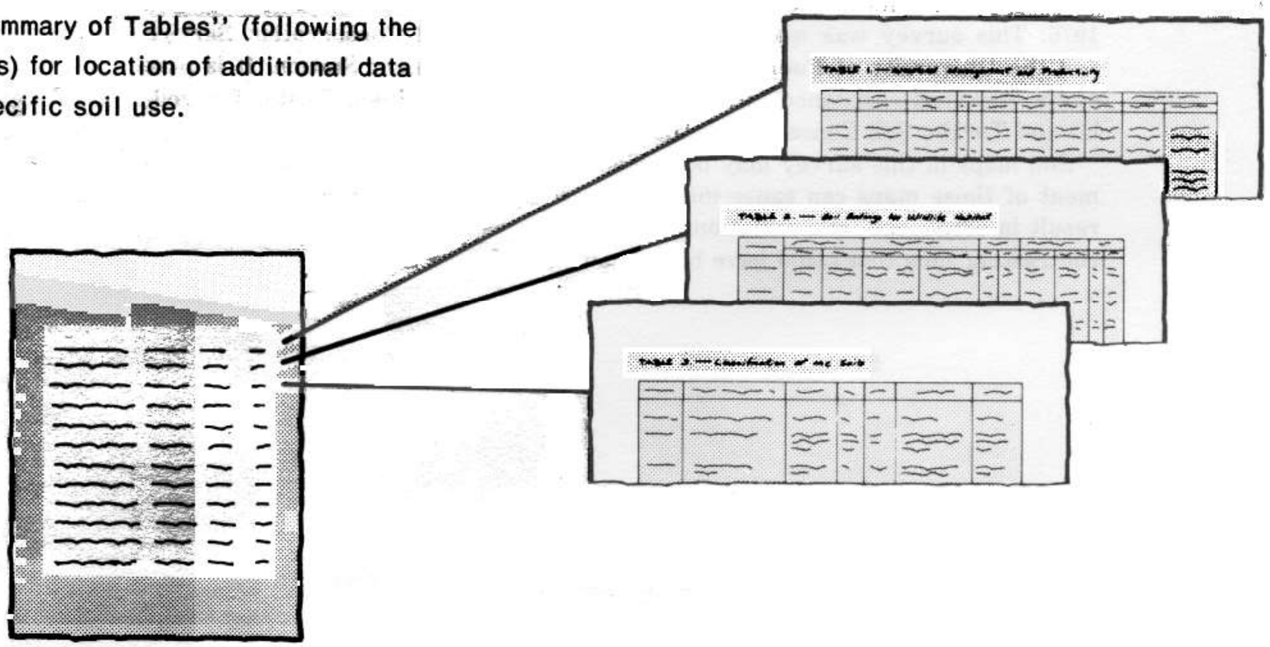


THIS SOIL SURVEY

Turn to "Index to Soil Mapping Units" which lists the name of each mapping unit and the page where that mapping unit is described.



6. See "Summary of Tables" (following the Contents) for location of additional data on a specific soil use.



Consult "Contents" for parts of the publication that will meet your specific needs. This survey contains useful information for farmers or ranchers, foresters or agronomists; for planners, community decision makers, engineers, developers, builders, or homebuyers; for conservationists, recreationists, teachers, or students; to specialists in wildlife management, waste disposal, or pollution control.

This is a publication of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and agencies of the States, usually the Agricultural Experiment Stations. In some surveys, other Federal and local agencies also contribute. The Soil Conservation Service has leadership for the Federal part of the National Cooperative Soil Survey. In line with Department of Agriculture policies, benefits of this program are available to all, regardless of race, color, national origin, sex, religion, marital status, or age.

Major fieldwork for this soil survey was completed in October 1972. Soil names and descriptions were approved in August 1973. Unless otherwise indicated, statements in the publication refer to conditions in the survey area in 1976. This survey was made cooperatively by the Soil Conservation Service and the University of Puerto Rico Agricultural Experiment Station. It is part of the technical assistance furnished to the Cibuco, San Juan, Torito, Torrecillas and Turabo Soil Conservation Districts.

Soil maps in this survey may be copied without permission, but any enlargement of these maps can cause misunderstanding of the detail of mapping and result in erroneous interpretations. Enlarged maps do not show small areas of contrasting soils that could have been shown at a larger mapping scale.

Cover: Contour plantings of bananas in the San Juan Area.

Contents

Contents—continued

Issued November 1978

Index to soil mapping units

Summary of Tables

Summary of Tables—Continued

Foreword

The Soil Survey of the San Juan Area contains much information useful in any land-planning program. Of prime importance are the predictions of soil behavior for selected land uses. Also highlighted are limitations or hazards to land uses that are inherent in the soil, improvements needed to overcome these limitations, and the impact that selected land uses will have on the environment.

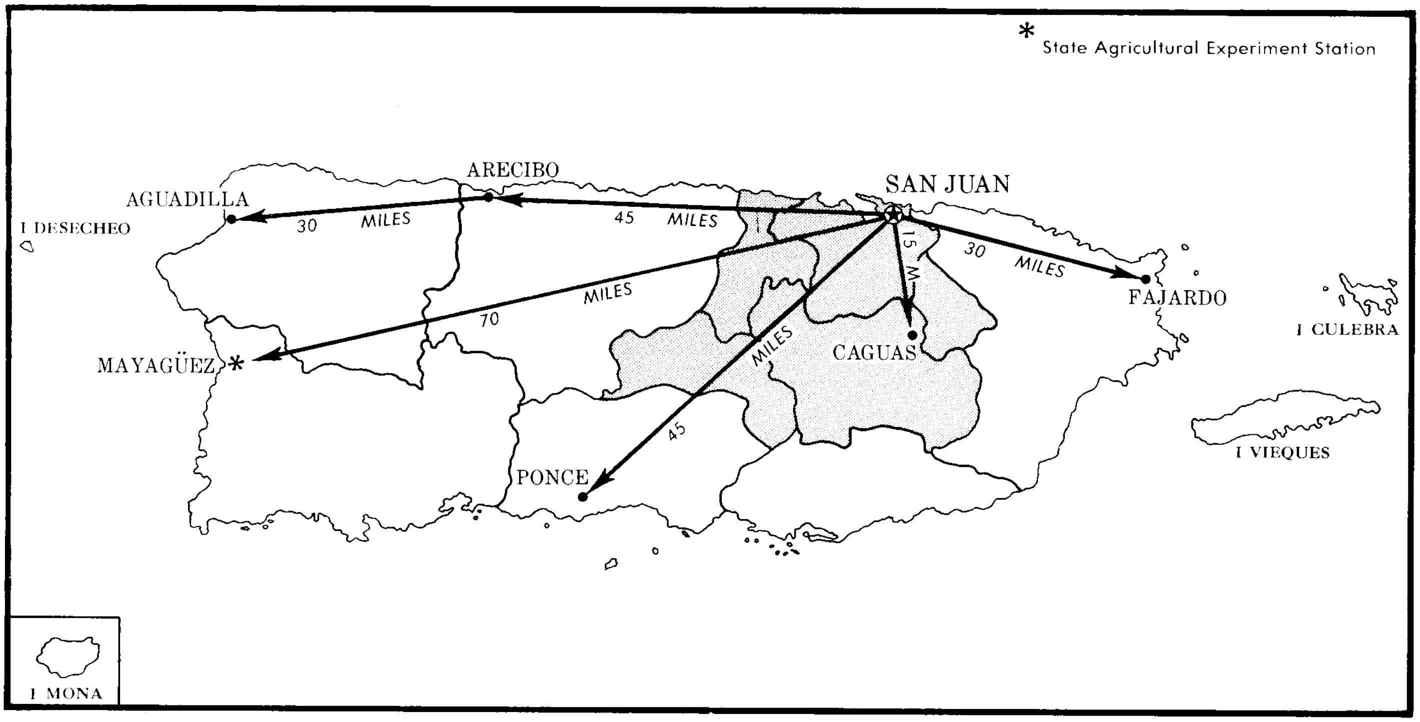
This soil survey has been prepared for many different users. Farmers, ranchers, foresters, and agronomists can use it to determine the potential of the soil and the management practices required for food and fiber production. Planners, community officials, engineers, developers, builders, and homebuyers can use it to plan land use, select sites for construction, develop soil resources, or identify any special practices that may be needed to insure proper performance. Conservationists, teachers, students, and specialists in recreation, wildlife management, waste disposal, and pollution control can use the soil survey to help them understand, protect, and enhance the environment.

Great differences in soil properties can occur even within short distances. Soils may be seasonally wet or subject to flooding. They may be shallow to bedrock. They may be too unstable to be used as a foundation for buildings or roads. Very clayey or wet soils are poorly suited to septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

These and many other soil properties that affect land use are described in this soil survey. Broad areas of soils are shown on the general soil map; the location of each kind of soil is shown on detailed soil maps. Each kind of soil in the survey area is described, and much information is given about each soil for specific uses. Additional information or assistance in using this publication can be obtained from the local office of the Soil Conservation Service or the Cooperative Extension Service.

This soil survey can be useful in the conservation, development, and productive use of soil, water, and other resources.

Angel Quintero
Director, Caribbean Area
Soil Conservation Service



Location of San Juan Area of Puerto Rico.

SOIL SURVEY OF SAN JUAN AREA OF PUERTO RICO

By Rafael A. Boccheciamp, Soil Conservation Service

Fieldwork by Rafael A. Boccheciamp, William Francia Rivera, Julio E. Trigo, G. Torres Ricci, Jose E. Brunet, and Luis H. Rivera, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service, in cooperation with the University of Puerto Rico, Agricultural Experiment Station

General nature of the area

The island of Puerto Rico is the smallest and farthest east of the four islands - Cuba, Jamaica, Hispaniola, and Puerto Rico - known as the Greater Antilles. It lies in the Torrid Zone. The north central coast of Puerto Rico is about 1,600 statute miles southeast of New York City, and the western part of the island is about 450 miles from the eastern point of Cuba. Ponce, on the south coast, is about 525 miles due north of Caracas, Venezuela.

The island was discovered by Christopher Columbus on his second voyage, November 19, 1493. The native inhabitants of the island, the friendly Taino Indians of the Arawak culture, lived in small villages, each ruled by a cacique, a chief. They grew food crops such as cassava and corn, and also tobacco and cotton. They also fished and hunted birds for their subsistence. They were clever at working stones, clay, and gold and adorned themselves with ornaments of these materials. The island was first settled in 1508 by Juan Ponce de Leon.

The San Juan Soil Survey Area is in northeast-central Puerto Rico (see facing page). It is bounded on the north by the Atlantic Ocean. San Juan, the capital of Puerto Rico, is in the northern part of the survey area. Mayaguez is 98 miles from San Juan. Ponce, the second largest city on the island, is 75 miles from the capital. The survey area covers an area of 447,279 acres. According to the census of 1970, the population totaled 1,172,609, of which 286,906 was rural and 885,703 urban. At that time there were 8,646 farms in the survey area.

The area consists of three major physiographic areas: the nearly level to sloping coastal plain, which is 10 percent of the area; the haystacks or limestone hills with their remarkable karst topography, which is about 4 percent; and the extensive igneous upland, which is 86 percent.

There are five soil conservation districts in the San Juan Soil Survey Area, namely: the Cibuco SCD, 80,101 acres, the municipalities of Corozal, Comerio, Naranjito, and Toa Alta; the San Juan SCD, 122,372 acres, the municipalities of Bayamon, Dorado, Toa Baja, Catano, Guaynabo, Rio Piedras, and Trujillo Alto; the Torito SCD, 74,533 acres, the municipalities of Cayey, Cidra, and Aguas Buenas; the Turabo SCD, 88,643 acres, the municipalities of Caguas, Gurabo, and San Lorenzo; and the Torrecillas SCD, 81,630 acres, the municipalities of Barranquitas, Aibonito, and Orocovis.

Farming is the principal enterprise of the area. Numerous industries, among which is the Consolidated Cigar Company, the largest cigar factory in the world, contribute to the welfare and economy of the island.

Improved pasture such as pangolagrass, stargrass, and Merker grass cover about 210,750 acres, or 47 percent of the area, according to the census of Agriculture of 1969. Most of the pastureland is used for raising beef and dairy cattle.

The principal cash and food crops of the area are plantains, taniers, yams, and tobacco. The total acreage is 89,353, or 20 percent of the area.

Woodland covers 72,239 acres, or 16 percent of the survey area.

Climate

In the San Juan Area of Puerto Rico the days are hot, except in January and February. The nights are warm all year. Winds from the Atlantic Ocean lower the afternoon temperatures on most days. Temperatures in the mountains of the interior are appreciably lower than elsewhere, but freezing temperatures are unknown anywhere in the area. Rainfall is abundant throughout the year in most of the area. The least falls in February and March. Except for the semiarid southernmost part, rainfall is heaviest in the mountains.

Tables 1 and 2 list data on temperature and precipitation for the survey area, as recorded at San Juan Airport for the period 1955 to 1974 and at Barranquitas, which is 2200 feet higher than San Juan, for the period 1963 to 1974.

In winter the average temperature at San Juan is 77 degrees F, and the average daily minimum temperature is 70. The lowest temperature on record, which occurred at

San Juan on March 3, 1957, is 60 degrees. In summer the average temperature is 82 degrees, and the average daily maximum temperature is 88. The highest recorded temperature, which occurred on June 21, 1972, is 96 degrees.

In winter the average temperature at Barranquitas is 69 degrees, and the average daily minimum temperature is 61. In summer the average temperature is 74 degrees, and the average daily maximum temperature is 82. The highest recorded temperature, which occurred on October 2, 1969, is 96 degrees.

Growing degree days, shown in tables 1 and 2, are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (60 degrees F).

Of the total annual precipitation at San Juan, 31 inches, or 56 percent, usually falls in April through September, which includes the growing season for most crops. In 2 years out of 10, the rainfall in April through September is less than 23 inches. The heaviest 1-day rainfall during the period of record was 5.01 inches at San Juan on August 6, 1955.

Of the total annual precipitation at Barranquitas, 28 inches, or 49 percent, usually falls in April through September. In 2 years out of 10, the rainfall during this period is less than 19 inches. The heaviest 1-day rainfall during the period of record at Barranquitas was 8.70 inches on October 9, 1970.

From June through November, an occasional tropical depression skirts or crosses the area and produces heavy rainfall that causes severe flooding. Thunderstorms number about 40 each year, 17 of which occur in summer. Every 10 to 20 years a hurricane causes wind damage and flooding.

The average relative humidity in midafternoon is about 65 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The percentage of possible sunshine is 60. The prevailing wind is from the northeast. Average windspeed is highest, 10 miles per hour, in March.

Climatic data in this section were specially prepared for the Soil Conservation Service by the National Climatic Center, Asheville, North Carolina.

How this survey was made

Soil scientists made this survey to learn what kinds of soil are in the survey area, where they are, and how they can be used. The soil scientists went into the area knowing they likely would locate many soils they already knew something about and perhaps identify some they had never seen before. They observed the steepness, length, and shape of slopes; the size of streams and the general pattern of drainage; the kinds of native plants or crops; the kinds of rock; and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material, which has been changed very little by leaching or by the action of plant roots.

The soil scientists recorded the characteristics of the profiles they studied, and they compared those profiles with others in areas nearby and in places more distant. Thus, through correlation, they classified and named the soils according to nationwide, uniform procedures.

After a guide for classifying and naming the soils was worked out, the soil scientists drew the boundaries of the individual soils on aerial photographs. These photographs show woodlands, buildings, field borders, roads, and other details that help in drawing boundaries accurately. The soil map at the back of this publication was prepared from aerial photographs.

The areas shown on a soil map are called soil map units. Some map units are made up of one kind of soil, others are made up of two or more kinds of soil, and a few have little or no soil material at all. Map units are discussed in the sections "General soil map for broad land use planning" and "Soil maps for detailed planning."

While a soil survey is in progress, samples of soils are taken as needed for laboratory measurements and for engineering tests. The soils are field tested, and interpretations of their behavior are modified as necessary during the course of the survey. New interpretations are added to meet local needs, mainly through field observations of different kinds of soil in different uses under different levels of management. Also, data are assembled from other sources, such as test results, records, field experience, and information available from state and local specialists. For example, data on crop yields under defined practices are assembled from farm records and from field or plot experiments on the same kinds of soil.

But only part of a soil survey is done when the soils have been named, described, interpreted, and delineated on aerial photographs and when the laboratory data and other data have been assembled. The mass of detailed information then needs to be organized so that it is readily available to different groups of users, among them farmers, managers of rangeland and woodland, engineers, planners, developers and builders, homebuyers, and those seeking recreation.

General soil map for broad land use planning

The general soil map at the back of this publication shows, in color, map units that have a distinct pattern of soils and of relief and drainage. Each map unit is a unique natural landscape. Typically, a map unit consists of one or more major soils and some minor soils. It is named for the major soils. The soils making up one unit can occur in other units but in a different pattern.

The general soil map provides a broad perspective of the soils and landscapes in the survey area. It provides a basis for comparing the potential of large areas for general kinds of land use. Areas that are, for the most part, suited to certain kinds of farming or to other land uses can be identified on the map. Likewise, areas of soils having properties that are distinctly unfavorable for certain land uses can be located.

Because of its small scale, the map does not show the kind of soil at a specific site. Thus, it is not suitable for planning the management of a farm or field or for selecting a site for a road or building or other structure. The kinds of soil in any one map unit differ from place to place in slope, depth, stoniness, drainage, or other characteristics that affect their management.

The soils in the survey area vary widely in their potential for major land uses. Table 3 shows the extent of the map units shown on the general soil map and gives general ratings of the potential of each, in relation to the other map units, for major land uses. Soil properties that pose limitations to the use are indicated. The ratings of soil potential are based on the assumption that practices in common use in the survey area are being used to overcome soil limitations. These ratings reflect the ease of overcoming the soil limitations and the probability of soil problems persisting after such practices are used.

Each map unit is rated for *cultivated farm crops, specialty crops, woodland, urban uses,* and *recreation areas.* Cultivated farm crops are those grown extensively by farmers in the survey area. Specialty crops include vegetables, fruits, and nursery crops grown on limited acreage and generally requiring intensive management. Woodland refers to land that is producing either trees native to the area or introduced species. Urban uses include residential, commercial, and industrial developments. Intensive recreation areas include campsites, picnic areas, ballfields, and other areas that are subject to heavy foot traffic. Extensive recreation areas include those used for nature study and as wilderness.

Map unit descriptions

Soils formed in residuum from basic volcanic rocks

These map units are in the central and southern parts of the soil survey area. The soils formed mainly in clayey material weathered from basic volcanic rocks. They are mostly steep to very steep. A few are gently sloping to sloping. V-shaped drainageways dissect the entire area. Many of the soils in the humid area are planted to clean cultivated crops regardless of the steepness of slope and hazard of erosion. The Descalabrado unit, in the southern part of the survey area, is mostly brushy pasture. The semiarid climate, steepness of slope, and shallow depth to bedrock make it unsuited to cultivated crops.

1. Maricao-Los Guineos

Deep, steep to very steep, well drained and moderately well drained soils of the humid mountainous areas

This unit is in the southeastern part of the survey area. The soils formed in residuum weathered from basic volcanic rocks. They are steep to very steep. They are used for food crops, pasture, and forest. They receive moisture throughout the year and are not deficient in moisture needed for the common crops.

This unit occupies 10 percent of the total acreage. The landscape is mountainous and is strongly dissected by intermittent streams. Steep to very steep side slopes and ridges are common.

The Maricao soils are deep to hard rock, well drained, and clayey. They are on strongly dissected uplands where slope gradients are 20 to 60 percent. They occupy about 55 percent of the unit.

The Los Guineos soils are deep to hard rock, moderately well drained, and clayey. They are on side slopes having gradients of 20 to 60 percent. They occupy about 40 percent of the unit.

The remaining 5 percent of the unit is made up of the deep, well drained, clayey Humatas soils.

This unit in general has severe limitations for farming because of the slope and the erosion hazard. Complex conservation practices and good management are needed in order to produce crops. These soils are best suited to grasses and trees. Steep slopes and the erosion hazard make fieldwork costly and difficult.

2. Humatas-Naranjito-Consumo

Deep to moderately deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, the second largest, makes up 29 percent of the total acreage. It is in the mountainous section of the survey area. The landscape is one of gently sloping foot slopes to very steep side slopes and ridges that are dissected by intermittent streams. These soils formed in the residuum of weathered basic volcanic rocks and siltstone. They are used for food crops and pasture. They receive adequate moisture throughout the year for the crops commonly grown.

The Humatas soils are deep, well drained, and clayey. They are on mountainsides where slope gradients are 20 to 60 percent. They make up about 36 percent of the unit.

The Naranjito soils are moderately deep, 20 to 40 inches to hard consolidated volcanic rocks, and are well drained and clayey. They are on strongly dissected uplands where slope gradients are 12 to 60 percent. They make up about 29 percent of the unit.

The Consumo soils are deep but have very highly weathered rock at a depth of 14 to 24 inches. They are well drained, clayey soils on the side slopes of naturally dissected uplands where slope gradients are 20 to 60 percent. They occupy about 17 percent of the unit.

The remaining 18 percent consists of the deep, well drained, clayey Daguey, Aceitunas, and Rio Piedras soils and the somewhat poorly drained Lares soils.

This unit in general has severe limitations for cultivated crops because of the slope and the erosion hazard.

The less steep slopes are suitable for cultivation if complex soil conservation practices are applied and the soils are well managed. Liming and fertilizing are necessary for better crop yields. The use of machinery is not feasible on most of this unit. The slope is a severe limitation for buildings or other developments.

3. Mucara-Caguabo

Moderately deep to shallow, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, the largest, makes up about 39 percent of the total survey area. The landscape is mountainous and is highly dissected by intermittent streams. Narrow ridges are common. This unit is in the humid mountainous region of the survey area extending from the vicinity of Orocovis to San Lorenzo.

The Mucara soils are moderately deep, 20 to 40 inches to semiconsolidated rock, and are well drained and clayey. They are on side slopes of strongly dissected uplands where slope gradients are 12 to 60 percent. They make up about 58 percent of the unit.

The Caguabo soils are shallow to hard rock, well drained, and loamy. They are on side slopes and ridgetops where slope gradients are 20 to 60 percent. They make up about 37 percent of the unit. In some areas the surface of these soils is covered with stones.

The remaining 5 percent consists of the well drained, loamy Morado and Sabana soils and the moderately well drained, clayey Juncos soils. The Morado and Sabana soils occupy similar positions on the landscape as the Mucara and Caguabo soils. The Juncos soils, which are more gently sloping, occupy the side slopes and foot slopes of strongly dissected uplands.

This unit in general is not suitable for cultivation because of the slope, erosion hazard, rapid runoff, and depth to rock. It is suitable for pasture and woodland. A large acreage is in brush and brushy native pasture. Some areas have been cleared and planted to pangolagrass. Small patches are in food crops. Steep slopes, the erosion hazard, and the depth to rock are permanent limitations that preclude the use of these soils for clean cultivation. Fieldwork is difficult and costly. The soils have severe limitations for nonfarm uses such as dwellings, roads, recreational facilities, and other intensive developments.

4. Descalabrado

Shallow, very steep, well drained soils of the semiarid mountainous areas

This unit is in the southern part of the survey area. The soils formed in the residuum of weathered basic volcanic rocks. They do not receive enough rainfall throughout the year and are deficient in moisture needed for growing common cultivated crops. The topography is rugged and very steep. This unit makes up 1 percent of the total survey area.

The Descalabrado soils are shallow to volcanic rock and well drained. They are on side slopes where slope gradients are 40 to 60 percent. They make up 91 percent of the unit. The remaining 9 percent consists of boulders and the shallow, well drained, acid Guayama soils.

Because of the low rainfall of the area, most of the soils are in native guineagrass and brush. Clean tilled crops are not suited because of the slopes, depth to rock, and moisture deficiency. Most of the plant cover dies during long periods of drought.

Soils formed in residuum from intrusive igneous rocks

This unit is in the southeastern part of the survey area near the town of San Lorenzo. The soils formed mainly in the residuum of granitic rocks. Most are steep and very steep. The landscape is mountainous, with V-shaped drainageways dissecting the entire area and with narrow, knife-like ridges, gullies, and slips. Some of the soils are planted to clean cultivated food crops, but many are in native and improved pasture. Most soils in this unit have low potential for crops because of the steep slopes and shallow depth to the granitic rock.

5. Pandura-Lirios

Shallow to deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit, one of the smaller, makes up 7 percent of the total acreage of the soil survey area. It is in the vicinity of San Lorenzo. The soils formed in the residuum of granitic rock that is part of the San Lorenzo Batholith. The landscape is mountainous and is highly dissected by numerous intermittent streams. Narrow ridges, gullies, and slip areas are common.

The Pandura soils are shallow to weathered granitic rocks, well drained, loamy, moderately steep to steep. They are on side slopes of the granitic uplands where slope gradients are 12 to 60 percent. They make up about 62 percent of the unit.

The Lirios soils are deep, but highly weathered granitic rock is at a depth of 20 to 34 inches. These are well drained, steep to very steep soils with a clayey subsoil. They are on side slopes and narrow ridgetops where slope gradients are 20 to 60 percent. They make up 26 percent of the unit.

The remaining 12 percent of the unit is made up of the deep, well drained, clayey Limones and Jagueyes soils and the somewhat poorly drained, clayey Cayagua soils. The Limones and Jagueyes soils are on side slopes and narrow ridgetops where slope gradients are 20 to 60 percent.

This unit in general has severe limitations for farming because of the slope, erosion hazard, and low fertility of the soils. It has been intensively cultivated for food crops. Some areas are in improved pasture. Others are in brush and brushy pasture.

Steep slopes and the erosion hazard are permanent limitations that preclude the use of these soils for clean cultivated crops. The slope is a severe limitation for nonfarm uses such as dwellings, septic tanks, recreational areas, and other intensive developments.

Soils formed in residuum from limestone

This unit is in the northwestern part of the survey area. The soils formed mainly in clayey materials weathered from limestone. Many are steep and very steep. Some are nearly level to sloping. The landscape has a karst topography, which is characterized by haystack hills, locally known as "mogotes;" sinkholes; and underground drainage. Most of the soils are in brushy forest. Others are in native and improved pasture. The soils have low potential for clean cultivated crops.

6. Tanama-Colinas-Soller

Shallow to moderately deep, moderately steep to very steep, well drained soils of the humid mountainous areas

This unit makes up 4 percent of the total acreage of the survey area. The landscape is one of karst topography characterized by the brush-covered "mogotes," or haystack hills. This unit is in the northwestern part of the survey area, between the northern coastal plains and the uplands. The soils of this unit are severely limited for farming because of the steep slopes and the shallow to moderate depth to limestone rock. Some have been cleared of brushy vegetation and planted to pangolagrass. A large part, however, is still in brush and brushy pasture.

The Tanama soils are shallow, are well drained, and have a clayey subsoil. They have slope gradients of 20 to 60 percent. They make up 39 percent of the unit.

The Colinas soils are moderately deep to mixed soft limestone, are well drained, and have a clayey subsoil. They have slope gradients of 12 to 60 percent. They make up 29 percent of the unit.

The Soller soils are shallow to hard fragmental limestone, are well drained, and have a thin clayey subsoil. They have slope gradients of 20 to 60 percent. They make up 28 percent of the unit.

The remaining 4 percent of the unit consists of the deep, well drained, clayey Juncal soils and areas of limestone rockland.

Soils formed in transported materials

Most of these units are in the northern part of the soil survey area. Some are in inner valleys in the central part. The soils formed mainly in clayey sediments of mixed origin and in organic materials. They are mainly nearly level to sloping. They are on the coastal plains, on flood plains, in inner valleys, and in low depressional and lagoonlike positions. Many are planted to clean cultivated crops to which they are well suited. Soils in the Martin Pena-Saladar-Hydraquents unit, however, are very poorly drained and are therefore limited for farming.

7. Almirante-Vega Alta-Matanzas

Deep, gently sloping to sloping, well drained soils on terraces and alluvial fans of the coastal plain

This unit occupies 3 percent of the total acreage. It consists of gently sloping to sloping soils on coastal plains, on terraces, and in valleys between the limestone hills. It is in the northern section of the survey area.

The Almirante soils are deep, well drained, and clayey. They are on coastal plains where slope gradients are 2 to 12 percent. They make up about 55 percent of the unit.

The Vega Alta soils are deep, well drained, and clayey. They are gently sloping to sloping. They are on coastal plains and terraces where slope gradients are 2 to 12 percent. They make up about 21 percent of the unit.

The Matanzas soils are deep, well drained, and clayey. They are on foot slopes and in small valleys between the limestone hills. They have slope gradients of 2 to 5 percent. They make up about 11 percent of the unit.

The remaining 13 percent of the unit is made up of the deep, gently sloping, well drained, clayey Bayamon and Torres soils. These soils are on coastal plain terraces and alluvial fans.

This unit is suited to farming. Most of it was used for sugarcane but is now in improved pasture such as pangolagrass and stargrass. The soils of this unit should be limed, fertilized, and worked at the proper moisture condition to prevent puddling. They receive adequate moisture throughout the year for the crops commonly grown. For nonfarm uses, they have only slight limitations.

8. Toa-Bajura-Coloso

Deep, nearly level, well drained to poorly drained soils on flood plains

This unit is in the northern part of the survey area. The soils formed in mixed sediments derived from miscellaneous volcanic rocks and deposited over nearly level river flood plains. They receive adequate moisture throughout the year for the cultivated crops commonly grown. Most of these soils were intensively cultivated for sugarcane. The trend now is toward improved pasture, such as pangolagrass and stargrass. This unit makes up 4 percent of the total acreage of the survey area.

The Toa soils are deep, are moderately well drained to well drained, are moderately permeable, and have a clayey subsoil. They make up 32 percent of the unit.

The Bajura soils are deep, are poorly drained, are slowly permeable, and have a clayey subsoil. They make up 27 percent of the unit.

The Coloso soils are deep, somewhat poorly drained, slowly permeable soils with a clayey subsoil. They make up 17 percent of the unit.

The remaining 24 percent of the unit consists of the nearly level, moderately deep, moderately permeable Estacion soils and the deep, well drained, sandy Reilly soils and areas of riverwash.

These soils have severe limitations for nonfarm uses such as dwellings, septic tanks, and roads because of poor drainage and the flood hazard.

9. Mabi-Rio Arriba

Deep, nearly level to sloping, moderately well drained to somewhat poorly drained soils on terraces, footslopes, and alluvial fans of inner valleys

This unit is in the east-central part of the survey area. The soils formed in fine textured sediments of mixed origin. They receive adequate moisture throughout the year for most crops.

This small unit makes up 2 percent of the total acreage of the survey area. Most of the soils were used for sugarcane production. The trend now is toward improved pasture, such as pangolagrass.

The mabi soils are deep, somewhat poorly drained, slowly permeable, clayey soils. They have slope gradients of 0 to 12 percent. They make up 54 percent of the unit.

The Rio Arriba soils are deep, moderately well drained, moderately slowly permeable soils with a clayey subsoil. They have slope gradients of 2 to 12 percent. They make up 41 percent of the unit.

The remaining 5 percent is the deep, poorly drained, clayey Montegrande soil.

The soils of this unit have severe limitations for nonfarm uses because of their clayey nature and high shrink-swell potential.

10. Martin Pena-Saladar-Hydraquents

Deep, nearly level, very poorly drained soils in low depressions and lagoons of the coastal plain

This unit occupies 1 percent of the total acreage of the survey area. The landscape consists of low-lying depressions filled with water most of the year. This unit is in the northwestern part of the coastal plain, in the vicinity of Dorado.

The Martin Pena soils are deep and very poorly drained. They have a thin surface layer of muck underlain by clayey material. They make up 51 percent of the unit.

The Saladar soils are deep, very poorly drained muck. They make up about 23 percent of the unit.

Hydraquents formed in variable materials in tidal marshes that are permanently saturated with brackish water. These soils have no sulfidic materials within 50 centimeters of the mineral surface. They make up 12 percent of the unit.

The remaining 14 percent of the unit is made up of the deep, excessively drained Catano and Durados soils. These soils occupy a nearly level area of the coastal plain in the northwestern part of the survey area.

These soils have severe limitations for farming because of very poor drainage. Complex drainage practices are needed if they are to be reclaimed. For nonfarm uses, they also have severe limitations because of very poor drainage and low bearing capacity. It is necessary to sink pilings and use other complex engineering practices.

The soils of this unit are in an area of intensive development, and most of this area is being reclaimed for dwellings.

Soil maps for detailed planning

The map units shown on the detailed soil maps at the back of this publication represent the kinds of soil in the survey area. They are described in this section. The descriptions together with the soil maps can be useful in determining the potential of a soil and in managing it for food and fiber production; in planning land use and developing soil resources; and in enhancing, protecting, and preserving the environment. More information for each map unit, or soil, is given in the section "Use and management of the soils."

Preceding the name of each map unit is the symbol that identifies the soil on the detailed soil maps. Each soil description includes general facts about the soil and a brief description of the soil profile. In each description, the principal hazards and limitations are indicated, and the management concerns and practices needed are discussed.

The map units on the detailed soil maps represent an area on the landscape made up mostly of the soil or soils for which the unit is named. Most of the delineations shown on the detailed soil map are phases of soil series.

Soils that have a profile that is almost alike make up a *soil series*. Except for allowable differences in texture of the surface layer or of the underlying substratum, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement in the profile. A soil series commonly is named for a town or geographic feature near the place where a soil of that series was first observed and mapped.

Soils of one series can differ in texture of the surface layer or in the underlying substratum and in slope, erosion, stoniness, salinity, wetness, or other characteristics that affect their use. On the basis of such differences, a soil series is divided into phases. The name of a *soil phase* commonly indicates a feature that affects use or management. For example, Colinas clay loam is one of several phases within the Colinas series.

Some map units are made up of two or more dominant kinds of soil. Such map units are called soil complexes, soil associations, and undifferentiated groups.

A *soil complex* consists of areas of two or more soils that are so intricately mixed or so small in size that they cannot be shown separately on the soil map. Each area includes some of each of the two or more dominant soils, and the pattern and proportion are somewhat similar in all areas. Urbanland-Mucara complex is an example.

A *soil association* is made up of soils that are geographically associated and are shown as one unit on the map because it is not practical to separate them. A soil association has considerable regularity in geographic pattern and in the kinds of soil that are a part of it. The extent of the soils can differ appreciably from one delineation to another; nevertheless, interpretations can be made for use and management of the soils.

An *undifferentiated group* is made up of two or more soils that could be mapped individually but are mapped as one unit because there is little value in separating them. The pattern and proportion of the soils are not uniform. An area shown on the map has at least one of the dominant (named) soils or may have all of them.

Most map units include small, scattered areas of soils other than those that appear in the name of the map unit. Some of these soils have properties that differ substantially from those of the dominant soil or soils and thus could significantly affect use and management of the map unit. These soils are described in the description of each map unit. Some of the more unusual or strongly contrasting soils that are included are identified by a special symbol on the soil map.

Most mapped areas include places that have little or no soil material and support little or no vegetation. Such places are called *miscellaneous areas*; they are delineated on the soil map and given descriptive names. Made land is an example. Some of these areas are too small to be delineated and are identified by a special symbol on the soil map.

The acreage and proportionate extent of each map unit are given in table 4, and additional information on properties, limitations, capabilities, and potentials for many soil uses is given for each kind of soil in other tables in this survey. (See "Summary of tables.") Many of the terms used in describing soils are defined in the Glossary.

Soil descriptions

AaB—Aceitunas clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on terraces and alluvial fans. Slopes are smooth and are 100 to 500 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is dark brown friable clay about 8 inches thick. The subsoil, to a depth of 60 inches, is yellowish red clay. It is firm to a depth of 30 inches and is friable from 30 inches to a depth of 60 inches.

Included with this soil in mapping are some small areas of Rio Arriba and Lares soils. The surface layer of the Rio Arriba soils is brown clay and that of the Lares soils is dark brown clay. These soils make up 10 to 20 percent of the acreage.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work because of the stickiness and plasticity of the clay. It should be tilled at the optimum moisture content to avoid puddling and the formation of large clods. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane, plantains, and taniers. It is best suited, however, to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately suited to most urban uses because of its clayey nature. If the soil is used as construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIe.

AaC—Aceitunas clay, 5 to 12 percent slopes. This is a sloping, well drained soil on terraces and alluvial fans. Slopes are smooth and are 100 to 800 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark brown friable clay about 8 inches thick. The subsoil, to a depth of 60 inches, is yellowish red clay. It is firm to a depth of 30 inches and is friable from 30 inches to a depth of 60 inches.

Included with this soil in mapping are some small areas of Rio Arriba, Lares, and Via soils. The surface layer of the Rio Arriba soils is brown clay and that of the Lares soils is dark brown clay. The surface layer of the Via soils is dark brown clay loam. These soils make up 15 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work because of the stickiness and plasticity of the clay. It should be tilled at the optimum moisture content to avoid puddling and the formation of large clods. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane, plantains, and taniers. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately suited to urban uses because of the slope and its clayey nature. If the soil is used as construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIIe.

AbD—Aibonito clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on ridgetops and side slopes of strongly dissected volcanic uplands. Slopes are 400 to 800 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is dark grayish brown, friable clay about 7 inches thick. The subsoil is about 36 inches thick; it is strong brown clay mottled with red and yellowish brown. The substratum, beginning at a depth of 43 inches, is red, strong brown, and white, friable clay saprolite to a depth of 65 inches and silty clay saprolite from 65 to 110 inches.

Included with this soil in mapping are small areas of Humatas, Consumo, and Los Guineos soils. The surface layer of the Humatas soils is dark brown clay, that of the Consumo soils is reddish brown clay, and that of the Los Guineos soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. The soil is medium in natural fertility and has a deep root zone. It is difficult to work because of slope and the stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for such crops as plantains, taniers, and yams. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, mahogany, kadam, mahoe, and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and a temporary plant cover established quickly in denuded areas. Capability subclass IVe.

AbE—Aibonito clay, 20 to 40 percent slopes. This is a steep, well drained soil on ridgetops and side slopes of strongly dissected uplands. Slopes are 400 to 1000 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark grayish brown, friable clay about 7 inches thick. The subsoil is about 36 inches thick; it is strong brown clay mottled with red and yellowish brown. The substratum, beginning at a depth of 43 inches, is red, strong brown, and white, friable clay saprolite to a depth of 65 inches and silty clay saprolite from 65 to 110 inches.

Included with this soil in mapping are small areas of Humatas, Consumo, and Los Guineos soils. The surface layer of the Humatas soils is dark brown clay; that of the Consumo soils is reddish brown clay; and that of the Los Guineos is dark yellowish brown clay. These soils make up 15 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. This soil is medium in natural fertility, and it has a deep root zone. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for such crops as plantains, taniers, and yams. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

AmB—Almirante clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on coastal plains and in valleys between the limestone hills. Slopes are smooth and are 800 to 1500 feet long. The areas range from 20 to 600 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is firm clay to a depth of 60 inches. From 7 to 34 inches, it is strong brown; from 34 to 46 inches, it is brownish yellow and dark red; and from 46 to 60 inches, it is variegated brownish yellow, dark red, and light gray.

Included with this soil in mapping are small areas of the Vega Alta, Matanzas, and Bayamon soils. The surface layer of the Vega Alta soils is dark yellowish brown clay loam, and that of the Matanzas and Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work due to the stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is a major concern of management.

This soil has been used for sugarcane. It is best suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because of its clayey nature. Capability subclass IIe.

AmC—Almirante clay, 5 to 12 percent slopes. This is a sloping, well drained soil on coastal plains and in valleys between the limestone hills. Slopes are smooth and are 400 to 1000 feet long. The areas range from 10 to 400 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is firm clay to a depth of 60 inches. From 7 to 34 inches, it is strong brown; from 34 to 46 inches, it is brownish yellow and dark red; and from 46 to 60 inches, it is variegated brownish yellow, dark red, and light gray.

Included with this soil in mapping are small areas of Vega Alta, Matanzas, and Bayamon soils. The surface layer of the Vega Alta soils is dark yellowish brown clay loam; that of the Matanzas and Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is medium in natural fertility and has a deep root zone. It is difficult to work due to stickiness and plasticity of the clay. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is a major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because of its clayey nature. Capability subclass IIIe.

Ba—Bajura clay. This is a nearly level, poorly drained soil on river flood plains. Slopes are smooth and are 500 to 2000 feet long. The areas range from 20 to 1000 acres.

Typically the surface layer is dark brown, firm clay about 5 inches thick. The subsoil, about 7 inches thick, is dark gray, firm clay mottled with yellowish brown, very dark gray, and dark brown. The substratum, from a depth of 12 inches to 31 inches, is gray and yellowish brown, firm clay mottled with greenish gray. From 31 inches to 60 inches, the substratum is greenish gray, firm clay mottled with brownish yellow and bluish gray.

Included with this soil in mapping are small areas of the Coloso soils. The surface layer of the Coloso soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow and the available water capacity is high. This soil is difficult to work due to stickiness and plasticity of the clay and wetness. It is fertile and has a deep root zone. When properly drained and managed, it is suited to crops (fig. 1).

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and paragrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of drainage, flood hazard, and high shrink-swell potential. Capability subclass IIIw.

BmB—Bayamon clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on foot slopes and in small valleys between the limestone hills. Slopes are 500 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark reddish brown, friable clay about 8 inches thick. The subsoil, to a depth of 66 inches is weak red and red, firm to friable clay.

Included with this soil in mapping are small areas of Matanzas soils. The surface layer of the Matanzas soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is medium, and the hazard of erosion is slight to moderate. This soil is difficult to work because of the stickiness and plasticity of the clay. It is medium in natural fertility and has a deep root zone. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion and maintaining natural fertility are the major concerns of management.

This soil has been used for sugarcane and pineapples. It is suited to pangolagrass, stargrass, and Merker grass (fig. 2).

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has slight to moderate limitations for most urban uses. If the soil is used for construction sites, temporary plant cover should be established quickly in denuded areas. Capability subclass IIe.

CaE—Caguabo clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and tops of strongly dissected uplands. Slopes are 500 to 1000 feet long. The areas range from 20 to 800 acres.

Typically the surface layer is dark grayish brown, friable clay loam about 4 inches thick. The next layer is brown, friable very gravelly clay loam about 6 inches thick. The substratum, beginning at a depth of 10 inches, is a mixture of weathered and partially weathered volcanic rocks. Consolidated rock is at a depth of 16 inches.

Included with this soil in mapping are small areas of Mucara, Naranjito, and Consumo soils and a few rocky hilltops. The surface layer of the Mucara soils is very dark grayish brown clay; that of the Naranjito soils is dark brown silty clay loam; and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate in this soil, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and shallow. Hillside ditches and diversions are difficult to lay out, establish, and maintain. This soil is fertile but has a shallow root zone. Controlling erosion is the major concern of management.

This soil has been used for tobacco and food crops such as sweet potatoes, bananas, and coffee. It is best suited to pangolagrass and stargrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, eucalyptus, and mahogany trees. Production of Honduras pine is low, about 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep, shallow, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

CaF—Caguabo clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and mountaintops of strongly dissected uplands. Slopes are 400 to 800 feet long. The areas range from 20 to 2000 acres.

Typically the surface layer is dark grayish brown, friable clay loam about 4 inches thick. The next layer is about 5 inches thick; it is brown, friable very gravelly clay loam. The substratum, beginning at a depth of 10 inches, is a mixture of weathered and partially weathered volcanic rocks. Consolidated rock is at a depth of 16 inches.

Included with this soil in mapping are small areas of Mucara and Naranjito soils and a few spots that have many boulders and stones on the surface. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Naranjito soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and shallow. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The soil is fertile but has a shallow root zone. Controlling erosion is the major concern of management.

This soil has been used for tobacco and food crops such as sweet potatoes, bananas, and coffee. It is best suited, however, to pangolagrass and stargrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is low, about 700 to 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep, shallow, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

CbF—Caguabo-Rock outcrop complex, 40 to 60 percent slopes. This complex consists of very steep, well drained soils and Rock outcrop on side slopes and narrow ridges. The areas range from 10 to 500 acres. The complex is about 60 percent Caguabo clay loam and 40 percent Rock outcrop and other minor soils. Caguabo and Rock outcrop form such an intricate pattern that they were not separated in mapping.

In a representative profile of Caguabo clay loam the surface layer is about 3 inches thick. The next layer, about 5 inches thick, is brown, friable very gravelly clay loam. It is underlain by a mixture of weathered and partially weathered volcanic rocks. Volcanic bedrock is at a depth of 10 to 20 inches.

Included with this soil complex in mapping are spots of deeper soils that formed between the rock outcrops. Also included are some areas of severely eroded Caguabo soils that have a thin surface layer of brown to dark grayish brown clay loam. These soils are on ridgetops.

Permeability is moderate in the Caguabo soil, and the available water capacity is low. The root zone is shallow. Tilth is fair to poor. Surface runoff is very rapid. In unlimed areas the soil is slightly acid.

The vegetation is shrubs, brush, and grass. This complex is not suited to cultivated crops. The potential for pasture is low. The Caguabo soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is low, about 700 board feet per acre per year. The hazard of erosion and the limitations on the use of equipment are moderate. Logging roads, skid trails, and machine plantings should be on the contour to help control erosion. The use of equipment is restricted mainly by the very steep slopes and the many rock outcrops.

This complex is poorly suited to most urban uses, mainly because of the very steep slopes and shallow depth to the volcanic rock, which is at a depth of 10 to 20 inches. Most of the areas are subject to slides. Erosion is a severe hazard in areas not protected by vegetative cover. In areas that are used as construction sites, development should be on the contour. Removal of vegetative cover should be held to a minimum, and plant cover established quickly on denuded areas. Capability subclass VIIIs.

Ce—Candelero loam. This is a gently sloping, somewhat poorly drained soil on terraces, alluvial fans, and foot slopes. Slopes are undulating and are 100 to 800 feet long. The areas range from 30 to 100 acres.

Typically the surface layer is dark grayish brown loam about 6 inches thick. The subsoil from 6 inches to a depth of 35 is mainly dark brown, dark gray, and very dark gray, firm sandy clay loam mottled with yellowish brown, greenish gray, and brownish yellow. From 35 inches to a depth of 60 inches, the subsoil is brownish yellow and yellowish brown, firm sandy clay mottled with gray, greenish gray, and yellowish red.

Included with this soil in mapping are small areas of Cayagua soils. The surface layer of the Cayagua soils is dark grayish brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is medium. This soil is difficult to work due to wetness and the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, Merker grass, and paragrass.

This soil is limited for most urban uses because of wetness, flood hazard, and its clayey nature. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

ClC—Catalina clay, 4 to 12 percent slopes. This is a sloping, well drained soil on side slopes and hilltops of the humid uplands. Slopes are 300 to 400 feet long. The areas range from 10 to 150 acres.

Typically the surface layer is dark reddish brown, friable clay about 6 inches thick. The subsoil layers from 6 inches to a depth of 84 inches are reddish brown and dark reddish brown firm clay. From 84 to 99 inches, the subsoil is variegated dusky red, dark reddish brown, and strong brown clay.

Included with this soil in mapping are small areas of Humatas, Daguey, and Consumo soils. The surface layer of the Humatas and Daguey soils is dark brown clay, and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains, yams, taniers, and coffee. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses due to slope, its clayey nature, and seepage. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Cn—Catano loamy sand. This is a nearly level, excessively drained soil on narrow strips of the coastal plain. The areas range from 20 to 200 acres.

Typically the surface layer of this soil is very dark grayish brown loamy sand about 7 inches thick. The next layer is about 16 inches thick; it is dark brown, loose sand. The substratum, beginning at a depth of 23 inches, is dark grayish brown, loose sand.

Included with this soil in mapping are small areas of Durados soils. The surface layer of the Durados soils is very dark grayish brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very slow. This soil is easily worked. The root zone is deep, but natural fertility is low. The soil is very limited for farming.

This soil has been used for growing coconuts. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to most urban uses. Capability subclass VIs.

Co—Cayagua sandy loam. This is a sloping, poorly drained soil on alluvial fans. Slopes are 200 to 800 feet long. The areas range from 50 to 300 acres.

Typically the surface layer is dark grayish brown, friable sandy loam about 8 inches thick. The subsoil is about 24 inches thick; it is yellowish brown and light olive gray, firm clay mottled with red, yellowish red, strong brown, and gray. The substratum, beginning at a depth of 32 inches, is yellowish brown, white, and gray, friable, sandy clay loam saprolite.

Included with this soil in mapping are some areas of Candelero soils. The surface layer of the Candelero soils is dark grayish brown loam. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of wetness. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of wetness, seepage, and slope. If the soil is used as construction sites, development should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

CrD2—Colinas clay loam, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on ridgetops and side slopes of low rolling hills. Slopes are convex and are 200 to 500 feet long. The areas range from 10 to 300 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white, soft limestone.

Included with this soil in mapping are small areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam; that of the

Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the surface layer. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, mahoe, and teak trees. Production of Honduras mahogany is very low, about 450 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

CrE2—Colinas clay loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on ridgetops and side slopes of low hills. Slopes are convex and are 100 to 300 feet long. The areas range from 20 to 400 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white soft limestone.

Included with this soil in mapping are some areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam, and that of the Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the surface layer. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is very low, about 350 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

CrF2—Colinas clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on ridgetops and side slopes of hills. Slopes are convex and are 100 to 400 feet long. The areas range from 50 to 300 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is dark brown, friable clay loam about 11 inches thick. The subsoil is about 15 inches thick; it is brownish yellow, friable clay loam. The substratum, beginning at a depth of 26 inches, is pale yellow, very friable, soft limestone that crushes to silty clay loam. From 48 to 52 inches, the substratum is yellow and white soft limestone.

Included with this soil in mapping are some areas of Soller and Tanama soils. The surface layer of the Soller soils is very dark grayish brown clay loam, and that of the Tanama soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the surface layer. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass.

Proper stocking rates and deferred grazing are chief management needs.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Cs—Coloso silty clay loam. This is a nearly level, somewhat poorly drained soil on river flood plains. Slopes are smooth and 200 to 1000 feet long. The areas range from 100 to 600 acres.

Typically the surface layer is dark brown, friable silty clay loam about 7 inches thick. The underlying material from 7 to 16 inches is dark brown and dark yellowish brown, friable silty clay loam, from 16 to 32 inches is dark grayish brown and light gray silty clay loam mottled with dark yellowish brown, and from 32 to 70 inches is greenish gray silty clay mottled with yellowish red and yellowish brown.

Included with this soil in mapping are small areas of Toa and Bajura soils. The surface layer of the Toa soils is dark brown silty clay loam, and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the wetness and the stickiness and plasticity of the surface layer. The root zone is deep. This soil is fertile. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane (fig. 3). It is suited to pangolagrass, stargrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because it is somewhat poorly drained, too clayey, and subject to overflow. Capability subclass IIw.

CuE—Consumo clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of maturely dissected humid uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 100 to 800 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is reddish brown friable clay about 10 inches thick. The subsoil is about 10 inches thick; it is yellowish red, friable clay. The substratum, beginning at a depth of 20 inches, is red, brownish yellow, and yellowish red, very friable, silty clay loam saprolite.

Included with this soil in mapping are spots of Humatas, Naranjito, and Mucara soils. The surface layer of the Humatas soils is dark brown clay, and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Mucara soils is very dark grayish brown clay. These included soils make up about 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management. This soil has been used for crops such as coffee. It is suited to pangolagrass and to molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

CuF—Consumo clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of maturely dissected humid uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 100 to 1000 acres. This soil has lost much of its original surface layer through erosion. A few shallow to deep gullies have formed.

Typically the surface layer is reddish brown friable clay about 10 inches thick. The subsoil is about 10 inches thick; it is yellowish red, friable clay. The substratum, beginning at a depth of 20 inches, is red, brownish yellow, and yellowish red, very friable, silty clay loam saprolite.

Included with this soil in mapping are spots of Humatas, Naranjito, and Mucara soils. The surface layer of the Humatas soils is dark brown clay, and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Mucara soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as coffee. It is suited to pangolagrass and to molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

CzC—Corozal clay, 5 to 12 percent slopes. This is a sloping, somewhat poorly drained soil on interfluves of strongly dissected low volcanic hills. Slopes are 200 to 400 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is dark reddish brown, firm clay about 7 inches thick. The subsoil is about 33 inches thick; it is mostly red, firm clay. The substratum, beginning at a depth of 40 inches, is yellowish red, light gray, and strong brown, friable, clay loam saprolite.

Included with this soil in mapping are small areas of Consumo, Daguey, and Humatas soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey and Humatas soils is dark brown clay. These soils make up 10 to 20 percent of the area of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers and plantains. It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses due to its clayey nature and wetness. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DaC—Daguey clay, 2 to 12 percent slopes. This is a gently sloping to sloping soil on stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes are 200 to 800 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is dark brown firm clay about 10 inches thick. The subsoil is about 62 inches thick; it is yellowish red and red, firm clay. The substratum, beginning at a depth of 72 inches, is yellowish red, strong brown, and reddish yellow, friable, silty clay loam saprolite.

Included with this soil in mapping are small areas of Humatas and Catalina soils. The surface layer of the Humatas soils is dark brown clay; that of the Catalina soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains, yams, taniers, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, and mahoe trees. Production of Honduras pine is moderate about 1300 board feet per acre per year. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

Slope is a moderate limitation for most urban uses. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DaD—Daguey clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes are 100 to 500 feet long. The areas range from 20 to 200 acres.

Typically the surface layer is brown, firm clay about 10 inches thick. The subsoil is about 62 inches thick; it is yellowish red and red, firm clay. The substratum, beginning at a depth of 72 inches, is yellowish red, friable silty clay loam saprolite mottled with strong brown and reddish yellow.

Included with this soil in mapping are small areas of Humatas and Catalina soils. The surface layer of the Humatas soils is dark brown clay. That of the Catalina soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is moderately steep (fig. 4) and because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains, yams, taniers, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

DeF—Descalabrado clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and tops of strongly dissected uplands. Slopes are 200 to 1000 feet long. The areas range from 100 to 1000 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 6 inches thick; it is dark brown, firm gravelly clay. The substratum, beginning at a depth of 11 inches, is dark yellowish brown and olive, friable gravelly sandy clay loam. Hard rock is at a depth of 17 inches.

Included with this soil in mapping are a few spots of Descalabrado-Rock outcrop complex and Guayama soils. The surface layer of the Guayama soils is dark reddish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. This soil is fertile, but has a shallow root zone. It is not suited to cultivated crops because it is in areas of low rainfall. The vegetation is brush and brushy pasture.

This soil is suited to Honduras pine. Production is very low, less than 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

DgF—Descalabrado-Rock outcrop complex, 40 to 60 percent slopes. This complex consists of very steep, well drained soils and Rock outcrop on strongly dissected slopes. The areas range from 100 to 500 acres. The complex is 70 percent Descalabrado clay loam and 30 percent Rock outcrop and other minor soils.

In a representative profile of Descalabrado clay loam the surface layer is very dark grayish brown clay loam about 5 inches thick. The subsoil, about 6 inches thick, is dark brown, firm gravelly sandy clay loam. The substratum, beginning at a depth of 11 inches, is dark yellowish brown and olive, friable gravelly sandy clay loam. Hard consolidated volcanic rock is at a depth of 17 inches.

Rock outcrop consists of exposed bedrock occurring in such an intricate pattern with the Descalabrado soils that it was impractical to separate them in mapping.

Included with this soil complex in mapping are spots of Guayama and other miscellaneous soils with varying soil properties.

Permeability is moderate in the Descalabrado soil, and the available water capacity is low. Runoff is rapid. Natural fertility is high, and organic matter content is moderate. Reaction is neutral. The root zone is shallow.

The vegetation is brush and brushy pasture. This complex is not suited to cultivated crops. The best potential is for wildlife habitat. Potential for production of Honduras pine is very low, less than 800 board feet per acre per year.

The hazard of erosion and the limitations on the use of equipment are major concerns of management. Plant competition is severe for Honduras pine.

This complex has severe limitations for most urban uses because it is very steep. Capability subclass VIIs.

Dm—Dique loam. This is a nearly level, well drained soil on river flood plains. Slopes are smooth and are 50 to 300 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is dark brown, friable loam about 6 inches thick. The subsoil is about 30 inches thick; it is dark brown and dark yellowish brown, friable loam. The substratum, beginning at a depth of 36 inches, is dark yellowish brown, friable loam.

Included with this soil in mapping are small areas of Toa soils. The surface layer of the Toa soils is dark brown silty clay loam.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is easily worked. The root zone is deep. Natural fertility is high. Crops respond well to fertilizer.

This soil has been used for sugarcane (fig. 5). It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard. Capability class I.

Dr—Durados sandy loam. This is a nearly level, excessively drained soil on coastal plains. Slopes are smooth and are 50 to 100 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, very friable sandy loam about 14 inches thick. The layer from 14 to 23 inches is very dark grayish brown, loose loamy sand. Below a depth of 23 inches is loose sand of mixed colors and some thick layers of cemented sand.

Included with this soil in mapping are some areas of Catano soils and coastal beaches. The surface layer of Catano soils is very dark grayish brown loamy sand. Catano soils and coastal beaches make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very slow. This soil is easily worked. The root zone is deep. Natural fertility is low.

This soil has been used for coconuts. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

This soil is limited for most urban uses because of the flood hazard. Capability subclass VIs.

Es—Estacion silty clay loam. This is a nearly level, well drained soil on river flood plains. Slopes are smooth and are 100 to 400 feet long. The areas range from 10 to 200 acres.

Typically the surface layer is dark brown, friable silty clay loam about 8 inches thick. The layer from 8 to 20 inches is very dark grayish brown, friable gravelly clay loam. Below 20 inches is dark brown, loose gravelly sand.

Included with this soil in mapping are small areas of Reilly, Dique, and Toa soils. The surface layer of the Reilly soils is dark brown sandy loam, that of the Toa soils is dark brown silty clay loam, and that of the Dique soils is dark brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is moderately deep. Natural fertility is high. Crops respond well to fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, Merker grass, and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard. Capability subclass IIIs.

GuF—Guayama clay loam, 20 to 60 percent slopes. This is a steep to very steep, well drained soil on side slopes and narrow ridgetops of dissected volcanic uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 50 to 300 acres.

Typically the surface layer is dark reddish brown, friable clay loam about 4 inches thick. The subsoil is about 8 inches thick; it is red, friable gravelly clay. The substratum, beginning at a depth of 12 inches, is red, friable gravelly silty clay loam. Consolidated volcanic rock is at a depth of 20 inches.

Included with this soil in mapping are small areas of Rock outcrop and Descalabrado soils. The surface layer of the Descalabrado soils is very dark grayish brown clay loam. Rock outcrop consists of exposed bedrock and thin patches of soil over rock. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been used for pasture. It is suited to guineagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production is very low, less than 800 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

Hm—Humacao loam. This is a nearly level, well drained soil on terraces. Slopes are smooth and are about 50 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark brown, friable loam about 8 inches thick. The subsoil is about 7 inches thick; it is dark yellowish brown, friable sandy clay loam. The substratum, beginning at a depth of 15 inches, is brown and strong brown, friable clay loam and reddish yellow, very friable sandy clay loam.

Included with this soil in mapping are some spots of Candelero soils. The surface layer of the Candelero soils is dark grayish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium. This soil is easily worked. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for crops such as sugarcane, taniers, and plantains. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to most urban uses. Capability subclass IIe.

HtE— Humatas clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and ridgetops of strongly dissected humid uplands (fig. 6). Slopes are convex and are 200 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite.

Included with this soil in mapping are some narrow foot slopes and soils that have less than 20 percent slopes. Also included are spots of Consumo soils and, on a few hilltops, small areas of Daguey soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, yams, tobacco, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

HtF—Humatas clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and ridgetops of strongly dissected humid uplands. Slopes are convex and are 200 to 1000 feet long. The areas range from 10 to 500 acres.

Typically the surface layer is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite.

Included with this soil in mapping are some spots of Consumo soils and, on a few hilltops, small areas of Daguey soils. The surface layer of the Consumo soils is reddish brown clay, and that of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, yams, tobacco, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and eucalyptus trees. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

HuF—Humatas-Rock outcrop complex, 20 to 60 percent slopes. This complex consists of steep and very steep, well drained Humatas soils and Rock outcrop on side slopes and narrow ridgetops of the volcanic humid uplands. Slopes are mostly convex and 200 to 800 feet long. The areas have rough surfaces that are covered with rock outcrops. The areas range from 20 to 100 acres. Humatas clay occurs in areas between the outcrops of rock in such an intricate pattern that it was not practical to separate them in mapping. The dark brown clay surface layer of the Humatas soils contrasts markedly with the outcrops and other included soils.

This complex is about 45 percent Humatas clay, 40 percent Rock outcrop, and 15 percent other soils.

Typically the surface layer of the Humatas soil in this complex is dark brown, friable clay about 5 inches thick. The subsoil is about 29 inches thick; it is red, friable clay and yellowish red, friable silty clay. The substratum, beginning at a depth of 34 inches, is red, dark red, yellowish red, strong brown, and olive yellow, friable silty clay saprolite. The other component of this complex consists of boulders ranging from 5 to 15 feet in diameter and outcrops of rock.

Included with this complex in mapping, making up about 15 percent of the areas, are other soils with variable properties.

Most areas of this complex are in brush and brushy pasture. Runoff is rapid, and erosion is a hazard. Because of steep to very steep slopes and the large number of boulders and outcrops of rock on the surface, the potential for farming is very poor. This soil has very poor potential for most urban uses because it is steep to very steep. Potential is best for growing trees and developing habitat for woodland wildlife. The hazard of erosion is severe. Removal of vegetation should be held to a minimum.

This complex is suitable for Honduras pine and eucalyptus trees. Productivity is moderate, the hazard of erosion is high, and there are limitations to the use of equipment. Management practices such as removal of undesirable brush, trees, and grasses and erosion control measures are difficult to apply.

This complex is limited for most urban uses because the soils are steep to very steep and rocky. Capability subclass VIIs.

Hy—Hydraquents, saline. These are nearly level, very poorly drained soils in lagoonlike places and in depressions adjacent to the coast. The areas range from 20 to 200 acres. These soils are covered with brackish water most of the year and are frequently flooded.

Color and texture vary throughout the profile of the soil. The underlying material ranges from sand to clay.

Permeability is very slow, and the available water capacity is very high. Runoff is very slow. Reclamation is very difficult and costly.

These soils support mangrove trees and other halophytic vegetation most of the time. They have severe limitations for most urban uses because they are very poorly drained and are subject to frequent overflow. Capability subclass VIIIw.

JaE2—Jagueyes loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on side slopes and narrow ridgetops. Slopes are 100 to 500 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark yellowish brown, friable loam about 5 inches thick. The subsoil is about 49 inches thick; it is yellowish red and red, friable clay loam to a depth of 41 inches. From 41 to 54 inches, it is red, friable sandy clay loam mottled with brownish yellow and light gray. The substratum, beginning at a depth of 54 inches, is yellowish red, friable, sandy clay loam saprolite.

Included with this soil in mapping are small areas of Lirios and Limones soils. Also included on some hilltops are areas of Jagueyes soils where slopes are less than 20 percent. The surface layer of the Lirios soil is brown silty clay loam, and that of the Limones soil is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for taniers and plantains. It is suited to pangolagrass, improved bermudagrass, Merker grass, and molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

JnD2—Juncal clay, 5 to 20 percent slopes, eroded. This is a sloping to moderately steep, moderately well drained soil on foot slopes and low rounded hills. Slopes are concave and are 100 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark grayish brown, firm clay about 10 inches thick. The subsoil is about 38 inches thick; it is dark yellowish brown, yellowish brown, and brownish yellow, firm clay. The substratum, beginning at a depth of 48 inches, is brownish yellow, friable silty clay loam.

Included with this soil in mapping are small areas of Colinas soils. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because it is sloping to moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for yams, taniers, and pigeon peas. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and grazing of pasture, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Honduras mahogany. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion is the major concern of management. All logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is sloping to moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

JuC—Juncos clay, 5 to 12 percent slopes. This is a sloping, moderately well drained soil on side slopes and foot slopes of strongly dissected uplands. Slopes are 100 to 500 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is black, firm clay about 8 inches thick. The subsoil is about 10 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 18 inches, is olive brown, firm clay. Volcanic rock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is moderate in this soil. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of stickiness and plasticity of clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion is the major concern of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because of slope, its clayey nature, and a high shrink-swell potential. If the soil is used as construction sites, development should be on the contour. Removal of the vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

JuD—Juncos clay, 12 to 20 percent slopes. This is a moderately steep, moderately well drained soil on side slopes and foot slopes of strongly dissected uplands. Slopes are 100 to 300 feet long. The areas range from 5 to 100 acres.

Typically the surface layer is black, firm clay about 8 inches thick. The subsoil is about 10 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 18 inches, is olive brown, firm clay. Volcanic rock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mabi and Mucara soils. The surface layer of the Mabi and Mucara soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because of the slope and the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of Honduras pine is moderate, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because of slope, its clayey nature, and a high shrink-swell potential. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

LaB—Lares clay, 2 to 5 percent slopes. This is a gently sloping, somewhat poorly drained soil on terraces. Slopes are smooth and are 200 to 800 feet long. The areas range from 50 to 500 acres.

Typically the surface layer is dark brown, firm clay about 6 inches thick. The subsoil is about 30 inches thick; it is red and yellowish red, firm clay. The substratum, beginning at a depth of 36 inches, is brownish yellow, red, very pale brown, and dark yellowish brown, firm clay.

Included with this soil in mapping are spots of Daguey soils. The surface layer of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane, plantains, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion is slight, and the limitations for the use of equipment is moderate.

This soil is limited for most urban uses because it is too clayey. Removal of vegetation should be held to a minimum, and a temporary plant cover established quickly in denuded areas. Capability subclass IIe.

LaC2—Lares clay, 5 to 12 percent slopes, eroded. This is a sloping, somewhat poorly drained soil on terraces. Slopes are smooth and are 200 to 800 feet long. The areas range from 50 to 500 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, firm clay about 6 inches thick. The subsoil is about 30 inches thick; it is red and yellowish red, firm clay. The substratum, beginning at a depth of 36 inches, is brownish yellow, red, very pale brown, and dark yellowish brown, firm clay.

Included with this soil in mapping are spots of Daguey soils. The surface layer of the Daguey soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is medium. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane, plantains, and coffee. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing of pasture, as well as liming and fertilizing, are the chief management needs (fig. 7).

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion is slight, and the limitations on the use of equipment are moderate.

This soil is limited for most urban uses because it is too clayey. A temporary plant cover should be established quickly in denuded areas. Capability subclass IIIe.

LmE—Limones clay, 20 to 40 percent slopes. This is a steep, moderately well drained soil on side slopes and narrow ridgetops. Slopes are irregular and are 100 to 500 feet long. The areas are 10 to 200 acres.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is about 41 inches thick; it is yellowish brown and red, firm clay. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite.

Included with this soil in mapping are narrow ridges that have less than 20 percent slopes and spots of Lirios and Pandura soils. The surface layer of the Lirios soils is brown silty clay loam, and that of the Pandura soil is dark brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. The soil is difficult to work because it is steep (fig. 8). Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as taniers, plantains, and yams. It is suited to pangolagrass, improved bermudagrass, Merker grass, and molasses grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

LmF—Limones clay, 40 to 60 percent slopes. This is a very steep, moderately well drained soil on side slopes and narrow ridgetops. Slopes are irregular and are 100 to 500 feet long. The areas range from 20 to 100 acres. A few shallow to deep gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 7 inches thick. The subsoil is about 41 inches thick; it is yellowish brown and red, firm clay. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite.

Included with this soil in mapping are some narrow ridgetops where slopes are less than 40 percent. Also included are spots of Lirios and Pandura soils. The surface layer of the Lirios soils is brown silty clay loam, and that of the Pandura soil is dark brown sandy loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. The soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains, yams, and taniers. It is suited to pangolagrass and improved bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine. Production of Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LoF2—Lirios silty clay loam, 20 to 60 percent slopes, eroded. This is a steep to very steep, well drained soil on side slopes and narrow ridgetops of the granitic humid uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 500 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is brown, friable silty clay loam in the upper part and red, friable clay in the lower part. The substratum, beginning at a depth of 24 inches, is variegated red, yellowish red, yellowish brown, brown, very pale brown, and white, friable clay and silty clay loam saprolite.

Included with this soil in mapping are small areas of Pandura and Limones soils. The surface layer of the Pandura soils is dark brown sandy loam, and that of the Limones soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep to very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for taniers, plantains, tobacco, bananas, and sweet potatoes. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LsE—Los Guineos clay, 20 to 40 percent slopes. This steep, moderately well drained soil is on side slopes of strongly dissected uplands. Slopes are irregular and are 300 to 1000 feet long. The areas range from 200 to 1000 acres. A few shallow gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 4 inches thick. The subsoil is about 44 inches thick; it is yellowish brown, red, and brownish yellow, firm clay with some white mottles in the lower part. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite mottled with brownish yellow, yellow, and white.

Included with this soil in mapping are some rounded hilltops and narrow foot slopes where slopes are less than 20 percent Also included are spots of Humatas, Consumo, and Naranjito soils. The surface layer of the Humatas soils is dark brown clay and that of the Naranjito soils is brown to dark brown silty clay loam. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee and bananas. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is moderate, about 1400 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

LsF—Los Guineos clay, 40 to 60 percent slopes. This is a very steep, moderately well drained soil on side slopes of strongly dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 200 to 1000 acres. A few shallow gullies have formed.

Typically the surface layer is dark yellowish brown, friable clay about 4 inches thick. The subsoil is about 44 inches thick; it is yellowish brown, red, and brownish yellow, firm clay with some white mottles in the lower part. The substratum, beginning at a depth of 48 inches, is red, friable clay saprolite mottled with brownish yellow, yellow, and white.

Included with this soil in mapping are some hilltops where slopes are less than 40 percent and some very steep ridges where they are more than 60 percent. Also included are spots of Consumo soils. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for coffee and bananas.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

MaA—Mabi clay, 0 to 2 percent slopes. This is a nearly level, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are smooth and are 100 to 300 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential (fig. 9) and the flood hazard. Capability subclass IIw.

MaB—Mabi clay, 2 to 5 percent slopes. This is a gently sloping, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are gently undulating and are 100 to 300 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential and the flood hazard. Capability subclass IIw.

MaC—Mabi clay, 5 to 12 percent slopes. This is a sloping, somewhat poorly drained soil on alluvial fans and terraces above the river flood plains. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 50 acres.

Typically the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is about 17 inches thick; it is dark yellowish brown and yellowish brown, very firm clay mottled with gray. The substratum, beginning at a depth of 24 inches, is yellowish brown, very firm clay mottled with gray and greenish gray.

Included with this soil in mapping are small areas of Montegrande soils. The surface layer of the Montegrande soils is very dark grayish brown clay. These soils make up 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is limited for most urban uses because of the high shrink-swell potential and the flood hazard. Capability subclass IIIe.

Md—Made land. Made land consists of areas that have been covered with gravel, rock, concrete blocks, and other debris. It has been built up for industrial uses and is not suited to farming.

MlF—Malaya clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of strongly dissected volcanic uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 100 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable clay about 6 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm gravelly clay. The substratum, beginning at a depth of 13 inches, is dark yellowish brown, firm gravelly clay loam. Bedrock is at a depth of 18 inches.

Included with this soil in mapping are spots of Caguabo soils. The surface layer of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is fertile, but is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

MoF—Maricao clay, 20 to 60 percent slopes. This is a steep to very steep, well drained soil on side slopes and narrow hilltops of the strongly dissected uplands. Slopes are irregular and are 300 to 800 feet long. The areas range from 20 to 500 acres. A few shallow and deep gullies have formed.

Typically the surface layer is reddish brown, friable clay about 6 inches thick. The subsoil is about 16 inches thick; it is red, friable clay in the upper part and silty clay in the lower part. The substratum, beginning at a depth of 22 inches, is red, strong brown, and pale brown, friable silty clay loam saprolite.

Included with this soil in mapping are spots of Consumo soils. Also included are some very severely eroded ridgetops. The surface layer of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep to very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep to very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Mp—Martin Pena muck. This is a nearly level, very poorly drained soil in low depressional areas of the humid coastal plains and river flood plains. The areas range from 10 to 800 acres.

Typically the surface layer is black muck about 8 inches thick. The underlying material is mostly mottled very dark brown and greenish gray clay.

Included with this soil in mapping are spots of Saladar and Bajura soils. The surface layer of the Saladar soils is black muck, and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is very slow and the available water capacity is very high. Runoff is slow. This soil is very difficult to work because of wetness. A very complex and expensive drainage system is needed if it is to be reclaimed.

This soil has been in cattails, sedges, papyrus, and other hydrophytic vegetation most of the time. It is suited to paragrass.

This soil is limited for most urban uses because of wetness, slow permeability, and the flood hazard. Capability subclass VIIw.

MsB—Matanzas clay, 2 to 5 percent slopes. This is a gently sloping, well drained soil on foot slopes and in small valleys between the limestone hills. Slopes are gently undulating and are 200 to 1000 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark reddish brown, firm clay about 7 inches thick. The subsoil is about 46 inches thick; it is dark reddish brown and red, friable clay. Limestone bedrock is at a depth of 53 inches.

Included with this soil in mapping are some spots of Bayamon soils. The surface layer of the Bayamon soils is dark reddish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is slow. This soil is difficult to work. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for crops such as plantains, yams, and taniers. It is suited to pangolagrass, Merker grass, and paragrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has limitations for most urban uses because of its clayey nature. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIe.

MtB—Montegrande clay, 2 to 5 percent slopes. This is a gently sloping, moderately well drained soil on alluvial fans and foot slopes of the volcanic uplands. Slopes are smooth and are 100 to 300 feet long. The areas range from 30 to 50 acres.

Typically the surface layer is very dark grayish brown, firm clay about 7 inches thick. The subsoil is about 14 inches thick; it is dark brown and grayish brown, firm clay mottled with yellowish brown, gray, and greenish gray. The substratum from a depth of 21 inches to 29 inches is mixed dark yellowish brown and yellowish brown, firm clay. From 29 inches to 48 inches it is brown and yellowish brown very gravelly clay.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown, very firm clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of its clayey nature, the high shrink-swell potential, and the flood hazard. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIw.

MtC—Montegrande clay, 5 to 12 percent slopes. This is a sloping, moderately well drained soil on alluvial fans and foot slopes of the volcanic uplands. Slopes are undulating and are 100 to 200 feet long. The areas range from 20 to 40 acres.

Typically the surface layer is very dark grayish brown, firm clay about 7 inches thick. The subsoil is about 14 inches thick; it is dark brown and grayish brown, firm clay mottled with yellowish brown, gray, and greenish gray. The substratum from a depth of 21 inches to 29 inches is mixed dark yellowish brown and yellowish brown, firm clay. From 29 inches to 48 inches it is brown and yellowish brown very gravelly clay.

Included with this soil in mapping are spots of Mabi soils. The surface layer of the Mabi soils is very dark grayish brown, very firm clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of stickiness and plasticity of the clay. The root zone is deep. Natural fertility is high. Crops respond well to heavy applications of fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of slope, clayey nature, and high shrink-swell potential. Capability subclass IIIe.

MuF2—Morado clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on side slopes, foot slopes, and hilltops of strongly dissected humid uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 70 to 500 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is weak red, friable clay loam about 8 inches thick. The subsoil is about 18 inches thick; it is reddish gray, dark reddish gray, red, weak red, and strong brown, friable clay loam. The substratum, beginning at a depth of 26 inches is variegated gray, light gray, and dark reddish gray clay loam saprolite. Bedrock is at a depth of 34 inches.

Included with this soil in mapping are spots of Caguabo soils. The surface layer of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Fertility is high. Controlling erosion is the major concern of management.

This soil has been in brushy forest and brushy pasture most of the time. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

MxD—Mucara clay, 12 to 20 percent slopes. This is a moderately steep, well drained soil on foot slopes, side slopes, and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 300 to 800 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Juncos and Naranjito soils. The surface layer of the Juncos soils is black clay, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. This soil is fertile. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as coffee, taniers, plantains, and pigeon peas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and Honduras mahogany. Production of the Honduras pine is low, about 1000 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

MxE—Mucara clay, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 200 to 1000 feet long. The areas range from 100 to 500 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Caguabo and Naranjito soils. Also included are some hilltops that have many rocks and boulders on the surface. The surface layer of the Caguabo soils is dark grayish brown clay loam, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. The soil is fertile. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs. This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and is shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

MxF—Mucara clay, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and rounded hilltops of strongly dissected uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 100 to 1000 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Bedrock is at a depth of 30 inches.

Included with this soil in mapping are spots of Caguabo and Naranjito soils. Also included are some hilltops that have many rocks and boulders on the surface. The surface layer of the Caguabo soils is dark grayish brown clay loam, and that of the Naranjito soils is brown to dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. This soil is fertile. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and grazing of pasture, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of plant seedlings.

This soil is limited for most urban uses because it is very steep and it is shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

NaD2—Naranjito silty clay loam, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on strongly dissected volcanic uplands. Slopes are irregular and are 100 to 500 feet long. The areas range from 20 to 200 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite. Bedrock is at a depth of 40 inches.

Included with this soil in mapping are spots of Mucara and Consumo soils. The surface layer of the Mucara soils is very dark grayish brown clay and that of the Consumo soils is reddish brown clay. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability and the available water capacity are moderate in this soil. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as plantains and bananas. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

NaE2—Naranjito silty clay loam, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on strongly dissected uplands. Slopes are irregular and are 100 to 400 feet long. The areas range from 50 to 100 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red, firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite.

Included with this soil in mapping are spots of Mucara and Caguabo soils. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

NaF2—Naranjito silty clay loam, 40 to 60 percent slopes, eroded. This is a very steep, well drained soil on strongly dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 30 to 1000 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is brown to dark brown, friable silty clay loam about 4 inches thick. The subsoil is about 20 inches thick; it is reddish brown and yellowish red, firm clay. The substratum, beginning at a depth of 24 inches, is variegated yellowish red, red, and light yellowish brown, friable, clay loam saprolite.

Included with this soil in mapping are spots of Mucara and Caguabo soils. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is moderately deep. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and is subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

PaD—Pandura sandy loam, 12 to 20 percent slopes. This is a moderately steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 300 acres.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. The surface layer of the Limones soils is dark yellowish brown clay, and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1200 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

PaE—Pandura sandy loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 400 feet long. The areas range from 50 to 500 acres.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. Also included are a few spots of rock land. The surface layer of the Limones soils is dark yellowish brown clay and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Eucalyptus robusta, and mahoe trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

PaF—Pandura sandy loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 200 to 800 feet long. The areas range from 50 to 1000 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable sandy loam about 7 inches thick. The subsoil is about 5 inches thick; it is dark yellowish brown, friable sandy loam. The substratum, beginning at a depth of 12 inches, is very pale brown, pale brown, dark yellowish brown, and white sandy loam saprolite.

Included with this soil in mapping are spots of Limones and Jagueyes soils. Also included are few spots of rock land. The surface layer of the Limones soils is dark yellowish brown clay, and that of the Jagueyes soils is dark yellowish brown loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and shallow to rock. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

PeF—Pellejas clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on short side slopes and narrow ridges of the strongly dissected humid uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 20 to 200 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, friable clay loam about 4 inches thick. The subsoil is about 12 inches thick; it is yellowish brown clay loam. The substratum, beginning at a depth of 16 inches, is pale brown, light yellowish brown, gray, pinkish gray, and dark greenish gray very friable sandy loam saprolite.

Included with this soil in mapping are spots of Lirios soils. Also included are small areas that have slopes less than 40 percent. The surface layer of the Lirios soils is brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 900 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour.

Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

Re—Reilly sandy loam. This is a nearly level, excessively drained soil on river flood plains adjacent to streams. The areas range from 10 to 100 acres.

Typically the surface layer is dark brown, very friable sandy loam about 7 inches thick. The underlying material is dark grayish brown gravelly sand to a depth of 18 inches and is coarse clean sand and gravel below 18 inches.

Included with this soil in mapping are spots of riverwash consisting of large size gravel. The spots of riverwash make up 10 to 20 percent of this mapping unit.

Permeability is rapid, and the available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is shallow. Natural fertility is low.

This soil has been in brush and brushy pasture. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard and seepage. Capability subclass IVs.

RoB—Rio Arriba clay, 2 to 5 percent slopes. This is a gently sloping, moderately well drained soil on alluvial fans and terraces above the river flood plains. Slopes are gently undulating and are 100 to 500 feet long. The areas range from 15 to 400 acres.

Typically the surface layer is brown, firm clay about 8 inches thick. The subsoil from 8 to 28 inches is yellowish brown, firm clay and from 28 to 60 inches is reddish yellow, firm clay. Below a depth of 16 inches, the subsoil is mottled with yellowish red and red.

Included with this soil in mapping are small areas of Mabi soils. The surface area of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of its clayey nature, slow permeability, high shrink-swell potential, and the flood hazard. Capability subclass IIs.

RoC2—Rio Arriba clay, 5 to 12 percent slopes, eroded. This is a sloping, moderately well drained soil on alluvial fans and terraces above the river flood plains. Slopes are undulating and are 100 to 500 feet long. The areas range from 10 to 300 acres. This soil has lost much of the surface layer through erosion.

Typically the surface layer is brown, firm clay about 8 inches thick. The subsoil from 8 to 28 inches is yellowish brown, firm clay and from 28 to 60 inches is reddish yellow, firm clay. Below a depth of 16 inches, the subsoil is mottled with yellowish red and red.

Included with this soil in mapping are small areas of Juncos and Mabi soils. The surface area of the Juncos soils is black clay, and that of the Mabi soils is very dark grayish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is high. Runoff is rapid, and erosion is a hazard. This soil is difficult to work. The root zone is deep. Natural fertility is medium. Crops respond well to lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and bermudagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of its clayey nature, slow permeability, high shrink-swell potential, and the flood hazard. Capability subclass IIIe.

RpD2—Rio Piedras clay, 12 to 20 percent slopes, eroded. This is a moderately steep, well drained soil on foot slopes and side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 10 to 300 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with yellowish brown, red, and brownish yellow mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles. Cemented shale bedrock is at a depth of 48 inches.

Included with this soil in mapping are spots of Yunes soils. The surface layer of the Yunes soils is dark reddish brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is medium, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is moderately steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for plantains. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine, Honduras mahogany, kadam, mahoe, and Eucalyptus robusta trees.

Production of Honduras pine is moderate, about 1300 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil if soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is moderately steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IVe.

RpE2—Rio Piedras clay, 20 to 40 percent slopes, eroded. This is a steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 200 feet long. The areas range from 20 to 200 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with yellowish brown, red, and brownish yellow mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles. Cemented shale bedrock is at a depth of 48 inches.

Included with this soil in mapping are spots of Yunes soils. The surface layer of the Yunes soils is dark reddish brown silty clay loam. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIe.

RpF2—Rio Piedras clay, 40 to 60 percent slopes, eroded. This a very steep, well drained soil on side slopes of dissected uplands. Slopes are irregular and are 100 to 300 feet long. The areas range from 50 to 400 acres. This soil has lost most of its original surface layer through erosion. A few shallow and deep gullies have formed.

Typically the surface layer is dark brown, firm clay about 8 inches thick. The subsoil is about 20 inches thick; it is red, very firm clay with red, brownish yellow, and yellowish brown mottles. The substratum, beginning at a depth of 28 inches, is mixed red and brownish yellow clay saprolite with strong brown and light gray mottles.

Included with this soil in mapping are a few spots of Yunes soils. Also included are severely eroded spots on tops of ridges and along drains where the substratum is exposed. The surface layer of the Yunes soils is dark reddish brown, silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderately slow, and the available water capacity is moderate. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep and because of the stickiness and plasticity of the clay. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is deep. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is moderate, about 1100 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep, and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

SaF—Sabana silty clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and tops of humid volcanic uplands. Slopes are irregular and are 100 to 800 feet long. The areas range from 20 to 300 acres. A few shallow and deep gullies have formed.

Typically the surface layer is very dark grayish brown, firm silty clay loam about 3 inches thick. The subsoil is about 12 inches thick; it is dark brown, friable silty clay in the upper part and variegated light brownish gray and strong brown, firm clay in the lower part. Consolidated volcanic rock is at a depth of 15 inches.

Included with this soil in mapping are spots of Mucara and Caguabo soils. Also included are some ridges with boulders and stones on the surface. The surface layer of the Mucara soils is very dark grayish brown clay, and that of the Caguabo soils is dark grayish brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is medium. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

ScB—Sabana Seca clay, 2 to 8 percent slopes. This is a gently sloping, poorly drained soil on coastal plains. The areas range from 10 to 200 acres.

Typically the surface layer is very dark grayish brown, firm clay about 10 inches thick. The clay subsoil is highly mottled. The dominant color from 10 to 13 inches is dark grayish brown, from 13 to 36 inches is light gray, and from 36 to 70 inches is white. The mottles are yellowish brown, red, dark red, dusky red, and strong brown.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is very slow, and the available water capacity is high. Runoff is very slow. This soil is very difficult to work because of wetness and because of the stickiness and plasticity of the clay. The root zone is shallow. Natural fertility is low.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass, common bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because it is wet and clayey. Capability subclass IIIw.

Sm—Saladar muck. This is a level, very poorly drained soil in closed depressions and in coastal marshes with inadequate outlets. The areas range from 10 to 700 acres.

Typically the surface layer is black muck about 10 inches thick. The underlying layers to a depth of 51 inches or more are black muck.

Included with this soil are spots of Martin Pena soils. The surface layer of the Martin Pena soils is black muck about 8 inches thick that overlies clayey material. These soils make up about 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. Runoff is slow. This soil is difficult to work because it is too wet. Reclamation projects of this soil would be difficult and costly.

This soil has been in cattails, sedges, and reeds most of the time.

This soil is limited for most urban uses because it is too wet and is subject to overflow. Capability subclass VIIIw.

SoE—Soller clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes and hilltops of rounded limestone hills. Slopes are convex, and are 100 to 300 feet long. The areas range from 20 to 100 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is yellow, friable, weathered limestone. Hard limestone is at a depth of 24 inches.

Included with this soil in mapping are spots of Colinas soils. Also included are severely eroded small areas on hilltops and along drainageways where the hard fragmental limestone parent material is exposed. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is low, about 350 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is steep and shallow to bedrock. If this soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

SoF—Soller clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes and hilltops of rounded limestone hills. Slopes are convex and are 100 to 200 feet long. The areas range from 30 to 500 acres.

Typically the surface layer is very dark grayish brown, friable clay loam about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is yellow, friable, weathered limestone. Hard limestone bedrock is at a depth of 24 inches.

Included with this soil in mapping are small areas of Colinas soils. Also included are some severely eroded spots on hilltops and along drainageways where the hard fragmental limestone parent material is exposed. The surface layer of the Colinas soils is dark brown clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is very rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is difficult to work because it is very steep. Hillside ditches and diversions are difficult to lay out, establish, and maintain. The root zone is shallow. Natural fertility is low. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as fertilizing, are chief management needs.

This soil is suited to Honduras mahogany. Production of Honduras mahogany is very low, less than 250 board feet per acre per year. The hazard of erosion and limitations in the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soil is soft and slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of planted seedlings.

This soil is limited for most urban uses because it is very steep and shallow to bedrock. If this soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIe.

TaF—Tanama-Rock outcrop complex, 20 to 60 percent slopes. This complex consists of steep to very steep, shallow, well drained Tanama soils and Rock outcrop. This complex has formed in karst topography characterized by pepino hills or haystack hills in the northern part of the survey area. The topography is very rugged, and slopes in many directions. This irregular topography is caused by the solutional destruction of the dense, thin bedded limestone. Most areas are asymmetrical in form and range from 25 to 300 feet in height. They are about 5 to 100 acres. This complex is about 45 percent Tanama soils, 40 percent Rock outcrop, and 15 percent minor soils.

Tanama soils and Rock outcrop form such an intricate pattern that it was not practical to separate them in mapping. In a representative profile of Tanama soils the surface layer is dark reddish brown, friable clay about 4 inches thick. The subsoil is about 10 inches thick; it is reddish brown, firm clay. Hard semiconsolidated limestone is at a depth of 14 inches.

Included with this complex in mapping are spots of Soller soils. Also included are small areas of miscellaneous soils that have formed between the limestone outcrops and in the crevices and holes formed in the limestone. The surface layer of the Soller soils is very dark grayish brown clay loam.

In the Tanama soils the permeability is moderate and the available water capacity is low. Runoff is rapid, and erosion is a hazard. This soil is difficult to work because it is steep to very steep, and because it is intermingled with Rock outcrop. The root zone is shallow. Natural fertility is low. Most of this complex is in brush.

This complex is limited for most urban uses mainly because of the slopes, rock outcrops, and shallow depth to rock. Capability subclass VIIs.

To—Toa silty clay loam. This is a nearly level, moderately well drained to well drained soil on flood plains (fig. 10). The areas range from 20 to 500 acres.

Typically the surface layer is dark brown, friable silty clay loam about 8 inches thick. The subsoil is about 8 inches thick; it is dark brown, friable silty clay loam with pale brown mottles. The substratum, beginning at a depth of 16 inches, is brown and dark brown, friable silty clay loam with dark reddish brown, light gray, and brown mottles.

Included with this soil in mapping are spots of Dique, Coloso, and Bajura soils. The surface layer of the Dique soils is dark brown loam; that of the Coloso soils is dark brown silty clay loam; and that of the Bajura soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. This soil is easy to work. The root zone is deep. Natural fertility is high. Crops respond well to applications of lime and fertilizers.

This soil has been used for sugarcane. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is limited for most urban uses because of the flood hazard, its clayey nature, and low strength. Capability class I.

TrB—Torres loamy sand, 2 to 5 percent slopes. This is a gently sloping, excessively drained soil on coastal plains and in trapped valleys among the haystack hills. Slopes are gently undulating and are 50 to 200 feet long. The areas range from 5 to 200 acres.

Typically the surface layer is very dark grayish brown and dark brown, loose loamy sand about 28 inches thick. The subsoil, to a depth of 64 inches, is yellowish brown, firm clay with prominent red, dark red, and light gray mottles.

Included with this soil in mapping are spots of Matanzas and Almirante soils. The surface layer of the Matanzas soils is dark reddish brown clay, and that of the Almirante soils is strong brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is rapid in the surface layer and moderate in the subsoil. The available water capacity is low. Runoff is slow. This soil is easily worked. The root zone is deep. Natural fertility is low.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass, improved bermudagrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suitable for most urban uses. It has limitations for some uses because of the clayey subsoil. Capability subclass VIs.

Ts—Tropopsamments. Tropopsamments consist of nearly level, deep, excessively drained soils formed in a thick accumulation of finely ground sea shells and sand. The areas are narrow strips of land that parallel the coast.

Commonly the soils to a depth of 60 inches are pale yellow or yellow, loose sand containing many shells and shell fragments.

Most areas of these soils are devoid of vegetation or they are producing a few coconuts.

These soils are limited for most urban uses because they are subject to the wave action of the sea. Capability subclass VIIIs.

Ud—Urban land-Durados complex. This nearly level complex is about 70 percent Urban land, 20 percent Durados soils, and about 10 percent other soils. The areas range from 500 to 2000 acres. The composition of this unit is about the same from place to place.

In undisturbed areas the surface layer of the Durados soils is very dark grayish brown, very friable sandy loam about 14 inches thick. The underlying material from 14 to 23 inches is very dark grayish brown, loose loamy sand; from 23 to 38 inches is very pale brown and very dark grayish brown loose sand; and from 38 to 60 inches is mixed dark yellowish brown, black, brownish yellow, and yellowish brown, loose sand with thick layers of cemented sand. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany community development. The landscape has been altered in places by cutting, filling, or grading and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas in the vicinity of Levittown. Capability subclass not assigned.

Um—Urban land-Mucara complex. This complex is about 50 percent Urban land, 30 percent Mucara soils, and about 20 percent Rock outcrop and other soils. Slopes are irregular and are 100 to 300 feet long. The areas range from 500 to 1000 acres.

Typically the surface layer of the Mucara soils is very dark grayish brown, firm clay about 5 inches thick. The subsoil is about 7 inches thick; it is dark brown, firm clay. The substratum, beginning at a depth of 12 inches, is highly weathered volcanic rock. Hard volcanic rock is at a depth of 30 inches. Urban land consists of areas that have been altered to prepare building sites, create trafficways, or create a better environment for growing lawn grasses and landscape plants.

Included with this complex are Rock outcrop and other minor soils. These make up about 20 percent of this mapping unit. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas around cities. Capability subclass not assigned.

Us—Urban land-Sabana Seca complex. This complex is about 60 percent Urban land, 30 percent Sabana Seca soils, and 10 percent other soils. The areas are nearly level to gently sloping and are on coastal plains. They range from 1000 to 3000 acres. The composition of this complex is about the same from place to place.

In undisturbed areas the surface layer of the Sabana Seca soils is very dark grayish brown, firm clay about 10 inches thick. The clay subsoil is highly mottled. The dominant color from 10 to 13 inches is dark grayish brown; from 13 to 36 inches is light gray; and from 36 to 70 inches is white. The mottles are yellowish brown, red, dark red, dusky red, and strong brown. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany community development. The landscape has been altered in places by cutting, filling, and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated areas in the vicinity of Levittown. Capability subclass not assigned.

Uv—Urban land-Vega Alta complex. This complex is about 60 percent Urban land, 25 percent Vega Alta soils, and 15 percent Aceitunas and Humatas soils. The areas are gently undulating to moderately undulating. They range from 3000 to 5000 acres. The composition of the complex is about the same from place to place.

In undisturbed areas the Vega Alta soils have a surface layer of dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray, friable clay. Urban land consists mainly of sites for houses, industrial buildings, parking lots, streets, and other structures that accompany development. The landscape has been altered in places by cutting, filling, or grading and shaping. It was not practical to map the soils separately because they were so intricately intermingled with Urban land.

Mapped areas of this complex are only in the populated and industrial areas in the vicinities of the San Juan metropolitan area, Bayamon, and other towns and communities. Capability subclass not assigned.

VaB—Vega Alta clay loam, 2 to 5 percent slopes. This is a gently sloping, well drained soil on coastal plains and terraces. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 100 acres.

Typically the surface layer is dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray, friable clay.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has moderate limitations for most urban uses because of its clayey nature and low strength. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIe.

VaC2—Vega Alta clay loam, 5 to 12 percent slopes, eroded. This is a sloping, well drained soil on coastal plains and terraces (fig. 11). Slopes are undulating and are 100 to 300 feet long. The areas range from 20 to 300 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark yellowish brown, friable clay loam about 8 inches thick. The subsoil from 8 inches to a depth of 52 inches is mainly red, strong brown, brownish yellow, and dark red clay. From 52 inches to a depth of 84 inches, the subsoil is dark red, brownish yellow, and light gray friable clay.

Included with this soil in mapping are spots of Almirante soils. The surface layer of the Almirante soils is dark yellowish brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for sugarcane. It is suited to pangolagrass, improved bermudagrass, paragrass, and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is moderately limited for most urban uses because it is sloping and clayey and has low strength. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Vg—Vega Baja silty clay. This is a nearly level, somewhat poorly drained soil on coastal plains and alluvial fans. The areas range from 50 to 100 acres.

Typically the surface layer is dark brown, dark grayish brown, and yellowish brown, firm silty clay to a depth of 12 inches. The subsoil from 12 to 17 inches is dark grayish brown and yellowish brown, firm silty clay; from 17 to 32 inches is mixed strong brown and gray clay; and from 32 to 50 inches is brownish yellow and gray silty clay loam. The substratum, beginning at a depth of 50 inches, is light gray and strong brown, firm clay.

Included with this soil in mapping are spots of Coloso soils. The surface layer of the Coloso soils is dark brown silty clay loam. These soils make up 10 to 20 percent of this mapping unit.

Permeability is slow, and the available water capacity is high. This soil is difficult to work because of wetness and because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of the flood hazard, wetness, slow permeability, and its clayey nature. Capability subclass IIw.

VkC2—Via clay loam, 5 to 12 percent slopes, eroded. This is a sloping, well drained soil on high stream terraces. Slopes are undulating and are 100 to 200 feet long. The areas range from 10 to 100 acres. This soil has lost much of its original surface layer through erosion.

Typically the surface layer is dark brown, friable clay loam about 9 inches thick. The subsoil is about 27 inches thick; it is strong brown and yellowish brown, firm clay loam. The substratum, beginning at a depth of 36 inches, is strong brown, firm very gravelly clay loam.

Included with this soil in mapping are spots of Rio Arriba and Mabi soils. The surface layer of the Mabi soils is very dark grayish brown clay, and that of the Rio Arriba soils is brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability and the available water capacity are moderate. Runoff is medium, and erosion is a hazard. This soil is difficult to work because of the stickiness and plasticity of the clay. The root zone is deep. Natural fertility is medium. Crops respond well to heavy applications of lime and fertilizers. Controlling erosion is the major concern of management.

This soil has been used for crops such as sugarcane. It is suited to pangolagrass and Merker grass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil has moderate to severe limitations for most urban uses because of slope, seepage, and its clayey nature. If the soil is used as construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass IIIe.

Vv—Vivi loam. This is a nearly level, somewhat excessively drained soil on river flood plains. The areas range from 10 to 100 acres.

Typically the surface layer of this soil is dark brown, very friable loam about 9 inches thick. The subsoil is about 13 inches thick; it is dark yellowish brown, friable loam. The substratum, beginning at a depth of 22 inches, is dark yellowish brown loam from 22 inches to 34 inches, yellowish brown, very friable very fine sandy loam from 34 to 47 inches, and yellowish brown loamy sand from 47 to 58 inches.

Included with this soil in mapping are spots of Reilly soils. The surface layer of the Reilly soils is dark brown sandy loam. These soils make up 10 to 20 percent of the areas of this mapping unit.

Permeability is rapid, and the available water capacity is low. This soil is fertile and is easily worked. The root zone is deep. Crops respond well to heavy applications of lime and fertilizers and to irrigation.

This soil has been used for sugarcane.

This soil is limited for most urban uses because of the flood hazard and seepage. Capability subclass IIs.

YeE—Yunes silty clay loam, 20 to 40 percent slopes. This is a steep, well drained soil on side slopes of strongly dissected uplands. The slopes are irregular and are 100 to 300 feet long. The areas range from 20 to 300 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark reddish brown, friable silty clay loam about 2 inches thick. The subsoil is about 14 inches thick; it is dark brown and brown, friable very shaly silty clay loam. Below a depth of 16 inches is bedded fragmental shale. The beds are 1 to 4 inches thick. The shale is light red, strong brown, and pink.

Included with this soil in mapping are spots of Rio Piedras soils. The surface layer of the Rio Piedras soils is dark brown clay. These soils make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is not suited to cultivated crops because it is steep and shallow to bedded shale. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is very low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of management. Logging roads, skid trails, and planting should be on the contour to help control erosion. The use of logging equipment is restricted at times because the soils are slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of seedlings.

This soil is limited for most urban uses because it is steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

YeF—Yunes silty clay loam, 40 to 60 percent slopes. This is a very steep, well drained soil on side slopes of strongly dissected uplands. The slopes are irregular and are 100 to 300 feet long. The areas range from 30 to 250 acres. A few shallow and deep gullies have formed.

Typically the surface layer is dark reddish brown, friable silty clay loam about 2 inches thick. The subsoil is about 14 inches thick; it is dark brown and brown, friable very shaly silty clay loam. Below a depth of 16 inches is bedded fragmental shale. The beds are 1 to 4 inches thick. The shale is light red, strong brown, and pink.

Included with this soil in mapping are spots of Yunes soils with less than 40 percent slopes. Also included are a few small areas on tops of hills and along drainageways where the bedded shale is exposed. These soils and areas of shale make up 10 to 20 percent of this mapping unit.

Permeability is moderate, and the available water capacity is low. Runoff is rapid, and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainageways. This soil is not suited to cultivated crops because it is very steep and shallow to bedded shale. Controlling erosion is the major concern of management.

This soil has been in brush and brushy pasture most of the time. It is suited to pangolagrass.

Proper stocking rates and deferred grazing, as well as liming and fertilizing, are chief management needs.

This soil is suited to Honduras pine and Eucalyptus robusta trees. Production of Honduras pine is low, about 700 board feet per acre per year. The hazard of erosion and limitations on the use of equipment are the major concerns of managment. Logging roads, skid trails, and planting should be on the contour to help control erosion.

The use of logging equipment is restricted at times because the soils are slippery when wet. Brush removal, careful hand planting, and fertilizing increase the survival of seedlings.

This soil is limited for most urban uses because it is very steep and subject to landslides. If the soil is used for construction sites, development should be on the contour. Removal of vegetation should be held to a minimum, and temporary plant cover established quickly in denuded areas. Capability subclass VIIs.

Use and management of the soils

The soil survey is a detailed inventory and evaluation of the most basic resource of the survey area—the soil. It is useful in adjusting land use, including urbanization, to the limitations and potentials of natural resources and the environment. Also, it can help avoid soil-related failures in uses of the land.

While a soil survey is in progress, soil scientists, conservationists, engineers, and others keep extensive notes about the nature of the soils and about unique aspects of behavior of the soils. These notes include data on erosion, drought damage to specific crops, yield estimates, flooding, the functioning of septic tank disposal systems, and other factors affecting the productivity, potential, and limitations of the soils under various uses and management. In this way, field experience and measured data on soil properties and performance are used as a basis for predicting soil behavior.

Information in this section is useful in planning use and management of soils for crops, pasture, and woodland and as sites for buildings, highways and other transportation systems, sanitary facilities, and parks and other recreation facilities. From the data presented, the potential of each soil for specified land uses can be determined, soil limitations to these land uses can be identified, and costly failures in houses and other structures, caused by unfavorable soil properties, can be avoided. A site where soil properties are favorable can be selected, or practices that will overcome the soil limitations can be planned.

Planners and others using the soil survey can evaluate the impact of specific land uses on the overall productivity of the survey area or other broad planning area and on the environment. Productivity and the environment are closely related to the nature of the soil. Plans should maintain or create a land-use pattern in harmony with the natural soil.

Contractors can find information that is useful in locating sources of sand and gravel, roadfill, and topsoil. Other information indicates the presence of bedrock, wetness, or very firm soil horizons that cause difficulty in excavation.

Health officials, highway officials, engineers, and many other specialists also can find useful information in this soil survey. The safe disposal of wastes, for example, is closely related to properties of the soil. Pavements, sidewalks, campsites, playgrounds, lawns, and trees and shrubs are influenced by the nature of the soil.

Crops and pasture

The major management concerns in the use of the soils for crops and pasture are described in this section. In addition, the crops or pasture plants best suited to the soil, including some not commonly grown in the survey area, are discussed; the system of land capability classification used by the Soil Conservation Service is explained; and the estimated yields of the main crops and hay and pasture plants are presented for each soil.

This section provides information about the overall agricultural potential of the survey area and about the management practices that are needed. The information is useful to equipment dealers, land improvement contractors, fertilizer companies, processing companies, planners, conservationists, and others. For each kind of soil, information about management is presented in the section "Soil maps for detailed planning." Planners of management systems for individual fields or farms should also consider the detailed information given in the description of each soil.

More than 300,000 acres in the survey area was used for crops and pasture in 1967, according to the Conservation Needs Inventory. Of this total, more than 89,000 acres was in crops and almost 211,000 acres in pasture.

The potential of the soils of the San Juan Area for increased production of food is good. There is considerable reserve productive capacity that is not being used for crops or pasture at the present time. This potential productive capacity could be further increased by extending the latest crop production technology to all land suitable for cropland in the survey area. This soil survey can greatly facilitate the application of such technology.

Acreage in crops and pasture has gradually been decreasing as more land is used for urban development. This is especially true in the urban fringe areas near the San Juan metropolitan area. The use of this soil survey can help in making land use decisions that will influence the role of farming in prime land retention.

Soil erosion is the major soil problem of cropland and pastureland in the San Juan Area. Where the slope is more than 5 percent, erosion is a hazard. Aceitunas, Almirante, Rio Arriba, and Vega Alta soils, for example, have slopes of 5 to 12 percent.

The loss of the surface layer through erosion is damaging for two reasons. First, productivity is reduced as the surface layer is lost and part of the subsoil is incorporated into the plowed layer. Loss of the surface layer is especially damaging on soils with a clayey subsoil such as the Lares, Mabi, and Montegrande soils. Erosion also reduces productivity on soils that tend to be droughty such as the Catano, Durados, Estacion, and Reilly soils. Second, soil erosion on farmland results in sediment entering streams and lakes. Control of erosion minimizes the pollution of streams by sediment and improves quality of water for human use, for recreation, and for fish and wildlife.

In many sloping fields, preparing a good seedbed and tilling are difficult on clayey spots, because the original, friable surface layer has been eroded away. Such spots are common in moderately eroded areas of Almirante and Vega Alta soils.

Erosion control practices provide protective surface cover, reduce runoff, and increase infiltration. A cropping system that keeps vegetative cover on the soil for extended periods can hold soil erosion losses to amounts that will not reduce the productive capacity of the soils. On livestock farms, which require pasture and cut grasses, the legume and grass forage crops reduce erosion on sloping land and also provide nitrogen and improve tilth.

Contour tillage or terracing is practical on soils that have long and regular slopes. On soils with short and irregular slopes, cropping systems that provide substantial vegetative cover are required to control erosion unless minimum tillage is practiced. Minimizing tillage and leaving crop residue on the surface help to increase infiltration and reduce the hazards of runoff and erosion. These practices can be adapted to most soils in the survey area. No tillage for row crops is effective in reducing erosion on sloping land and can be adapted to many soils with loamy surface layers, but is more difficult to practice successfully on soils with a clayey surface layer.

Diversions, terraces, and hillside ditches (fig. 12) reduce the length of slope and reduce runoff and erosion. They are more practical on deep, well drained soils that have regular slopes.

Information for the design of erosion control practices for each kind of soil is contained in the Technical Guide, available in the local offices of the Soil Conservation Service.

Soil drainage is the major management practice in some soils of the San Juan Area which are used for crops and pastures. Some soils are naturally so wet that the production of crops common to the area is not generally possible. These are the very poorly drained Hydraquents, Martin Pena, and Saladar soils.

Unless artificially drained, some poorly drained and somewhat poorly drained soils are so wet that crops are damaged during most years when the seasonal water table is high. In this category are the Bajura, Sabana Seca, and Vega Baja soils.

Soils such as the Coloso, Mabi, and Montegrande require less intensive drainage systems for sustained production.

The design of drainage systems varies with the kind of soil. A combination of surface and subsurface drainage is needed for the poorly drained soils for intensive row cropping. Drains have to be more closely spaced in soils with slow permeability than in permeable soils. Finding adequate outlets for drainage systems is difficult in some areas of the Bajura, Sabana Seca, and Vega Baja soils. Information on drainage design for each kind of soil is contained in the Technical Guide, available in local offices of the Soil Conservation Service.

Soil fertility is naturally low in most soils of the coastal plains of the survey area. These soils are very strongly acid and leached. Unless limed and fertilized, Aceitunas, Almirante, Bayamon, Lares, Torres, and Vega Alta soils have low to moderate productivity. The soils on the flood plains, such as the Toa, Bajura, and Coloso, range from neutral to slightly acid and are naturally higher in plant nutrients.

Some soils of the uplands such as Aibonito, Consumo, Daguey, Humatas, Limones, and Los Guineos are steep and very strongly acid, and the fertility is naturally low. They require applications of lime and fertilizer.

Others, such as Juncos, Morado, and Mucara soils, are slightly acid and are naturally higher in plant nutrients.

On all soils, additions of lime and fertilizer should be based on the results of soil tests, on the need of the crop, and on the expected level of yields.

Soil tilth is an important factor in the germination of seeds and in the infiltration of water into the soil. Soils with good tilth are granular and porous.

Many of the soils of the survey area have moderate amounts of organic matter in the surface layer. Generally the structure is moderate granular, and physical condition is good. However, if the erosion is moderate or severe, the subsoil, which is clayey, is exposed. The subsoil reduces infiltration and increases runoff. Regular additions of crop residue, manure, and other organic material can help to improve soil structure and reduce erosion.

Crops suited to the soils and climate of the San Juan Area and grown commercially are plantains, bananas, taniers, yams, sweet potatoes, tobacco, and fruit orchards.

There is high potential for the production of sugarcane in the San Juan Area.

Special crops, such as tomatoes, green peppers, cabbage, oranges, grapefruits, limes, chironjas and West Indian cherries, have high potential in the area. There is also a high potential for ornamental plants and shrubs in the uplands and in the coastal plains of the area.

The best adapted species for pasture are stargrass and pangolagrass and, to some extent, guineagrass.

Commercial plantings of rice are feasible in the somewhat poorly drained and poorly drained soils of the flood plains such as the Coloso and Bajura soils.

Coffee, both sun and shade varieties, does very well in the cooler uplands of the San Juan Area.

Latest information and suggestions for growing these crops can be obtained from the local offices of the Soil Conservation Service.

Yields per acre

The average yields per acre that can be expected of the principal crops under a high level of management are shown in table 5. In any given year, yields may be higher or lower than those indicated in the table because of variations in rainfall and other climatic factors. Absence of an estimated yield indicates that the crop is not suited to or not commonly grown on the soil or that a given crop is not commonly irrigated.

The estimated yields were based mainly on the experience and records of farmers, conservationists, and extension agents. Results of field trials and demonstrations and available yield data from nearby areas were also considered.

The yields were estimated assuming that the latest soil and crop management practices were used. Hay and pasture yields were estimated for the most productive varieties of grasses and legumes suited to the climate and the soil. A few farmers may be obtaining average yields higher than those shown in table 5.

The management needed to achieve the indicated yields of the various crops depends on the kind of soil and the crop. Such management provides drainage, erosion control, and protection from flooding; the proper planting and seeding rates; suitable high-yielding crop varieties; appropriate tillage practices, including time of tillage and seedbed preparation and tilling when soil moisture is favorable; control of weeds, plant diseases, and harmful insects; favorable soil reaction and optimum levels of nitrogen, phosphorus, potassium, and trace elements for each crop; effective use of crop residue, barnyard manure, and green-manure crops; harvesting crops with the smallest possible loss; and timeliness of all fieldwork.

The estimated yields reflect the productive capacity of the soils for each of the principal crops. Yields are likely to increase as new production technology is developed. The productivity of a given soil compared with that of other soils, however, is not likely to change.

Crops other than those shown in table 5 are grown in the survey area, but estimated yields are not included because the acreage of these crops is small. The local offices of the Soil Conservation Service and the Cooperative Extension Service can provide information about the management concerns and productivity of the soils for these crops.

Capability classes and subclasses

Capability classes and subclasses show, in a general way, the suitability of soils for most kinds of field crops. The soils are classed according to their limitations when they are used for field crops, the risk of damage when they are used, and the way they respond to treatment. The grouping does not take into account major and generally expensive landforming that would change slope, depth, or other characteristics of the soils; does not take into consideration possible but unlikely major reclamation projects; and does not apply to rice, cranberries, horticultural crops, or other crops that require special management. Capability classification is not a substitute for interpretations designed to show suitability and limitations of groups of soils for rangeland, for forest trees, or for engineering purposes.

In the capability system, all kinds of soil are grouped at three levels: capability class, subclass, and unit. These levels are defined in the following paragraphs. A survey area may not have soils of all classes.

Capability classes, the broadest groups, are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use. The classes are defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.

Class III soils have severe limitations that reduce the choice of plants, or that require special conservation practices, or both.

Class IV soils have very severe limitations that reduce the choice of plants, or that require very careful management, or both.

Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use.

Class VI soils have severe limitations that make them generally unsuitable for cultivation.

Class VII soils have very severe limitations that make them unsuitable for cultivation.

Class VIII soils and landforms have limitations that nearly preclude their use for commercial crop production.

Capability subclasses are soil groups within one class; they are designated by adding a small letter, *e*, *w*, *s*, or *c*, to the class numeral, for example, IIe. The letter *e* shows that the main limitation is risk of erosion unless close-growing plant cover is maintained; *w* shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); *s* shows that the soil is limited mainly because it is shallow, droughty, or stony; and *c*, used in only some parts of the United States, shows that the chief limitation is climate that is too cold or too dry.

In class I there are no subclasses because the soils of this class have few limitations. Class V contains only the subclasses indicated by *w*, *s*, or *c* because the soils in class V are subject to little or no erosion, though they have other limitations that restrict their use to pasture, rangeland, woodland, wildlife habitat, or recreation.

The acreage of soils in each capability class and subclass is indicated in table 6. All soils in the survey area except those named at a level higher than the series are included. Some of the soils that are well suited to crops and pasture may be in low-intensity use, for example, soils in capability classes I and II. Data in this table can be used to determine the farming potential of such soils.

Woodland

When Puerto Rico was colonized in the early 1500's, the island was completely covered by forests, but land clearing for farms was soon begun. By 1880 most of the forests had been cut. Some areas were unsuitable for permanent cultivation and were abandoned when their fertility was lost. Later, some of these areas were again cleared, cultivated, and abandoned. Land thus abandoned generally was taken over by inferior volunteer trees.

According to the 1967 Conservation Needs Inventory, there was a total of 72,239 acres of woodland: 11,637 acres of commercial forests and 60,602 of noncommercial forests. The total forested acreage is about 16 percent of the San Juan Area.

Forest is an excellent use of the soils of the San Juan Area for the protection of soil and water resources. Forest cover can minimize floods, reduce the amount of soil material lost as sediment in rivers, and hold runoff into periods of dry weather. Some natural noncommercial forests should be converted to commercial. Others should be protected and left in their natural state. Trees should be planted in some nonforested areas.

Species having the best potential for the San Juan area are Honduras pine, Honduras mahogany, kadam, teak, and eucalyptus.

Woodland management and productivity

Table 7 contains information useful to woodland owners or forest managers planning use of soils for wood crops. Mapping unit symbols for soils suitable for wood crops are listed, and the ordination (woodland suitability) symbol for each soil is given. All soils bearing the same ordination symbol require the same general kinds of woodland management and have about the same potential productivity.

The first part of the *ordination symbol*, a number, indicates the potential productivity of the soils for important trees. The number 1 indicates very high productivity; 2, high; 3, moderately high; 4, moderate; and 5, low. The second part of the symbol, a letter, indicates the major kind of soil limitation. The letter *x* indicates stoniness or rockiness; *w*, excessive water in or on the soil; *t*, toxic substances in the soil; *d*, restricted root depth; *c*, clay in the upper part of the soil; *s*, sandy texture; *f*, high content of coarse fragments in the soil profile; and *r*, steep slopes. The letter *o* indicates insignificant limitations or restrictions. If a soil has more than one limitation, priority in placing the soil into a limitation class is in the following order: x, w, t, d, c, s, f, and r.

In table 7 the soils are also rated for a number of factors to be considered in management. *Slight*, *moderate*, and *severe* are used to indicate the degree of major soil limitations.

Ratings of the *erosion hazard* indicate the risk of loss of soil in well managed woodland. The risk is *slight* if the expected soil loss is small, *moderate* if some measures are needed to control erosion during logging and road construction, and *severe* if intensive management or special equipment and methods are needed to prevent excessive loss of soil.

Ratings of *equipment limitation* reflect the characteristics and conditions of the soil that restrict use of the equipment generally needed in woodland management or harvesting. A rating of *slight* indicates that use of equipment is not limited to a particular kind of equipment or time of year; *moderate* indicates a short seasonal limitation or a need for some modification in management or equipment; *severe* indicates a seasonal limitation, a need for special equipment or management, or a hazard in the use of equipment.

Seedling mortality ratings indicate the degree that the soil affects expected mortality of planted tree seedlings. Plant competition is not considered in the ratings. Seedlings from good planting stock that are properly planted during a period of sufficient rainfall are rated. A rating of *slight* indicates that the expected mortality of the planted seedlings is less than 25 percent; *moderate*, 25 to 50 percent; and *severe*, more than 50 percent.

The *potential productivity* of merchantable or *important trees* on a soil is expressed as the average yearly growth in board feet per acre. The trees listed are not native, but appear to be those best suited to the soil. The figures for average yearly growth are estimates. Important trees are those that woodland managers generally favor in intermediate or improvement cuttings. They are selected on the basis of growth rate, quality, value, and marketability.

Trees to plant are those that are suitable for commercial wood production and that are suited to the soils.

Engineering

This section provides information about the use of soils for building sites, sanitary facilities, construction material, and water management. Among those who can benefit from this information are engineers, landowners, community planners, town and city managers, land developers, builders, contractors, and farmers and ranchers.

The ratings in the engineering tables are based on test data and estimated data in the "Soil properties" section. The ratings were determined jointly by soil scientists and engineers of the Soil Conservation Service using known relationships between the soil properties and the behavior of soils in various engineering uses.

Among the soil properties and site conditions identified by a soil survey and used in determining the ratings in this section were grain-size distribution, liquid limit, plasticity index, soil reaction, depth to bedrock, hardness of bedrock that is within 5 or 6 feet of the surface, soil wetness, depth to a seasonal high water table, slope, likelihood of flooding, natural soil structure or aggregation, in-place soil density, and geologic origin of the soil material. Where pertinent, data about kinds of clay minerals, mineralogy of the sand and silt fractions, and the kind of absorbed cations were also considered.

On the basis of information assembled about soil properties, ranges of values can be estimated for erodibility, permeability, corrosivity, shrink-swell potential, available water capacity, shear strength, compressibility, slope stability, and other factors of expected soil behavior in engineering uses. As appropriate, these values can be applied to each major horizon of each soil or to the entire profile.

These factors of soil behavior affect construction and maintenance of roads, airport runways, pipelines, foundations for small buildings, ponds and small dams, irrigation projects, drainage systems, sewage and refuse disposal systems, and other engineering works. The ranges of values can be used to (1) select potential residential, commercial, industrial, and recreational uses; (2) make preliminary estimates pertinent to construction in a particular area; (3) evaluate alternative routes for roads, streets, highways, pipelines, and underground cables; (4) evaluate alternative sites for location of sanitary landfills, onsite sewage disposal systems, and other waste disposal facilities; (5) plan detailed onsite investigations of soils and geology; (6) find sources of gravel, sand, clay, and topsoil; (7) plan farm drainage systems, irrigation systems, ponds, terraces, and other structures for soil and water conservation; (8) relate performance of structures already built to the properties of the kinds of soil on which they are built so that performance of similar structures on the same or a similar soil in other locations can be predicted; and (9) predict the trafficability of soils for cross-country movement of vehicles and construction equipment.

Data presented in this section are useful for land-use planning and for choosing alternative practices or general designs that will overcome unfavorable soil properties and minimize soil-related failures. Limitations to the use of these data, however, should be well understood. First, the data are generally not presented for soil material below a depth of 5 or 6 feet. Also, because of the scale of the detailed map in this soil survey, small areas of soils that differ from the dominant soil may be included in mapping. Thus, these data do not eliminate the need for onsite investigations, testing, and analysis by personnel having expertise in the specific use contemplated.

The information is presented mainly in tables. Table 8 shows, for each kind of soil, the degree and kind of limitations for building site development; table 9, for sanitary facilities; and table 11, for water management. Table 10 shows the suitability of each kind of soil as a source of construction materials.

The information in the tables, along with the soil map, the soil descriptions, and other data provided in this survey, can be used to make additional interpretations and to construct interpretive maps for specific uses of land.

Some of the terms used in this soil survey have a special meaning in soil science. Many of these terms are defined in the Glossary.

Building site development

The degree and kind of soil limitations that affect shallow excavations, dwellings with and without basements, small commercial buildings, and local roads and streets are indicated in table 8. A *slight* limitation indicates that soil properties generally are favorable for the specified use; any limitation is minor and easily overcome. A *moderate* limitation indicates that soil properties and site features are unfavorable for the specified use, but the limitations can be overcome or minimized by special planning and design. A *severe* limitation indicates that one or more soil properties or site features are so unfavorable or difficult to overcome that a major increase in construction effort, special design, or intensive maintenance is required. For some soils rated severe, such costly measures may not be feasible.

Shallow excavations are made for pipelines, sewerlines, communications and power transmission lines, basements, and open ditches. Such digging or trenching is influenced by soil wetness caused by a seasonal high water table; the texture and consistence of soils; the tendency of soils to cave in or slough; and the presence of very firm, dense soil layers, bedrock, or large stones. In addition, excavations are affected by slope of the soil and the probability of flooding. Ratings do not apply to soil horizons below a depth of 6 feet unless otherwise noted.

In the soil series descriptions, the consistence of each soil horizon is given, and the presence of very firm or extremely firm horizons, usually difficult to excavate, is indicated.

Dwellings without basements and *small commercial buildings* referred to in table 8 are built on undisturbed soil and have foundation loads of a dwelling no more than three stories high. Separate ratings are made for small commercial buildings without basements and for dwellings without basements. For such structures, soils should be sufficiently stable that cracking or subsidence of the structure from settling or shear failure of the foundation does not occur. These ratings were determined from estimates of the shear strength, compressibility, and shrink-swell potential of the soil. Soil texture, plasticity and in-place density, potential frost action, soil wetness, and depth to a seasonal high water table were also considered. Soil wetness and depth to a seasonal high water table indicate potential difficulty in providing adequate drainage for basements, lawns, and gardens. Depth to bedrock, slope, and large stones in or on the soil are also important considerations in the choice of sites for these structures and were considered in determining the ratings. Susceptibility to flooding is a serious hazard.

Local roads and streets referred to in table 8 have an all-weather surface that can carry light to medium traffic all year. They consist of a subgrade of the underlying soil material; a base of gravel, crushed rock fragments, or soil material stabilized with lime or cement; and a flexible or rigid surface, commonly asphalt or concrete. The roads are graded with soil material at hand, and most cuts and fills are less than 6 feet deep.

The load supporting capacity and the stability of the soil as well as the quantity and workability of fill material available are important in design and construction of roads and streets. The classifications of the soil and the soil texture, density, shrink-swell potential, and potential frost action are indicators of the traffic supporting capacity used in making the ratings. Soil wetness, flooding, slope, depth to hard rock or very compact layers, and content of large stones affect stability and ease of excavation.

Sanitary facilities

Favorable soil properties and site features are needed for proper functioning of septic tank absorption fields, sewage lagoons, and sanitary landfills. The nature of the soil is important in selecting sites for these facilities and in identifying limiting soil properties and site features to be considered in design and installation. Also, those soil properties that affect ease of excavation or installation of these facilities will be of interest to contractors and local officials. Table 9 shows the degree and kind of limitations of each soil for such uses and for use of the soil as daily cover for landfills. It is important to observe local ordinances and regulations.

If the degree of soil limitation is expressed as *slight*, soils are generally favorable for the specified use and limitations are minor and easily overcome; if *moderate*, soil properties or site features are unfavorable for the specified use, but limitations can be overcome by special planning and design; and if *severe*, soil properties or site features are so unfavorable or difficult to overcome that major soil reclamation, special designs, or intensive maintenance is required. Soil suitability is rated by the terms *good*, *fair*, or *poor*, which, respectively, mean about the same as the terms *slight*, *moderate*, and *severe*.

Septic tank absorption fields are subsurface systems of tile or perforated pipe that distribute effluent from a septic tank into the natural soil. Only the soil horizons between depths of 18 and 72 inches are evaluated for this use. The soil properties and site features considered are those that affect the absorption of the effluent and those that affect the construction of the system.

Properties and features that affect absorption of the effluent are permeability, depth to seasonal high water table, depth to bedrock, and susceptibility to flooding. Stones, boulders, and shallowness to bedrock interfere with installation. Excessive slope can cause lateral seepage and surfacing of the effluent. Also, soil erosion and soil slippage are hazards if absorption fields are installed on sloping soils.

In some soils, loose sand and gravel or fractured bedrock is less than 4 feet below the tile lines. In these soils the absorption field does not adequately filter the effluent, and ground water in the area may be contaminated.

On many of the soils that have moderate or severe limitations for use as septic tank absorption fields, a system to lower the seasonal water table can be installed or the size of the absorption field can be increased so that performance is satisfactory.

Sewage lagoons are shallow ponds constructed to hold sewage while aerobic bacteria decompose the solid and liquid wastes. Lagoons have a nearly level floor and cut slopes or embankments of compacted soil material. Aerobic lagoons generally are designed to hold sewage within a depth of 2 to 5 feet. Nearly impervious soil material for the lagoon floor and sides is required to minimize seepage and contamination of ground water. Soils that are very high in content of organic matter and those that have cobbles, stones, or boulders are not suitable. Unless the soil has very slow permeability, contamination of ground water is a hazard where the seasonal high water table is above the level of the lagoon floor. In soils where the water table is seasonally high, seepage of ground water into the lagoon can seriously reduce the lagoon's capacity for liquid waste. Slope, depth to bedrock, and susceptibility to flooding also affect the suitability of sites for sewage lagoons or the cost of construction. Shear strength and permeability of compacted soil material affect the performance of embankments.

Sanitary landfill is a method of disposing of solid waste by placing refuse in successive layers either in excavated trenches or on the surface of the soil. The waste is spread, compacted, and covered daily with a thin layer of soil material. Landfill areas are subject to heavy vehicular traffic. Risk of polluting ground water and trafficability affect the suitability of a soil for this use. The best soils have a loamy or silty texture, have moderate to slow permeability, are deep to a seasonal water table, and are not subject to flooding. Clayey soils are likely to be sticky and difficult to spread. Sandy or gravelly soils generally have rapid permeability, which might allow noxious liquids to contaminate ground water. Soil wetness can be a limitation, because operating heavy equipment on a wet soil is difficult. Seepage into the refuse increases the risk of pollution of ground water.

Ease of excavation affects the suitability of a soil for the trench type of landfill. A suitable soil is deep to bedrock and free of large stones and boulders. If the seasonal water table is high, water will seep into trenches.

Unless otherwise stated, the limitations in table 9 apply only to the soil material within a depth of about 6 feet. If the trench is deeper, a limitation of slight or moderate may not be valid. Site investigation is needed before a site is selected.

Daily cover for landfill should be soil that is easy to excavate and spread over the compacted fill in wet and dry periods. Soils that are loamy or silty and free of stones or boulders are better than other soils. Clayey soils may be sticky and difficult to spread; sandy soils may be subject to soil blowing.

The soils selected for final cover of landfills should be suitable for growing plants. Of all the horizons, the A horizon in most soils has the best workability, more organic matter, and the best potential for growing plants. Thus, for either the area- or trench-type landfill, stockpiling material from the A horizon for use as the surface layer of the final cover is desirable.

Where it is necessary to bring in soil material for daily or final cover, thickness of suitable soil material available and depth to a seasonal high water table in soils surrounding the sites should be evaluated. Other factors to be evaluated are those that affect reclamation of the borrow areas. These factors include slope, erodibility, and potential for plant growth.

Construction materials

The suitability of each soil as a source of roadfill, sand, gravel, and topsoil is indicated in table 10 by ratings of good, fair, or poor. The texture, thickness, and organic-matter content of each soil horizon are important factors in rating soils for use as construction materials. Each soil is evaluated to the depth observed, generally about 6 feet.

Roadfill is soil material used in embankments for roads. Soils are evaluated as a source of roadfill for low embankments, which generally are less than 6 feet high and less exacting in design than high embankments. The ratings reflect the ease of excavating and working the material and the expected performance of the material where it has been compacted and adequately drained. The performance of soil after it is stabilized with lime or cement is not considered in the ratings, but information about some of the soil properties that influence such performance is given in the descriptions of the soil series.

The ratings apply to the soil material between the A horizon and a depth of 5 to 6 feet. It is assumed that soil horizons will be mixed during excavation and spreading. Many soils have horizons of contrasting suitability within their profile. The estimated engineering properties in table 13 provide specific information about the nature of each horizon. This information can help determine the suitability of each horizon for roadfill.

Soils rated *good* are coarse grained. They have low shrink-swell potential, low potential frost action, and few cobbles and stones. They are at least moderately well drained and have slopes of 15 percent or less. Soils rated *fair* have a plasticity index of less than 15 and have other limiting features, such as moderate shrink-swell potential, moderately steep slopes, wetness, or many stones. If the thickness of suitable material is less than 3 feet, the entire soil is rated *poor.*

Sand and *gravel* are used in great quantities in many kinds of construction. The ratings in table 10 provide guidance as to where to look for probable sources and are based on the probability that soils in a given area contain sizable quantities of sand or gravel. A soil rated *good* or *fair* has a layer of suitable material at least 3 feet thick, the top of which is within a depth of 6 feet. Coarse fragments of soft bedrock material, such as shale and siltstone, are not considered to be sand and gravel. Fine-grained soils are not suitable sources of sand and gravel.

The ratings do not take into account depth to the water table or other factors that affect excavation of the material. Descriptions of grain size, kinds of minerals, reaction, and stratification are given in the soil series descriptions and in table 13.

Topsoil is used in areas where vegetation is to be established and maintained. Suitability is affected mainly by the ease of working and spreading the soil material in preparing a seedbed and by the ability of the soil material to support plantlife. Also considered is the damage that can result at the area from which the topsoil is taken.

The ease of excavation is influenced by the thickness of suitable material, wetness, slope, and amount of stones. The ability of the soil to support plantlife is determined by texture, structure, and the amount of soluble salts or toxic substances. Organic matter in the A1 or Ap horizon greatly increases the absorption and retention of moisture and nutrients. Therefore, the soil material from these horizons should be carefully preserved for later use.

Soils rated *good* have at least 16 inches of friable loamy material at their surface. They are free of stones and cobbles, are low in content of gravel, and have gentle slopes. They are low in soluble salts that can limit or prevent plant growth. They are naturally fertile or respond well to fertilizer. They are not so wet that excavation is difficult during most of the year.

Soils rated *fair* are loose sandy soils or firm loamy or clayey soils in which the suitable material is only 8 to 16 inches thick or soils that have appreciable amounts of gravel, stones, or soluble salt.

Soils rated *poor* are very sandy soils and very firm clayey soils; soils with suitable layers less than 8 inches thick; soils having large amounts of gravel, stones, or soluble salt; steep soils; and poorly drained soils.

Although a rating of *good* is not based entirely on high content of organic matter, a surface horizon is generally preferred for topsoil because of its organic-matter content. This horizon is designated as A1 or Ap in the soil series descriptions. The absorption and retention of moisture and nutrients for plant growth are greatly increased by organic matter.

Water management

Many soil properties and site features that affect water management practices have been identified in this soil survey. In table 11 soil and site features that affect use are indicated for each kind of soil. This information is significant in planning, installing, and maintaining water control structures.

Pond reservoir areas hold water behind a dam or embankment. Soils best suited to this use have a low seepage potential, which is determined by permeability and the depth to fractured or permeable bedrock or other permeable material.

Embankments, dikes, and levees require soil material that is resistant to seepage, erosion, and piping and has favorable stability, shrink-swell potential, shear strength, and compaction characteristics. Large stones and organic matter in a soil downgrade the suitability of a soil for use in embankments, dikes, and levees.

Drainage of soil is affected by such soil properties as permeability; texture; depth to bedrock, hardpan, or other layers that affect the rate of water movement; depth to the water table; slope; stability of ditchbanks; susceptibility to flooding; salinity and alkalinity; and availability of outlets for drainage.

Terraces and diversions are embankments or a combination of channels and ridges constructed across a slope to intercept runoff. They allow water to soak into the soil or flow slowly to an outlet. Features that affect suitability of a soil for terraces are uniformity and steepness of slope; depth to bedrock, hardpan, or other unfavorable material; large stones; permeability; ease of establishing vegetation; and resistance to water erosion, soil blowing, soil slipping, and piping.

Grassed waterways are constructed to channel runoff to outlets at a nonerosive velocity. Features that affect the use of soils for waterways are slope, permeability, erodibility, wetness, and suitability for permanent vegetation.

Recreation

The soils of the survey area are rated in table 12 according to limitations that affect their suitability for recreation uses. The ratings are based on such restrictive soil features as flooding, wetness, slope, and texture of the surface layer. Not considered in these ratings, but important in evaluating a site, are location and accessibility of the area, size and shape of the area and its scenic quality, the ability of the soil to support vegetation, access to water, potential water impoundment sites available, and either access to public sewerlines or capacity of the soil to absorb septic tank effluent. Soils subject to flooding are limited, in varying degree, for recreation use by the duration and intensity of flooding and the season when flooding occurs. Onsite assessment of height, duration, intensity, and frequency of flooding is essential in planning recreation facilities.

The degree of the limitation of the soils is expressed as slight, moderate, or severe. *Slight* means that the soil properties are generally favorable and that the limitations are minor and easily overcome. *Moderate* means that the limitations can be overcome or alleviated by planning, design, or special maintenance. *Severe* means that soil properties are unfavorable and that limitations can be offset only by costly soil reclamation, special design, intensive maintenance, limited use, or by a combination of these measures.

The information in table 12 can be supplemented by information in other parts of this survey. Especially helpful are interpretations for septic tank absorption fields, given in table 9, and interpretations for dwellings without basements and for local roads and streets, given in table 8.

Camp areas require such site preparation as shaping and leveling for tent and parking areas, stabilizing roads and intensively used areas, and installing sanitary facilities and utility lines. Camp areas are subject to heavy foot traffic and some vehicular traffic. The best soils for this use have mild slopes and are not wet or subject to flooding during the period of use. The surface has few or no stones or boulders, absorbs rainfall readily but remains firm, and is not dusty when dry. Strong slopes and stones or boulders can greatly increase the cost of constructing camping sites.

Picnic areas are subject to heavy foot traffic. Most vehicular traffic is confined to access roads and parking areas. The best soils for use as picnic areas are firm when wet, are not dusty when dry, are not subject to flooding during the period of use, and do not have slopes or stones or boulders that will increase the cost of shaping sites or of building access roads and parking areas.

Playgrounds require soils that can withstand intensive foot traffic. The best soils are almost level and are not wet or subject to flooding during the season of use. The surface is free of stones or boulders, is firm after rains, and is not dusty when dry. If shaping is required to obtain a uniform grade, the depth of the soil over bedrock or hardpan should be enough to allow necessary grading.

Paths and trails for walking, horseback riding, bicycling, and other uses should require little or no cutting and filling. The best soils for this use are those that are not wet, are firm after rains, are not dusty when dry, and are not subject to flooding more than once during the annual period of use. They should have moderate slopes and have few or no stones or boulders on the surface.

Soil properties

Extensive data about soil properties are summarized on the following pages. The two main sources of these data are the many thousands of soil borings made during the course of the survey and the laboratory analyses of selected soil samples from typical profiles.

In making soil borings during field mapping, soil scientists can identify several important soil properties. They note the seasonal soil moisture condition or the presence of free water and its depth. For each horizon in the profile, they note the thickness and color of the soil material; the texture, or amount of clay, silt, sand, and gravel or other coarse fragments; the structure, or the natural pattern of cracks and pores in the undisturbed soil; and the consistence of the soil material in place under the existing soil moisture conditions. They record the depth of plant roots, determine the pH or reaction of the soil, and identify any free carbonates.

Samples of soil material are analyzed in the laboratory to verify the field estimates of soil properties and to determine all major properties of key soils, especially properties that cannot be estimated accurately by field observation. Laboratory analyses are not conducted for all soil series in the survey area, but laboratory data for many soil series not tested are available from nearby survey areas.

The available field and laboratory data are summarized in tables. The tables give the estimated range of engineering properties, the engineering classifications, and the physical and chemical properties of each major horizon of each soil in the survey area. They also present data about pertinent soil and water features.

Engineering properties

Table 13 gives estimates of engineering properties and classifications for the major horizons of each soil in the survey area.

Most soils have, within the upper 5 or 6 feet, horizons of contrasting properties. Table 13 gives information for each of these contrasting horizons in a typical profile. *Depth* to the upper and lower boundaries of each horizon is indicated. More information about the range in depth and about other properties in each horizon is given for each soil series in the section "Soil series and morphology."

Texture is described in table 13 in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in soil material that is less than 2 millimeters in diameter. "Loam," for example, is soil material that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If a soil contains gravel or other particles coarser than sand, an appropriate modifier is added, for example, "gravelly loam." Other texture terms are defined in the Glossary.

The two systems commonly used in classifying soils for engineering use are the Unified Soil Classification System (Unified) (*2*) and the system adopted by the American Association of State Highway and Transportation Officials (AASHTO) (*1*).

The *Unified* system classifies soils according to properties that affect their use as construction material. Soils are classified according to grain-size distribution of the fraction less than 3 inches in diameter, plasticity index, liquid limit, and organic-matter content. Soils are grouped into 15 classes—eight classes of coarse-grained soils, identified as GW, GP, GM, GC, SW, SP, SM, and SC; six classes of fine-grained soils, identified as ML, CL, OL, MH, CH, and OH; and one class of highly organic soils, identified as Pt. Soils on the borderline between two classes have a dual classification symbol, for example, CL-ML.

The *AASHTO* system classifies soils according to those properties that affect their use in highway construction and maintenance. In this system a mineral soil is classified in one of seven basic groups ranging from A-1 through A-7 on the basis of grain-size distribution, liquid limit, and plasticity index. Soils in group A-1 are coarse grained and low in content of fines. At the other extreme, in group A-7, are fine-grained soils. Highly organic soils are classified in group A-8 on the basis of visual inspection.

When laboratory data are available, the A-1, A-2, and A-7 groups are further classified as follows: A-1-a, A-1-b, A-2-4, A-2-5, A-2-6, A-2-7, A-7-5, and A-7-6. As an additional refinement, the desirability of soils as subgrade material can be indicated by a group index number. These numbers range from 0 for the best subgrade material to 20 or higher for the poorest. The estimated classification, without group index numbers, is given in table 13. Also in table 13 the percentage, by weight, of rock fragments more than 3 inches in diameter is estimated for each major horizon. These estimates are determined mainly by observing volume percentage in the field and then converting that, by formula, to weight percentage.

Percentage of the soil material less than 3 inches in diameter that passes each of four sieves (U.S. standard) is estimated for each major horizon. The estimates are based on tests of soils that were sampled in the survey area and in nearby areas and on field estimates from many borings made during the survey.

Liquid limit and *plasticity index* indicate the effect of water on the strength and consistence of soil. These indexes are used in both the Unified and AASHTO soil classification systems. They are also used as indicators in making general predictions of soil behavior. Range in liquid limit and plasticity index are estimated on the basis of test data from the survey area or from nearby areas and on observations of the many soil borings made during the survey.

The estimates are rounded to the nearest 5 percent. Thus, if the ranges of gradation and Atterburg limits extend a marginal amount across classification boundaries (1 or 2 percent), the classification in the marginal zone is omitted.

Physical and chemical properties

Table 14 shows estimated values for several soil characteristics and features that affect behavior of soils in engineering uses. These estimates are given for each major horizon, at the depths indicated, in the typical pedon of each soil. The estimates are based on field observations and on test data for these and similar soils.

Permeability is estimated on the basis of known relationships among the soil characteristics observed in the field—particularly soil structure, porosity, and gradation or texture—that influence the downward movement of water in the soil. The estimates are for vertical water movement when the soil is saturated. Not considered in the estimates is lateral seepage or such transient soil features as plowpans and surface crusts. Permeability of the soil is an important factor to be considered in planning and designing drainage systems, in evaluating the potential of soils for septic tank systems and other waste disposal systems, and in many other aspects of land use and management.

Available water capacity is rated on the basis of soil characteristics that influence the ability of the soil to hold water and make it available to plants. Important characteristics are content of organic matter, soil texture, and soil structure. Shallow-rooted plants are not likely to use the available water from the deeper soil horizons. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design of irrigation systems.

Soil reaction is expressed as a range in pH values. The range in pH of each major horizon is based on many field checks. For many soils, the values have been verified by laboratory analyses. Soil reaction is important in selecting the crops, ornamental plants, or other plants to be grown; in evaluating soil amendments for fertility and stabilization; and in evaluating the corrosivity of soils.

Shrink-swell potential depends mainly on the amount and kind of clay in the soil. Laboratory measurements of the swelling of undisturbed clods were made for many soils. For others the swelling was estimated on the basis of the kind and amount of clay in the soil and on measurements of similar soils. The size of the load and the magnitude of the change in soil moisture content also influence the swelling of soils. Shrinking and swelling of some soils can cause damage to building foundations, basement walls, roads, and other structures unless special designs are used. A high shrink-swell potential indicates that special design and added expense may be required if the planned use of the soil will not tolerate large volume changes.

Risk of corrosion pertains to potential soil-induced chemical action that dissolves or weakens uncoated steel or concrete. The rate of corrosion of uncoated steel is related to soil moisture, particle-size distribution, total acidity, and electrical conductivity of the soil material. The rate of corrosion of concrete is based mainly on the sulfate content, texture, and acidity of the soil. Protective measures for steel or more resistant concrete help to avoid or minimize damage resulting from the corrosion. Uncoated steel intersecting soil boundaries or soil horizons is more susceptible to corrosion than an installation that is entirely within one kind of soil or within one soil horizon.

Erosion factors are used to predict the erodibility of a soil and its tolerance to erosion in relation to specific kinds of land use and treatment. The soil erodibility factor (K) is a measure of the susceptibility of the soil to erosion by water. Soils having the highest K values are the most erodible. K values range from 0.10 to 0.64. To estimate annual soil loss per acre, the K value of a soil is modified by factors representing plant cover, grade and length of slope, management practices, and climate. The soil-loss tolerance factor (T) is the maximum rate of soil erosion, whether from rainfall or soil blowing, that can occur without reducing crop production or environmental quality. The rate is expressed in tons of soil loss per acre per year.

Soil and water features

Table 15 contains information helpful in planning land uses and engineering projects that are likely to be affected by soil and water features.

Hydrologic soil groups are used to estimate runoff from precipitation. Soils not protected by vegetation are placed in one of four groups on the basis of the intake of water after the soils have been wetted and have received precipitation from long-duration storms.

The four hydrologic soil groups are:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils that have a layer that impedes the downward movement of water or soils that have moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clay soils that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Flooding is the temporary covering of soil with water from overflowing streams, with runoff from adjacent slopes, and by tides. Water standing for short periods after rains or after snow melts is not considered flooding, nor is water in swamps and marshes. Flooding is rated in general terms that describe the frequency and duration of flooding and the time of year when flooding is most likely. The ratings are based on evidence in the soil profile of the effects of flooding, namely thin strata of gravel, sand, silt, or, in places, clay deposited by floodwater; irregular decrease in organic-matter content with increasing depth; and absence of distinctive soil horizons that form in soils of the area that are not subject to flooding. The ratings are also based on local information about floodwater levels in the area and the extent of flooding and on information that relates the position of each soil on the landscape to historic floods.

The generalized description of flood hazards is of value in land-use planning and provides a valid basis for land-use restrictions. The soil data are less specific, however, than those provided by detailed engineering surveys that delineate flood-prone areas at specific flood frequency levels.

High water table is the highest level of a saturated zone more than 6 inches thick for a continuous period of more than 2 weeks during most years. The depth to a seasonal high water table applies to undrained soils. Estimates are based mainly on the relationship between grayish colors or mottles in the soil and the depth to free water observed in many borings made during the course of the soil survey. Indicated in table 15 are the depth to the seasonal high water table; the kind of water table, that is, perched, artesian, or apparent; and the months of the year that the water table commonly is high. Only saturated zones above a depth of 5 or 6 feet are indicated.

Information about the seasonal high water table helps in assessing the need for specially designed foundations, the need for specific kinds of drainage systems, and the need for footing drains to insure dry basements. Such information is also needed to decide whether or not construction of basements is feasible and to determine how septic tank absorption fields and other underground installations will function. Also, a seasonal high water table affects ease of excavation.

Depth to bedrock is shown for all soils that are underlain by bedrock at a depth of 5 to 6 feet or less. For many soils, the limited depth to bedrock is a part of the definition of the soil series. The depths shown are based on measurements made in many soil borings and on other observations during the mapping of the soils. The kind of bedrock and its hardness as related to ease of excavation is also shown. Rippable bedrock can be excavated with a single-tooth ripping attachment on a 200-horsepower tractor, but hard bedrock generally requires blasting.

Subsidence is the settlement of organic soils or of soils containing semifluid layers. Initial subsidence generally results from drainage. Total subsidence is initial subsidence plus the slow sinking that occurs over a period of several years as a result of the oxidation or compression of organic material.

Classification of soils

This section describes the soil series of the survey area, defines the current system of classifying soils, and classifies the soils of the area according to that system.

Soil series and morphology

In this section, each soil series recognized in the survey area is described in detail. The descriptions are arranged in alphabetic order by series name.

Characteristics of the soil and the material in which it formed are discussed for each series. The soil is then compared to similar soils and to nearby soils of other series. Then a pedon, a small three-dimensional area of soil that is typical of the soil series in the survey area, is described. The detailed descriptions of each soil horizon follow standards in the Soil Survey Manual (*3*). Unless otherwise noted, colors described are for moist soil.

Following the pedon description is the range of important characteristics of the soil series in this survey area. Phases, or mapping units, of each soil series are described in the section "Soil maps for detailed planning."

Aceitunas series

The Aceitunas series consists of clayey, oxidic, isohyperthermic Typic Palehumults. These soils are deep, well drained, and have a B2 horizon of yellowish red clay. They formed in fine textured sediments washed from limestone. The Aceitunas soils are on alluvial fans and in valleys. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 66 inches, and the mean annual temperature is 77 degrees F.

The Aceitunas soils are associated with the Via, Rio Arriba, and Mabi soils, but the clayey subsoil is not so expansive as that of those soils.

Typical pedon of Aceitunas clay, 5 to 12 percent slopes, 0.8 kilometer south of intersection of Highway 250 and Highway 1, then 25 feet west in a pangolagrass field.

Ap—0 to 8 inches, dark brown (7.5YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; few fine dark concretions; few fine pores; few krotovinas; very strongly acid; clear smooth boundary.

B21t—8 to 15 inches, yellowish red (5YR 4/6) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; many fine roots; common dead dark roots; few krotovinas; few fine pores; very strongly acid; gradual smooth boundary.

B22t—15 to 30 inches, yellowish red (5YR 4/8) clay; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; common dead roots; common patchy clay films; few pores; few fine roots; few fine weathered rock fragments; very strongly acid; gradual smooth boundary.

B23t—30 to 43 inches, yellowish red (5YR 4/8) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few dead roots; few pores; few weathered rock fragments; few patchy clay films on ped surfaces; very strongly acid; gradual smooth boundary.

B24t—43 to 60 inches, yellowish red (5YR 4/8) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine dark stains; patchy clay films, very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR or 5YR, value of 3 or 4, and chroma of 3 or 4.

The B2t horizon has hue of 5YR and 2.5YR, value of 4 to 6, and chroma of 6 to 8. It has weak to moderate fine and medium subangular blocky structure.

Aibonito series

The Aibonito series consists of clayey, oxidic, isohyperthermic Orthoxic Tropohumults. These soils are deep, well drained, and have a B2 horizon of strong brown clay. They formed in residuum of volcanic rocks. The Aibonito soils are on side slopes and ridgetops of volcanic uplands. Slopes range from 12 to 40 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 75 degrees F.

The Aibonito soils are associated with the Catalina, Comerio, and Mucara soils. They have a thinner solum than the Catalina and Comerio soils and a thicker solum than the Mucara soils.

Typical pedon of Aibonito clay, 20 to 40 percent slopes, 5 feet east from kilometer 6.2 of Highway 162, Aibonito, P.R.

Ap—0 to 7 inches, dark grayish brown (10YR 4/2) clay; moderate fine subangular blocky structure; very hard, friable, slightly sticky, plastic; many fine roots; very strongly acid; abrupt irregular boundary.

B1—7 to 11 inches, strong brown (7.5YR 5/6) clay; common fine distinct yellowish red (5YR 4/6) mottles in ped interiors and brown (10YR 4/3) coatings on ped surfaces; extremely firm, sticky, plastic; few fine roots restricted to the ped surfaces; few sand size grains; extremely acid; gradual wavy boundary.

B21t—11 to 22 inches, strong brown (7.5YR 5/6) clay; common fine distinct yellowish red (5YR 4/6) mottles and brown (10YR 4/3) coatings on surfaces of peds; strong coarse prismatic parting to moderate medium subangular blocky structure; extremely firm, sticky, plastic; few fine roots restricted to surfaces of peds; few sand size grains; extremely acid; gradual wavy boundary.

B22t—22 to 32 inches, strong brown (7.5YR 5/6) clay; common fine distinct red (2.5YR 5/6) mottles; strong coarse prismatic structure parting to moderate medium subangular blocky; brown (10YR 4/3) coatings on ped surfaces; extremely firm, sticky, plastic; few fine roots; few sand size grains; extremely acid; gradual wavy boundary.

B3—32 to 43 inches, strong brown (7.5YR 5/6) clay; many medium prominent yellowish brown (10YR 5/6) and red (2.5YR 4/6) mottles, and few medium prominent white (10YR 8/1) mottles; weak medium subangular blocky structure; thin patchy clay films; friable, slightly sticky, plastic; very few fine roots; extremely acid; gradual wavy boundary; 30 percent of this horizon is saprolite.

C1—43 to 65 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6), and white (10YR 8/1) clay saprolite; massive; friable, slightly sticky, plastic; extremely acid; gradual wavy boundary.

C2—65 to 110 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6), and white (10YR 8/1) silty clay saprolite; massive; friable, slightly sticky, slightly plastic; extremely acid. Rock structure is visible. Material can be easily crushed with fingers.

The solum is 33 to 56 inches thick. Reaction throughout is very strongly acid or extremely acid.

The A horizon has hue of 10YR and 7.5YR, value of 4, and chroma of 2 to 4.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 6 to 8.

The C horizons are clay and silty clay.

Almirante series

The Almirante series consists of clayey, oxidic, isohyperthermic Plinthic Paleudults. These soils are deep, are well drained, and have a B2 horizon of strong brown and brownish yellow clay underlain by plinthite layers. They formed in fine textured sediments of mixed origin. The Almirante soils are on coastal plains and in valleys between the limestone hills. Slopes range from 2 to 12 percent, but are dominantly 2 to 5 percent. The mean annual precipitation is 65 inches, and the mean annual temperature is 78 degrees F.

The Almirante soils are associated with the Bayamon, Matanzas, Tanama, and Vega Alta soils. They have a thicker solum than the Matanzas and the Tanama soils. They have plinthite which the Bayamon soils lack. They are deeper over the plinthite than the Vega Alta soils.

Typical pedon of Almirante clay, 2 to 5 percent slopes, 1 kilometer from intersection of Highway 693 and 694, then 40 feet north, Dorado, P.R.

Ap—0 to 7 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; many quartz grains; many fine dark concretions; very strongly acid; clear smooth boundary.

B21t—7 to 34 inches, strong brown (7.5YR 5/6) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; few patchy clay films; many quartz grains; common black stains; common fine roots; few fine pores; very strongly acid; clear smooth boundary.

B22t—34 to 46 inches, brownish yellow (10YR 6/8) and dark red (10R 3/6) clay; weak medium subangular blocky structure; firm, sticky, plastic; dark concretions; purple stains; few fine rock fragments; about 8 percent by volume is plinthite; very strongly acid; gradual smooth boundary.

B23t—46 to 60 inches, variegated brownish yellow (10YR 6/8), dark red (10R 3/6), and light gray (5Y 7/1) clay; weak medium subangular blocky structure; firm, sticky, plastic; about 15 percent by volume is plinthite; very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR, 7.5YR, or 5YR; value of 3 or 4; and chroma of 2 to 4.

The B2t horizon has hue of 10YR, 7.5YR, or 5YR; value of 4 to 6; and chroma of 4 to 8. It has a weak to moderate fine to medium subangular blocky structure.

Bajura series

The Bajura series consists of fine, mixed, nonacid isohyperthermic Vertic Tropaquepts. These soils are deep, are poorly drained, and have a B horizon of dark gray clay. They formed in fine textured sediments of mixed origin. The Bajura soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 84 inches, and the mean annual temperature is 78 degrees F.

The Bajura soils are associated with the Coloso, Toa, and Dique soils. They have more expansive clays than the Coloso soils. They are finer textured than the Toa and the Dique soils.

Typical pedon of Bajura clay, 0.2 miles east, 0.2 miles north, and 25 feet east from kilometer 18.4 of Highway 165.

Ap—0 to 5 inches, dark brown (10YR 3/3) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few dead roots; few krotovinas; few root channels; few fine pebbles; medium acid; gradual smooth boundary.

B—5 to 12 inches, dark gray (10YR 4/1) clay; mottles are common medium distinct yellowish brown (10YR 5/6), few medium distinct very dark gray (5Y 3/1), and few fine brown to dark brown (7.5YR 4/4); weak coarse subangular blocky structure; firm, slightly sticky, plastic; few pressure faces; few fine roots; few dead roots; few fine pebbles; medium acid; gradual smooth boundary.

C1g—12 to 31 inches, gray to light gray (5Y 6/1) and yellowish brown (10YR 5/6) clay; few fine greenish gray (5G 6/1) mottles; weak coarse subangular blocky structure; firm, sticky, plastic; few pebbles; few dead roots; slightly acid; gradual smooth boundary.

C2g—31 to 38 inches, greenish gray (5G 6/1) clay; many medium distinct brownish yellow (10YR 6/6) and few medium distinct bluish gray (5B 5/1) mottles; weak coarse subangular blocky structure; firm, sticky, plastic; neutral; gradual smooth boundary.

C3g—38 to 60 inches, greenish gray (5GY 6/1) clay; with common medium prominent bluish gray (5B 5/1) and common medium distinct olive brown (2.5Y 4/4) mottles; massive; firm, very sticky, very plastic; few dead roots; few soft black concretions; neutral.

The solum is 12 to 20 inches thick. Reaction is medium acid to slightly acid.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 3 or less. It has moderate medium subangular blocky structure.

Bayamon series

The Bayamon series consists of clayey, oxidic, isohyperthermic Typic Haplorthox. These soils are deep, are well drained, and have a B horizon of red clay. They formed in fine textured sediments of mixed origin. The Bayamon soils are on stable coastal plains and in valleys between limestone hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 65 inches, and the mean annual temperature is 78 degrees F.

The Bayamon soils are associated with the Almirante, Matanzas, and Vega Alta soils. They have a thicker solum than the Matanzas and Vega Alta soils. They lack the plinthic horizons of the Almirante and Vega Alta soils.

Typical pedon of Bayamon clay, 2 to 5 percent slopes, 80 feet east of shed and 50 feet north of junction of dirt roads, 0.4 miles west from farm entrance on dirt road. A.S.A. farm at Finca Monterrey, Bo. Higuillar, Dorado, P.R.

Ap—0 to 8 inches, dark reddish brown (2.5YR 3/4) clay; moderate fine granular structure; friable, slightly sticky, slightly plastic; common fine roots; few fine iron concretions; common fine sand size quartz grains; very strongly acid; clear smooth boundary.

B21—8 to 27 inches, weak red (10R 4/4) clay; weak coarse subangular blocky structure parting to moderate fine angular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine oxide concretions; common fine quartz grains; common fine pores; black coatings on old root channels; very strongly acid; gradual smooth boundary.

B22—27 to 42 inches, red (10R 4/6) clay; massive in place, parting to weak very fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine pores; few fine sand size quartz grains; few fine black specks; very strongly acid; gradual smooth boundary.

B23—42 to 66 inches, red (10R 4/6) clay; massive in place, parting to weak very fine subangular blocky structure; very friable, slightly sticky, slightly plastic; few sand size quartz grains; few very fine black specks; few fine pores; yellow waxy coatings on ped surfaces and root channels; very strongly acid.

The solum is more than 60 inches thick. Reaction is very strongly acid.

The A horizon has hue of 5YR, 2.5YR, or 10R; value of 3 or 4; and chroma of 3 or 4.

The B2 horizon has hue of 2.5YR or 10R, value of 4 to 6, and chroma of 3 to 8. It is massive or has weak coarse and medium subangular blocky structure which parts readily into weak and moderate fine and medium angular and subangular blocky structure.

Caguabo series

The Caguabo series consists of loamy-skeletal, mixed, isohyperthermic Lithic Eutropepts. These soils are shallow, are well drained, and have an AC horizon of brown very gravelly clay loam. They formed in residuum of volcanic rocks. The Caguabo soils are on side slopes and ridgetops of strongly dissected uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Caguabo soils are associated with the Mucara, Morado, and Sabana soils. They have a thinner solum than the Mucara and Morado soils. They are less acid than the Sabana soils.

Typical pedon of Caguabo clay loam, 20 to 40 percent slopes, 300 feet east and 400 feet south of the tobacco drying barn which is approximately 1000 feet west of station headquarters, Gurabo Experiment Station.

Ap—0 to 4 inches, dark grayish brown (10YR 4/2) clay loam; weak fine granular structure; slightly hard, friable, nonsticky, slightly plastic; common fine volcanic rock fragments, common fine roots; slightly acid; clear smooth boundary.

AC—4 to 10 inches, brown (10YR 4/3) very gravelly clay loam; massive in place, parting to weak fine granular structure; friable, slightly sticky, slightly plastic; more than 50 percent by volume fine volcanic fragments; few fine roots; slightly acid; clear smooth boundary.

C—10 to 16 inches, mixture of weathered and partially weathered volcanic rock fragments that can be penetrated by spade.

R—16 inches, consolidated rock.

The solum is 8 to 16 inches thick. Reaction throughout is slightly acid.

The A horizon has hue of 10YR or 2.5Y, value of 3 or 4, and chroma of 2 to 4.

The AC horizon has hue of 10YR or 7.5YR, value of 3 to 5, and chroma of 3 or 4.

Candelero series

The Candelero series consists of fine-loamy, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are somewhat poorly drained, and have a B2g horizon of dark gray or very dark gray sandy clay loam. They formed in moderately fine textured sediments high in quartz, feldspar, and hornblende minerals derived from granitic rocks.

The Candelero soils are on terraces, alluvial fans, and foot slopes. Slopes range from 2 to 5 percent. The mean annual precipitation is 87 inches, and the mean annual temperature is 77 degrees F.

The Candelero soils are associated with the Humacao and Cayagua soils. They have a thicker solum than the Humacao and Cayagua soils.

Typical pedon of Candelero loam, 0.1 mile northeast from kilometer 0.6 of Highway 183, then 450 feet northwest from a farm road, San Lorenzo, P.R.

Ap—0 to 6 inches, dark grayish brown (10YR 4/2) loam; few fine dark gray (10YR 4/1) mottles; weak fine subangular blocky structure parting to granular; friable; nonsticky, slightly plastic; common fine roots; common fine quartz grains; common fine black concretions; very strongly acid; clear smooth boundary.

B1—6 to 11 inches, dark brown (10YR 4/3) and dark gray (10YR 4/1), sandy clay loam; few fine yellowish red (5YR 4/6) and dark yellowish brown (10YR 4/4) mottles; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; many fine quartz crystals; common fine black concretions; very strongly acid; clear smooth boundary.

B21tg—11 to 20 inches, dark gray (10YR 4/1) sandy clay loam; many medium distinct yellowish brown (10YR 5/8) and few fine faint gray (N 5/0) mottles; weak medium and coarse subangular blocky structure; firm, slightly sticky, plastic; few fine roots; many quartz grains; common soft black concretions; strongly acid; gradual smooth boundary.

B22tg—20 to 35 inches, very dark gray (10YR 3/1) sandy clay loam; common medium distinct greenish gray (5GY 6/1) and brownish yellow (10YR 6/6) mottles; massive; firm, slightly sticky, plastic; few fine roots; many quartz grains; few fine dark minerals; common dark minerals; common dark stains due to dead roots; strongly acid; gradual smooth boundary.

B31g—35 to 49 inches, brownish yellow (10YR 6/8) sandy clay; mottles are common medium distinct dark gray (5Y 4/1) and few fine greenish gray (5G 5/1) and light brownish gray (10YR 6/2); massive; firm, slightly sticky, plastic; few fine quartz grains; few dark soft concretions; few dark stains; medium acid; gradual smooth boundary.

B32g—49 to 60 inches, yellowish brown (10YR 5/4) sandy clay; mottles are many fine distinct gray (5Y 6/1) and few fine yellowish red (5YR 4/6) and dark reddish brown (2.5YR 3/4); firm, slightly sticky, plastic; few fine quartz grains; few sand lenses; few soft black concretions; medium acid.

The solum is more than 60 inches thick. Reaction throughout is medium acid to very strongly acid.

The A horizon has hue of 10YR, value of 3 or 4, and chroma of 2 or 3.

The B2t horizon has hue of 10YR, value of 3 or 4, and chroma of 1 to 3. It has weak medium and coarse subangular blocky structure or is massive.

Catalina series

The Catalina series consists of clayey, oxidic, isohyperthermic Tropeptic Haplorthox. These soils are deep, are well drained, and have a B2 horizon of dark reddish brown and reddish brown clay. They formed in fine textured residuum of volcanic rocks. The Catalina soils are on side slopes and hilltops. Slopes range from 4 to 12 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 75 degrees F.

The Catalina soils are associated with the Humatas, Daguey, and Consumo soils. They have a thicker solum than the Daguey soils and have a thicker B2 horizon than the Humatas and Consumo soils.

Typical pedon of Catalina clay, 4 to 12 percent slopes, 45 feet east of field road and 470 feet south of house at kilometer 8.8 of Highway 152, Barranquitas, P.R.

Ap—0 to 6 inches, dark reddish brown (5YR 3/3) clay, few fine distinct reddish brown (2.5YR 4/4) pockets; weak fine granular structure; friable, slightly sticky, slightly plastic; many fine roots; many sand size particles; few fine pieces of charcoal; medium acid; abrupt smooth boundary.

B21—6 to 20 inches, dark reddish brown (2.5YR 3/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; common fine roots; common fine pores; many soft black sand size particles; very strongly acid; clear smooth boundary.

B22—20 to 34 inches, reddish brown (2.5YR 5/4) clay; few reddish brown (2.5YR 4/4) ped faces; weak fine subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few fine pores; few fine sand size particles; few pressure faces; very strongly acid; clear smooth boundary.

B23—34 to 84 inches, dark reddish brown (2.5YR 3/4) clay; weak fine angular blocky structure; firm, slightly sticky, plastic; few fine pores; common pressure faces; strongly acid; gradual wavy boundary.

B24—84 to 99 inches, variegated dusky red (10R 3/4), dark reddish brown (2.5YR 3/4), and strong brown (7.5YR 5/8) clay; few dark gray and white splotches; massive; firm, plastic; very strongly acid.

The solum is more than 60 inches thick. Reaction throughout is medium acid to very strongly acid.

The A horizon has hue of 5YR or 2.5YR, value of 3 or 4, and chroma of 3 or 4.

The B2 horizon has hue of 2.5YR or 10R, value of 3 or 4, and chroma of 4 to 8. It has weak to moderate fine or medium subangular blocky structure or is massive.

Catano series

The Catano series consists of carbonatic, isohyperthermic Typic Troposamments. These soils are deep and excessively drained. They have A horizons of very dark brown sand and C horizons of dark brown and dark grayish brown sand. They formed in quartz sand, shell fragments, and miscellaneous volcanic rocks. The Catano soils are on coastal plains adjacent to the sea. Slopes range from 0 to 2 percent. The mean annual precipitation is 76 inches, and the mean annual temperature is 78 degrees F.

The Catano soils are associated with the Durados soils. They are coarser textured than the Durados soils.

Typical pedon of Catano loamy sand, 50 feet north of electrical transformers on east end of Punta Salinas, Catano, P.R.

A—0 to 7 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose, nonsticky, nonplastic; many fine roots; violent effervescence; clear smooth boundary.

AC—7 to 23 inches, dark brown (10YR 4/3) sand; single grain; loose; nonsticky, nonplastic; common fine roots; violent effervescence; clear smooth boundary.

C—23 to 58 inches; dark grayish brown (10YR 4/2) sand; single grain; loose, nonsticky, nonplastic; many fine shell fragments; violent effervescence.

Effervescence with dilute HCL ranges from slight to violent.

The A horizon has hue of 10YR and value and chroma of 2 or 3.

Cayagua series

The Cayagua series consists of fine, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are somewhat poorly drained, and have a B2tg horizon of light olive gray clay. They formed in residuum of coarse textured plutonic rocks. The Cayagua soils are on foot slopes and side slopes. Slopes range from 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Cayagua soils are associated with the Candelero and Humacao soils. They have a thinner solum than the Candelero soils and finer textured B horizons than the Humacao soils.

Typical pedon of Cayagua sandy loam, 70 feet north from kilometer 13.75 of Highway 183, San Lorenzo, P.R.

Ap—0 to 8 inches, dark grayish brown (10YR 4/2) sandy loam; few fine dark gray (5Y 4/1) mottles; weak fine subangular blocky structure; friable, nonsticky, nonplastic; common fine roots; common fine quartz grains; few fine black concretions; very strongly acid; abrupt smooth boundary.

B21t—8 to 16 inches, yellowish brown (10YR 5/4) clay; mottles are common fine prominent dark gray (5Y 4/1), yellowish red (5YR 5/8), and red (2.5YR 4/8); firm, slightly sticky, plastic; few fine roots; few patchy clay films; common fine quartz grains; common dark stains in root channels; few soft black concretions; very strongly acid; clear smooth boundary.

B22tg—16 to 22 inches, light olive gray (5Y 6/2) clay; common fine distinct yellowish brown (10YR 5/4) and strong brown (7.5YR 5/8) mottles; and few fine red (2.5YR 5/8) and greenish gray (5G 6/1) mottles; weak coarse subangular blocky structure; firm, slightly sticky, plastic; few fine roots; common fine quartz grains; few soft black concretions; very strongly acid; clear smooth boundary.

B3g—22 to 32 inches, light olive gray (5Y 6/2) sandy clay loam; common medium prominent yellowish brown (10YR 5/8) mottles, and few fine greenish gray (5BG 6/1) and light gray (2.5Y 7/2) mottles; massive; firm, slightly sticky, slightly plastic; common fine quartz grains; few soft black concretions; strongly acid; gradual smooth boundary.

C—32 to 43 inches, mixed yellowish brown (10YR 5/4 and 5/8), white (2.5Y 8/2), and gray (5Y 5/1) sandy clay loam saprolite; massive; friable, nonsticky, nonplastic; common fine quartz grains; common fine dark minerals; horizon consists of 80 percent saprolite; strongly acid.

The solum is 28 to 36 inches thick. Reaction throughout is very strongly acid to strongly acid.

The A horizon has hue of 10YR or 2.5Y, value of 3 or 4, and chroma of 2 or 3.

The B2 horizon has hue of 10YR to 5Y, value of 4 to 7, and chroma of 2 to 4. It has weak coarse angular blocky structure.

The C horizons are sandy clay loam and sandy loam.

Colinas series

The Colinas series consists of fine-loamy, carbonatic, isohyperthermic Eutropeptic Rendolls. These soils are moderately deep to soft limestone, are well drained, and have a B horizon of brownish yellow clay loam. They formed in moderately fine textured residuum of limestone. The Colinas soils are on ridgetops and side slopes. Slopes range from 12 to 60 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Colinas soils are associated with the Soller and Tanama soils. They are underlain by softer limestone than that of the Soller or Tanama soils. They are yellower than the Tanama soils.

Typical pedon of Colinas clay loam, 40 to 60 percent slopes, eroded, 500 feet southeast of junction of Highways 820 and 823, Bo. Quebrada Arenas, Toa Alta, P.R.

A1—0 to 11 inches, dark brown (10YR 3/3) clay loam; moderate medium granular structure; friable, nonsticky, plastic; many fine roots; few limestone fragments; mildly alkaline; clear smooth boundary.

B—11 to 26 inches, brownish yellow (10YR 6/6) clay loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; few limestone fragments; mildly alkaline; clear smooth boundary.

C1—26 to 48 inches, pale yellow (2.5Y 7/4) soft limestone crushing to silty clay loam; massive; very friable, nonsticky, slightly plastic; mildly alkaline.

C2—48 to 52 inches, mixture of yellow and white limestone containing common fine and medium limestone fragments.

The solum is 15 to 30 inches thick. Reaction throughout is mildly alkaline.

The A horizon has hue of 10YR, value of 3 to 6, and chroma of 2 or more.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 2 or more.

The C horizon is clay loam or silty clay loam.

Coloso series

The Coloso series consists of fine, mixed, nonacid, isohyperthermic Aeric Tropic Fluvaquents. These soils are deep, are somewhat poorly drained, and have a C horizon of dark grayish brown, dark brown, and dark gray silty clay. They formed in fine textured and moderately fine textured alluvial sediments of mixed origin. The Coloso soils are on flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Coloso soils are associated with the Bajura, Toa, and Dique soils. They are coarser textured and better drained than the Bajura soils, but finer textured and more poorly drained than the Toa and Dique soils.

Typical pedon of Coloso silty clay loam, 300 feet west of road and 400 feet north of the terrace break, which is approximately 2800 feet north of the Gurabo Experiment Station's headquarters.

Ap—0 to 7 inches, dark brown (10YR 3/3) silty clay loam; few fine distinct dark reddish brown (2.5YR 3/4) mottles; medium coarse granular structure; slightly hard, friable, nonsticky, slightly plastic; many roots; medium acid; clear smooth boundary.

C1—7 to 16 inches, mixed dark brown (10YR 4/3) and dark yellowish brown (10YR 4/4) silty clay loam; weak coarse subangular blocky structure; friable, nonsticky, slightly plastic; many roots; organic stains on ped surfaces; medium acid; clear smooth boundary.

C2g—16 to 32 inches, dark grayish brown (10YR 4/2) and light gray (10YR 6/1) silty clay loam; many medium distinct dark yellowish brown (10YR 4/4) mottles; weak coarse subangular blocky structure; firm, slightly sticky, plastic; black stains along fracture planes and in root channels, the light gray color is more concentrated in root channels and on fracture faces; many roots; medium acid; gradual smooth boundary.

C3g—32 to 55 inches, greenish gray (5G 5/1) silty clay; many medium distinct yellowish red (5YR 5/8) mottles; massive; firm, slightly sticky, plastic; common roots; medium acid; gradual smooth boundary.

C4g—55 to 70 inches, greenish gray (5G 5/1) silty clay; many medium distinct yellowish brown (10YR 5/6) mottles; massive; firm, slightly sticky, plastic; few roots; medium acid.

The A horizon has hue of 10YR, value of 3 or 4, and chroma of 2 to 4.

The Cg horizon has hue of 10YR, 2.5Y, or 5G; value of 3 to 6; and chroma of 2 or less.

Consumo series

The Consumo series consists of clayey, mixed, isohyperthermic Dystropeptic Tropudults. These soils are deep, are well drained, and have a B2t horizon of yellowish red clay. They formed in residuum of basic volcanic rocks. The Consumo soils are on side slopes and narrow ridges of strongly dissected, humid uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 76 degrees F.

The Consumo soils are associated with the Daguey, Humatas, Morado, and Mucara soils. They are shallower to saprolite than the Daguey and Humatas soils. They are redder, are more acid, and have finer texture than the Morado and Mucara soils.

Typical pedon of Consumo clay, 40 to 60 percent slopes, 0.7 mile south from kilometer 48.1 of Highway 1, along farm road of La Mina de Oro Restaurant, then 20 feet south.

Ap—0 to 10 inches, reddish brown (5YR 4/4) clay; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few small subrounded rock fragments; very strongly acid; clear smooth boundary.

B2t—10 to 14 inches, yellowish red (5YR 5/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; thin patchy clay films; few fine pores; few small subrounded rock fragments; very strongly acid; clear smooth boundary.

B3—14 to 20 inches; yellowish red (5YR 5/6) clay; many medium distinct red (2.5YR 4/6) and common fine distinct brownish yellow (10YR 6/6) mottles; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; about 50 percent saprolite; very strongly acid; clear smooth boundary.

C—20 to 46 inches, variegated red (2.5YR 4/6 and 5/6), brownish yellow (10YR 6/6), and yellowish red (5YR 5/6), silty clay loam saprolite; massive; very friable, slightly sticky, slightly plastic; original rock structure visible; can be crushed with fingers; very strongly acid.

The solum is 14 to 24 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 5YR or 2.5YR, value of 3 to 5, and chroma of 4 to 6.

The B2 horizon has hue of 5YR or 2.5YR, value of 4 or 5, and chroma of 6 or more.

Corozal series

The Corozal series consists of clayey, mixed, isohyperthermic Aquic Tropudults. These soils are deep, are somewhat poorly drained, and have a B2 horizon of red clay. They formed in residuum of volcanic rocks. The sloping Corozal soils are on interfluves of strongly dissected low volcanic hills. Slopes range from 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 75 degrees F.

The Corozal soils are associated with the Consumo and Humatas soils. They have a thicker solum and are more poorly drained than the Consumo and Humatas soils.

Typical pedon of Corozal clay, 5 to 12 percent slopes, 3 miles southwest of the town of Corozal on the Corozal Experiment Station farm, 60 feet east of cattle weighing pen.

Ap—0 to 7 inches, dark reddish brown (5YR 3/4) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; many fine roots; very strongly acid; clear wavy boundary.

B1—7 to 9 inches, mixed dark red (2.5YR 3/6) and grayish brown (10YR 5/2) clay; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thick continuous clay films; many fine roots; very strongly acid; clear wavy boundary.

B21t—9 to 13 inches, red (2.5YR 4/6) clay; reddish brown (5YR 4/4) on ped surfaces and root channels; moderate medium prismatic structure parting to moderate medium subangular blocky; firm, slightly sticky, plastic; thick continous clay films; many fine roots; very strongly acid; gradual wavy boundary.

B22t—13 to 24 inches, red (2.5YR 4/6) clay; yellowish brown (10YR 5/6) coatings on ped surfaces and in root channels; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films on ped faces and in root channels; common fine roots; very strongly acid; gradual wavy boundary.

B23t—24 to 32 inches, red (2.5YR 5/6) clay; yellowish brown (10YR 5/6) coatings on ped surfaces and in root channels; moderate medium subangular blocky structure parting to weak fine subangular blocky; friable, slightly sticky, slightly plastic; very few patchy clay films on vertical ped faces; few fine roots; very strongly acid; gradual wavy boundary.

B3—32 to 40 inches, yellowish red (5YR 5/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; very few patchy clay films on vertical ped faces; about 30 percent by volume is saprolite; pseudomorphs of feldspars easily crushed to shiny faces (kaolin books); very strongly acid; gradual irregular boundary.

C—40 to 60 inches; variegated yellowish red (5YR 5/6), light gray (5YR 7/1), and strong brown (7.5YR 5/6) clay loam saprolite; massive; friable, slightly sticky, slightly plastic; saprolite is easily crushed with fingers; rock structure visible; pseudomorphs of feldspars easily crushed to shiny faces (kaolin books); very strongly acid.

The solum is 40 to 50 inches thick. Reaction is very strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 or 4, and chroma of 4.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 or 5, and chroma of 6 to 8. It has strong to moderate subangular blocky structure or prismatic structure parting to subangular blocky.

Daguey series

The Daguey series consists of clayey, oxidic, isohyperthermic Orthoxic Tropohumults. These soils are deep, are well drained, and have a B horizon of reddish clay. They formed in the residuum of basic volcanic rocks. The Daguey soils are on the more stable side slopes, ridgetops, and foot slopes of the humid volcanic uplands. Slopes range from 2 to 20 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 78 degrees F.

The Daguey soils are associated with the Humatas and Consumo soils. The Daguey soils are more leached and have a thicker solum than the Humatas and Consumo soils.

Typical pedon of Daguey clay, 12 to 20 percent slopes, 40 feet west of Highway 813, then 80 feet south of road junction to house, Cibuco SCD, P.R.

Ap—0 to 10 inches, dark brown (7.5YR 4/4) clay; weak medium subangular blocky structure parting to moderate fine granular; firm, slightly sticky, slightly plastic; very strongly acid; abrupt wavy boundary.

B1—10 to 14 inches, reddish brown (5YR 5/4) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; clear smooth boundary.

B21t—14 to 23 inches, yellowish red (5YR 4/6) clay; few medium distinct yellowish brown (10YR 5/4) mottles; weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; clear smooth boundary.

B22t—23 to 31 inches, red (2.5YR 4/6) clay; strong medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin continuous clay films on ped faces; very strongly acid; gradual smooth boundary.

B23t—31 to 43 inches, red (2.5YR 4/6) clay; strong medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B24t—43 to 59 inches, red (2.5YR 4/6) clay; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B3—59 to 72 inches, red (2.5YR 4/6) clay; weak medium and fine subangular blocky structure; firm, slightly sticky, slightly plastic; very thin patchy clay films; few small angular fragments of rock; very strongly acid; clear smooth boundary.

C1—72 to 86 inches, yellowish red (5YR 4/6) silty clay loam; common fine distinct strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) mottles; massive but with some evidence of original rock structure; friable, slightly sticky, slightly plastic; very strongly acid; gradual smooth boundary.

C2—86 to 90 inches, yellowish red (5YR 4/6) silty clay loam saprolite with well defined rock structure; common fine distinct strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) mottles; very strongly acid.

The solum is 50 to 80 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 7.5YR or 5YR, value of 3 to 5, and chroma of 2 to 4.

The B2 horizon has hue of 10R or 2.5YR, value of 4 or 5, and chroma of 6 to 8. It has moderate to strong medium and fine subangular blocky structure.

Descalabrado series

The Descalabrado series consists of clayey, mixed, isohyperthermic Lithic Vertic Ustropepts. These soils are shallow, are well drained, and have a B horizon of dark brown gravelly clay. They formed in residuum of basic volcanic rocks. The Descalabrado soils are on foot slopes, long and short side slopes, and ridgetops of semiarid volcanic uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 40 inches, and the mean annual temperature is 80 degrees F.

The Descalabrado soils are associated with the Guayama soils. The Descalabrado soils have colors with yellower hues and lack the argillic horizons of the Guayama soils.

Typical pedon of Descalabrado clay loam, 40 to 60 percent slopes, 1250 feet south from elementary school of Bo. Cercadillo, Cayey, P.R.

A1—0 to 5 inches, very dark grayish brown (10YR 3/2) clay loam; moderate fine granular structure; friable, nonsticky, slightly plastic, few fine roots; few fine pores; few rock fragments 2 millimeters to 25 millimeters in diameter; neutral; clear smooth boundary.

B—5 to 11 inches, dark brown (10YR 3/3) gravelly clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine pores; 20 percent rock fragments 2 millimeters to 25 millimeters in diameter; neutral; clear smooth boundary.

C—11 to 17 inches, mixed dark yellowish brown (10YR 3/4 and 10YR 4/4) and olive (5Y 5/3) gravelly sandy clay loam weathered rock; massive; friable, nonsticky, slightly plastic; 25 percent rock fragments 1 to 3 inches in diameter; neutral; clear abrupt boundary.

R—17 inches, hard semiconsolidated volcanic rock.

The solum is 8 to 14 inches thick. Reaction throughout is neutral.

The A horizon has hue of 10YR and 7.5YR, value of 2 or 3, and chroma of 2 or 3.

The B horizon has hue of 10YR or 7.5YR, value of 3 or 4, and chroma of 2 to 4.

Dique series

The Dique series consists of fine-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are well drained, and have a B2 horizon of dark yellowish brown loam. They formed in medium textured alluvial sediments of mixed origin. The Dique soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 72 inches, and the mean annual temperature is 77 degrees F.

The Dique soils are associated with the Toa, Bajura, Coloso, and Reilly soils. They are better drained and have coarser textures than the Bajura and Coloso soils. They are thicker and lack the gravelly layers of the Reilly soils. They are coarser textured and better drained than the Toa soils.

Typical pedon of Dique loam, 100 feet west from entrance of Gurabo Experiment Station, then 75 feet north of Highway 941.

Ap—0 to 6 inches, dark brown (10YR 4/3) loam; weak fine granular structure; friable, nonsticky, slightly plastic; many fine roots; medium acid; clear smooth boundary.

B1—6 to 16 inches, dark brown (10YR 4/3) loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few fine black concretions; medium acid; abrupt wavy boundary.

B2—16 to 20 inches, dark yellowish brown (10YR 4/4) loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; medium acid; gradual smooth boundary.

B3—20 to 36 inches, dark brown (10YR 4/3) loam; weak fine subangular blocky structure; friable; medium acid; abrupt smooth boundary.

C—36 to 54 inches, dark yellowish brown (10YR 4/4) loam; friable, nonsticky, nonplastic; medium acid.

The solum is 20 to 40 inches thick. Reaction throughout is medium acid.

The A and B horizons have hue of 10YR, value of 4 or 5, and chroma of 2 to 4.

Durados series

The Durados series consists of sandy, mixed, isohyperthermic Fluventic Hapludolls. These soils are deep, are excessively drained, and have dark grayish brown sandy loam Ap horizons over dark grayish brown loamy sand and sand C horizons. They formed in coarse textured materials which consist of sand size shell fragments and miscellaneous volcanic subrounded fragments. The Durados soils are on the coast at elevations close to sea level. Slope ranges from 0 to 2 percent. The mean annual precipitation is 70 inches, and the mean annual temperature is 80 degrees F.

The Durados soils are associated with the Coloso, Toa, and Catano soils. They are coarser textured and more permeable than the Coloso and Toa soils. They are finer textured than the Catano soils.

Typical pedon of Durados sandy loam, 0.2 mile northwest of kilometer 19.9, Highway 165, following a farm road, then 150 feet north.

Ap—0 to 14 inches, very dark grayish brown (10YR 3/2) sandy loam; massive; very friable, nonsticky, nonplastic; few fine roots; few medium coconut roots; few quartz grains; neutral; abrupt smooth boundary.

C1—14 to 23 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose; few fine cemented sandy concretions; neutral; abrupt smooth boundary.

C2—23 to 38 inches, very pale brown (10YR 7/3) and very dark grayish brown (10YR 3/2) sand; single grain; loose; about 25 percent of horizon is light gray (5Y 7/1) cemented sand that is strongly calcareous; moderately alkaline; abrupt smooth boundary.

C3—38 to 60 inches; sand that is mixed dark yellowish brown (10YR 4/4), black (10YR 2/1), brownish yellow (10YR 6/6), and yellowish brown (10YR 6/4); single grain; loose; this horizon has a thick layer of cemented sand that could be penetrated with an auger; few sea shells; common quartz grains; strongly alkaline, calcareous.

The mollic epipedon is 10 to 30 inches thick. Reaction throughout is neutral to strongly alkaline.

The A horizon has hue of 10YR or 7.5YR, value and chroma of 2 or 3.

Estacion series

The Estacion series consists of fine loamy over sandy or sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls. These soils are shallow, are well drained, and have an Ap horizon of dark brown silty clay loam and a C horizon of very dark grayish brown gravelly clay loam and sand. They formed in stratified moderately fine textured sediments over gravelly layers of mixed origin. The Estacion soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 70 inches, and the mean annual temperature is 80 degrees F.

The Estacion soils are associated with the Reilly, Toa, Coloso, Bajura, and Dique soils. They are finer textured in the upper horizons than the Reilly soils. They are coarser textured than the Bajura soils. They have gravelly subhorizons that the Toa, Coloso, and Dique soils lack.

Typical pedon of Estacion silty clay loam, 0.5 mile northwest from kilometer 32.8 of Highway 1, Caguas, P.R.

Ap—0 to 8 inches, dark brown (10YR 3/3) silty clay loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few subrounded gravel 1/2 to 2 inches in diameter; medium acid; clear smooth boundary.

C1—8 to 20 inches, very dark grayish brown (10YR 3/2) gravelly clay loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; many fine and coarse gravel-size subrounded fragments; medium acid; gradual smooth boundary.

C2—20 to 50 inches; dark brown (10YR 4/3) gravelly sand; single grain; loose, nonsticky, nonplastic; about 50 percent coarse gravel; many rounded cobbles 3 to 7 inches in diameter; slightly acid.

Reaction throughout is slightly acid to medium acid.

The A horizon has hue of 10YR or 7.5YR, value of 3, and chroma of 2 or 3.

The C horizons are gravelly clay loam and gravelly sand.

Guayama series

The Guayama series consists of clayey, mixed, isohyperthermic Lithic Haplustalfs. These soils are shallow, are well drained, and have a B horizon of red gravelly clay. They formed in residuum of volcanic rocks. The Guayama soils are on side slopes and narrow ridgetops of dissected uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 35 inches, and the mean annual temperature is 80 degrees F.

The Guayama soils are associated with the Descalabrado soils. The Guayama soils have a redder B horizon than the Descalabrado soils.

Typical pedon of Guayama clay loam, 20 to 60 percent slopes, 0.5 mile west from Jajome Bajo School, then 25 feet north from dirt road, Cayey, P.R.

A—0 to 4 inches, dark reddish brown (5YR 3/4) clay loam; weak fine granular structure; slightly hard, friable, slightly sticky, slightly plastic; common fine roots; common angular rock fragments 1/8 to 1 inch in diameter; neutral; clear smooth boundary.

B—4 to 12 inches, red (2.5YR 4/6) gravelly clay; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; about 25 percent angular rock fragments 1/4 to 2 inches in diameter; neutral; clear smooth boundary.

C—12 to 20 inches, red (2.5YR 5/8) gravelly silty clay loam; massive; friable, slightly sticky, slightly plastic; horizon consists of about 60 percent light yellowish brown (2.5Y 6/4) saprolite; about 25 percent weathered rock fragments; neutral; clear smooth boundary.

R—20 inches; greenish colored consolidated volcanic rock.

The solum is 10 to 14 inches thick. Depth to consolidated rock is 20 inches or less. Reaction throughout is neutral to mildly alkaline.

The A horizon has hue of 7.5YR or 5YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 5YR or 2.5YR, value of 3 or 4, and chroma of 4 to 6.

Humacao series

The Humacao series consists of fine-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are moderately well drained, and have a B horizon of dark yellowish brown sandy clay loam. They formed in medium and moderately fine textured sediments derived from plutonic rocks. The Humacao soils are on terraces above the river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 75 degrees F.

The Humacao soils are associated with the Candelero and Vivi soils. The Humacao soils have a thinner and coarser textured solum than the Candelero soils, but are finer textured throughout than the Vivi soils.

Typical pedon of Humacao loam, 0.4 mile west from kilometer 1.5 of Highway 912, then 18 feet north from rectangular cattle drinking tank, Bo. Cerro Gordo, San Lorenzo, P.R.

A—0 to 8 inches, dark brown (10YR 4/3) loam; weak fine granular structure; friable, nonsticky, nonplastic; many fine roots; common fine quartz grains; few dark minerals; strongly acid; clear smooth boundary.

B—8 to 15 inches, dark yellowish brown (10YR 4/4) sandy clay loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; common fine quartz grains; few dark concretions; strongly acid; clear smooth boundary.

C1—15 to 26 inches, brown (7.5YR 5/4) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; common fine quartz grains; common fine dark minerals; few dark concretions; strongly acid; clear smooth boundary.

C2—26 to 44 inches, strong brown (7.5YR 5/6) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine roots; common fine quartz grains; common fine dark minerals; few dark concretions; strongly acid; clear smooth boundary.

C3—44 to 60 inches, redddish yellow (7.5YR 6/6) sandy clay loam; massive; very friable, nonsticky, nonplastic; many quartz grains; few dark minerals; strongly acid.

The solum is 13 to 24 inches thick. Reaction throughout is strongly acid to medium acid.

The A horizon has hue of 10YR or 7.5YR, value of 2 to 4, and chroma of 2 or 3.

The B horizon has hue of 10YR or 5YR, value of 4 to 6, and chroma of 3 to 8.

The C horizons are clay loam and sandy clay loam.

Humatas series

The Humatas series consists of clayey, kaolinitic, isohyperthermic Typic Tropohumults. These soils are deep, are well drained, and have a B2 horizon of red clay. They formed in residuum of basic volcanic rocks. The Humatas soils are on narrow ridgetops and side slopes. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 86 inches, and the mean annual temperature is 76 degrees F.

The Humatas soils are associated with the Catalina, Consumo, and Daguey soils. They have a thinner solum than the Catalina and Daguey soils and a thicker B2 horizon than the Consumo soils. They are also associated with the Naranjito soils, but are deeper than the Naranjito soils.

Typical pedon of Humatas clay, 40 to 60 percent slopes, 0.9 mile from kilometer 9.8 of Highway 765 and 200 feet northwest from dirt road, San Lorenzo, P.R.

Ap—0 to 5 inches, dark brown (7.5YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; few fine pores; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B21t—5 to 14 inches; red (2.5YR 4/6) clay; moderate medium subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few fine black concretions; common thin clay films on surfaces of peds and in pores; very strongly acid; clear smooth boundary.

B22t—14 to 24 inches, red (2.5YR 4/6) clay, few yellowish brown (10YR 5/4) mottles; moderate medium subangular blocky structure; friable, slightly sticky, plastic; few fine pores; common thin clay films on surfaces of peds and in pores; very strongly acid; gradual smooth boundary.

B3—24 to 34 inches, yellowish red (5YR 5/6) silty clay, few fine dark yellowish brown (10YR 4/4), red (10R 4/6), yellowish brown (10YR 5/6), and dusky red (2.5YR 3/4) mottles; weak fine and medium subangular blocky structure; friable, nonsticky, slightly plastic; few thin clay films; 2 percent weathered rock fragments; very strongly acid; clear smooth boundary.

C1—34 to 45 inches, red (10R 4/8), yellowish red (5YR 5/6), and strong brown (7.5YR 5/6) silty clay; massive; very friable, nonsticky, slightly plastic; few fine pores; 2 percent weathered rock fragments; 75 percent of horizon is saprolite; strongly acid; gradual smooth boundary.

C2—45 to 60 inches, dark red (10R 3/6), red (10R 4/6), reddish brown (5YR 5/4), olive yellow (2.5Y 6/8), and white (N 8/0) silty clay saprolite; massive; very friable, nonsticky, slightly plastic; few fine pores; 2 percent weathered rock fragments; strongly acid.

The solum is 23 to 41 inches thick. Reaction throughout is very strongly acid or strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 to 5, and chroma of 4 to 6.

The B2t horizon has hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 3 to 6. It has weak to moderate fine and medium subangular blocky structure.

The C horizon is silty clay, clay, or clay loam.

Jagueyes series

The Jagueyes series consists of fine-loamy, mixed, isohyperthermic Orthoxic Tropudults. These soils are deep, are well drained, and have a B2t horizon of red clay loam. They formed in residuum of plutonic rocks. The Jagueyes soils are on side slopes and narrow ridgetops of humid uplands. Slopes range from 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Jagueyes soils are associated with the Lirios, Limones, and Pandura soils. The Jagueyes have thicker and redder B2 horizons than the Pandura soils. They are coarser textured than Limones soils and have a thicker solum than Lirios soils.

Typical pedon of Jagueyes loam, 20 to 40 percent slopes, eroded, 2.8 miles southeast of kilometer 11.4 of Highway 181, then 350 feet southwest from dirt road, then 50 feet west, San Lorenzo, P.R.

Ap—0 to 5 inches, dark yellowish brown (10YR 4/4) loam; few fine grayish brown (2.5Y 5/2) mottles; weak fine subangular blocky structure parting to granular; friable, nonsticky, nonplastic; few fine roots; common fine quartz grains; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B21t—5 to 14 inches, yellowish red (5YR 4/6) and yellowish brown (10YR 5/6) clay loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; few fine pores; few patchy clay films; common quartz grains; few fine black concretions; few krotovinas; very strongly acid; clear smooth boundary.

B22t—14 to 24 inches, red (2.5YR 4/6) clay loam; common medium distinct light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few fine pores; common patchy clay films; common fine quartz grains; few dark concretions; very strongly acid; gradual smooth boundary.

B23t—24 to 41 inches; red (2.5YR 4/6) clay loam; few medium distinct light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine pores; common patchy clay films, many fine quartz grains; few black concretions; very strongly acid; gradual smooth boundary.

B3—41 to 54 inches, red (2.5YR 4/8) sandy clay loam; common medium distinct brownish yellow (10YR 6/6) and few medium distinct light gray (10YR 7/2) mottles; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine pores; many fine quartz grains; few fine black minerals; very strongly acid; clear smooth boundary.

C—54 to 62 inches, yellowish red (5YR 5/8) sandy clay loam; mottles are many fine distinct pink (7.5YR 7/4), common fine distinct very pale brown (10YR 7/4), and few fine red (2.5YR 4/8); weak fine subangular blocky structure; friable, nonsticky, slightly plastic; many fine quartz grains; few fine black minerals; about 75 percent of horizon is saprolite; very strongly acid.

The solum is 48 to 60 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR or 7.5YR, value of 2 to 4, and chroma of 2 to 4.

The B2t horizon has hue of 5YR or 2.5YR, value of 4 to 7, and chroma of 6 to 8. It has weak to moderate fine to medium subangular blocky structure.

Juncal series

The Juncal series consists of fine, mixed, isohyperthermic Typic Tropudalfs. These soils are deep, are moderately well drained, and have B2t horizons of dark yellowish brown, brownish yellow, and yellowish brown clay. They formed in residuum of limestone. The Juncal soils are on foot slopes and low rounded hills. Slopes range from 5 to 20 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 77 degrees F.

The Juncal soils are associated with the Colinas soils. They are thicker and have yellower and lighter colors than the Colinas soils.

Typical pedon of Juncal clay, 5 to 20 percent slopes, eroded, 1.9 kilometers south of junction of Highways 2 and 677, 2.5 kilometers east of junction of Highways 823 and 677, 1700 feet northeast of a dairy barn, 800 feet northeast of a farm pond, Barrio Rio Lajas, Toa Alta, P.R.

Ap—0 to 10 inches, dark grayish brown (10YR 4/2) clay; weak coarse subangular blocky structure; firm, slightly sticky, plastic; many fine roots; medium acid; clear wavy boundary.

B21t—10 to 14 inches, dark yellowish brown (10YR 4/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; common fine roots; mildly alkaline; clear wavy boundary.

B22t—14 to 20 inches, yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin discontinuous patchy clay films; few fine roots; mildly alkaline; clear wavy boundary.

B23t—20 to 34 inches; brownish yellow (10YR 6/8) clay; common fine distinct yellowish red (5YR 5/8) mottles; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; mildly alkaline; clear wavy boundary.

B24t—34 to 40 inches; brownish yellow (10YR 6/6) clay; few fine prominent yellowish red (5YR 5/6) and few fine prominent light greenish gray (5BG 7/1) mottles; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films, few fine roots; few black concretions; neutral; clear wavy boundary.

B25t—40 to 48 inches; yellowish brown (10YR 5/6) clay; few fine prominent red (2.5YR 5/6) mottles; moderate fine subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films; few roots; few black stains; neutral; clear wavy boundary.

C—48 to 60 inches, brownish yellow (10YR 6/8) silty clay loam; common fine faint light gray (10YR 7/2) mottles; friable, slightly sticky, plastic; there are lime splotches present in this horizon; about 40 percent of the horizon is soft limestone; mildly alkaline.

The solum is 36 to 58 inches thick. Reaction throughout ranges from medium acid to mildly alkaline.

The A horizon has hue of 7.5YR and 10YR, value of 4, and chroma of 2 or 3.

The B2t horizon has hue of 7.5YR and 10YR, value of 4 to 6, and chroma of 4 to 8. It has moderate fine to medium subangular blocky structure.

Juncos series

The Juncos series consists of fine, montmorillonitic, isohyperthermic Vertic Eutropepts. These soils are deep, are well drained, and have a B2 horizon of dark brown clay. They formed in residuum of basic volcanic rocks.

The Juncos soils are on side slopes and foot slopes of strongly dissected uplands. Slopes range from 5 to 20 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 66 inches, and the mean annual temperature is 77 degrees F.

The Juncos soils are associated with the Montegrande, Mabi, Mucara, and Caguabo soils. They have a thinner solum than the Montegrande and Mabi soils, but have a thicker solum than the Mucara and Caguabo soils.

Typical pedon of Juncos clay, 12 to 20 percent slopes, 800 feet north of the southwestern corner of the Gurabo Experiment Substation.

Ap—0 to 8 inches, black (10YR 2/1) clay; common fine distinct yellow (10YR 7/6) mottles; weak fine and medium subangular blocky structure; very hard, firm, slightly sticky; plastic; many fine roots; few fine black concretions, slightly acid; clear smooth boundary.

B2—8 to 18 inches, dark brown (7.5YR 4/4) clay; small amount of Ap horizon mixed throughout; weak fine and medium subangular blocky structure; very hard, firm, slightly sticky, plastic; common fine roots; few pressure faces; common fine black concretions; few subrounded volcanic fragments 1/4 to 1 inch in diameter; black coatings along root channels; neutral; clear smooth boundary.

C1—18 to 31 inches, olive brown (2.5Y 4/4) clay; massive; firm, slightly sticky, plastic; common fine roots; pressure faces and slickensides; many fine black concretions; black coatings on root channels; few subrounded volcanic fragments 1/4 to 1 inch in diameter; neutral; gradual smooth boundary.

C2—31 to 40 inches; olive brown (2.5Y 4/4) clay; massive with thin clay stringers between cleavage planes; firm, slightly sticky, slightly plastic; few roots; 15 percent by volume consists of weathered volcanic rocks; neutral; gradual wavy boundary.

R—40 inches; semiconsolidated volcanic rock.

The solum is 12 to 24 inches thick. Reaction throughout ranges from slightly acid to neutral.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 1 or 2.

The B2 horizon has hue of 7.5YR, value of 4 or 5, and chroma of 4 to 6.

Lares series

The Lares series consists of clayey, mixed, isohyperthermic Aquic Tropohumults. These soils are deep, are moderately well drained, and have a B2t horizon of yellowish red clay. They formed in fine textured material derived from volcanic rocks. The Lares soils are on dissected terraces and foot slopes. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Lares soils are associated with the Daguey, Humatas, and Consumo soils. They are deeper to saprolite and are not so well drained as the Daguey, Humatas, and Consumo soils.

Typical pedon of Lares clay, 2 to 5 percent slopes, north of Urbanizacion Miraflores, 500 feet east of kilometer 3.0 of Highway 861, then 200 feet north along farm boundary.

Ap—0 to 6 inches, dark brown (10YR 4/3) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; common fine roots; few fine black concretions; few krotovinas; few fine pores; few fine quartz grains; very strongly acid; abrupt smooth boundary.

B1—6 to 15 inches, red (2.5YR 4/8) clay; reddish brown (5YR 5/4) ped faces; few fine brownish yellow (10YR 6/6) mottles; moderate, medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; common fine pores; few fine krotovinas; common patchy clay films on ped surfaces and in pores; few fine concretions; few quartz grains; very strongly acid; clear smooth boundary.

B2t—15 to 22 inches, yellowish red (5YR 5/6) clay; common fine distinct pale red (10R 6/4) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy clay films; very strongly acid; gradual smooth boundary.

B3—22 to 36 inches, yellowish red (5YR 5/8) clay; common medium distinct pale yellow (5Y 7/4); few fine distinct strong brown (7.5YR 5/8) and red (2.5YR 4/8) mottles and common fine distinct light gray (10YR 7/2) mottles; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots, few quartz grains; few fine pores; few patchy clay films; very strongly acid; gradual smooth boundary.

C1—36 to 52 inches; variegated brownish yellow (10YR 6/8), red (2.5YR 4/8), very pale brown (10YR 7/4), and dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; firm, nonsticky, slightly plastic; few fine quartz grains; few fine dark minerals; few fine pores; very strongly acid; gradual smooth boundary.

C2—52 to 60 inches, variegated brownish yellow (10YR 6/6), dark red (2.5YR 3/6), light gray (7.5YR 7/2), and red (2.5YR 4/8) clay; weak fine subangular blocky structure; firm, nonsticky, nonplastic; many quartz grains; few dark minerals; few fine pores; very strongly acid.

The solum is 26 to 53 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 7.5YR or 10YR, value of 4, and chroma of 3 or 4.

The B2t horizon has hue of 7.5YR or 5YR, value of 4 to 6, and chroma of 4 or more.

Limones series

The Limones series consists of clayey, kaolinitic, isohyperthermic Epiaquic Orthoxic Tropohumults. These soils are deep, are moderately well drained, and have B2t horizons of yellowish brown and red clay. They formed in residuum of plutonic rocks. The Limones soils are on side slopes and narrow ridgetops of concordant remnants of highly dissected peneplains. Slopes range from 20 to 60 percent, but are dominantly 20 to 40 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Limones soils are associated with the Pandura, Jagueyes, and Lirios soils. They have a thicker solum than the Pandura and Lirios soils and are moderately well drained. They have a redder B2t horizon and are finer textured than the Jagueyes soils.

Typical pedon of Limones clay, 20 to 40 percent slopes, 1500 feet east from farm pond, 800 feet west from a dairy barn, 1700 feet west of the Quebrada Arenas school, 2100 feet east of the Cayaguas River and 1100 feet southwest of junction of Highway 912 and unnumbered road to the dairy barn.

Ap—0 to 7 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; few mottles caused by mixed A and B horizons during plowing; many quartz grains; few fine black concretions; very strongly acid; clear smooth boundary.

B1—7 to 18 inches, yellowish brown (10YR 5/4) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; few thin patchy clay films; few quartz grains; very strongly acid; clear smooth boundary.

B21t—18 to 30 inches, yellowish brown (10YR 5/8) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films; common fine quartz grains; few fine dark grains; very strongly acid; clear smooth boundary.

B22t—30 to 41 inches, red (2.5YR 4/6) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; thin continuous clay films; common fine quartz grains; few fine dark minerals; very strongly acid; gradual smooth boundary.

B3—41 to 48 inches, red (2.5YR 4/8) clay; common distinct reddish yellow (5YR 6/6); mottles; weak medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; thin patchy clay films; few fine quartz grains; very strongly acid; gradual smooth boundary.

C1—48 to 59 inches, red (2.5YR 4/6) clay; massive; friable; nonsticky, slightly plastic; few fine quartz grains; few dark minerals; about 30 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C2—59 to 79 inches, variegated red (2.5YR 5/8, 4/6, and 4/8) clay saprolite; massive; friable; nonsticky, nonplastic; many fine quartz grains; few dark minerals; very strongly acid.

The solum is 33 to 53 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 4, and chroma of 2 to 4.

The B2t horizon has hue of 10YR or 2.5YR, value of 4 or 5, and chroma of 4 to 8.

Lirios series

The Lirios series consists of clayey over loamy, mixed, isohyperthermic Typic Tropudults. These soils are deep, are well drained, and have a B2t horizon of brown silty clay loam and a B3 horizon of red clay. They formed in residuum of plutonic rocks. The Lirios soils are on side slopes of the strongly dissected humid uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 77 degrees F.

The Lirios soils are associated with the Limones, Jagueyes, and Pandura soils. They have a thinner solum and are better drained than the Limones and Jagueyes soils. They are redder and overlie more highly weathered plutonic rocks than those of the Pandura soils.

Typical pedon of Lirios silty clay loam, 20 to 60 percent slopes, eroded, 2.7 miles west from kilometer 11.4 Highway 181, and 300 feet east from dirt road.

Ap—0 to 4 inches, brown (7.5YR 4/4) silty clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; common fine quartz grains; few krotovinas; very strongly acid; clear smooth boundary.

B2t—4 to 12 inches, brown (7.5YR 4/4) silty clay loam; weak fine subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few patchy clay films on ped surfaces, common fine quartz grains; few fine dark minerals; very strongly acid; clear smooth boundary.

B3—12 to 24 inches, red (2.5YR 4/8) clay; common fine distinct light yellowish brown (2.5Y 6/4) and yellowish brown (10YR 5/4 and 5/6) mottles and few fine brownish yellow (10YR 6/6) mottles; weak medium subangular blocky structure; friable, slightly sticky, plastic; few fine roots; few fine pores; few patchy clay films on ped surfaces; common fine quartz grains; few fine dark minerals; horizon is about 25 percent saprolite; very strongly acid; clear smooth boundary.

C1—24 to 34 inches, variegated red (2.5YR 4/8), yellowish brown (10YR 5/8), yellowish red (5YR 5/8), very pale brown (10YR 7/3), brown (7.5YR 5/4), white (2.5Y 8/2), and red (10R 4/8) clay; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine quartz grains; few fine dark minerals, few mica flakes; about 75 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C2—34 to 45 inches, variegated red (2.5YR 4/8), yellowish brown (10YR 5/8), yellowish red (5YR 5/8), very pale brown (10YR 7/3), brown (7.5YR 5/4), white (2.5Y 8/2), and red (10R 4/8) silty clay loam; massive; very friable, nonsticky, slightly plastic; many quartz grains; few dark minerals and mica flakes; very strongly acid; gradual smooth boundary.

C3—45 to 60 inches, variegated brownish yellow (10YR 6/8), yellow (10YR 7/8), red (10R 4/8), and very pale brown (10YR 7/4) silty clay loam; massive; very friable, nonsticky, slightly plastic; many fine dark minerals and quartz grains; structure of rock is more evident in this horizon; very strongly acid.

The solum is 20 to 24 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR or 10YR, value of 4 or 5, and chroma of 3 or 4.

The B2t horizon has hue of 7.5YR, 5YR, and 2.5YR; value of 4 to 6; and chroma of 4 to 8.

The C horizon is silty clay loam and clay.

Los Guineos series

The Los Guineos series consists of clayey, mixed, isothermic Epiaquic Tropohumults. These soils are deep, are moderately well drained, and have a B2t horizon of yellowish brown and red clay. They formed in residuum of basic volcanic rocks. The Los Guineos soils are on side slopes and hilltops of humid volcanic uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 95 inches, and the mean annual temperature is 70 degrees F.

The Los Guineos soils are associated with the Humatas, Consumo, Mucara, Naranjito, and Caguabo soils. They have a thicker solum and are less well drained than the Humatas, Consumo, Mucara, Naranjito, and Caguabo soils.

Typical pedon of Los Guineos clay, 20 to 40 percent slopes, 3.2 miles southeast of junction of Highway 1 and 184, along Highway 184 to Guavate and 40 feet north of highway.

Ap—0 to 4 inches, dark yellowish brown (10YR 4/4) clay; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few fine black concretions; few krotovinas; very strongly acid; abrupt smooth boundary.

B21t—4 to 11 inches, yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm; slightly sticky, plastic; few fine pebbles; very strongly acid; clear smooth boundary.

B22t—11 to 19 inches, yellowish brown (10YR 5/6) clay with common fine prominent red (2.5YR 4/8) mottles; moderate medium subangular blocky structure; firm, slightly sticky, plastic; few fine roots; few fine pores; common patchy clay films on ped surfaces and in pores; very strongly acid; clear smooth boundary.

B23t—19 to 34 inches, red (2.5YR 4/8) and brownish yellow (10YR 6/6) clay; moderate medium subangular blocky structure parting to moderate fine subangular blocky; firm, slightly sticky, plastic; few fine pores; common patchy clay films on ped surfaces and in pores; very strongly acid; gradual smooth boundary.

B3—34 to 48 inches, red (10R 4/8) clay; mottles are common medium distinct red (2.5YR 4/8), common medium prominent brownish yellow (10YR 6/8), few medium prominent yellow (10YR 7/6), and few fine prominent white (10YR 8/2); weak medium subangular blocky structure parting to weak fine subangular blocky; firm, slightly sticky, plastic; few fine pores; few patchy clay films on ped surfaces and in pores; about 25 percent of horizon consists of saprolite; very strongly acid; gradual smooth boundary.

C—48 to 60 inches, red (10R 4/8) clay; mottles are many medium prominent brownish yellow (10YR 6/8), few medium prominent yellow (10YR 7/6), and few fine prominent white (10YR 8/2); weak fine subangular blocky structure; friable, slightly sticky, plastic; horizon consists of about 75 percent saprolite; very strongly acid.

The solum is 41 to 54 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 4 or 5, and chroma of 3 to 5.

The B2t horizon has hue of 10YR and 7.5YR in the upper part and hue of 2.5YR and 10R in the lower part, value of 4 to 6, and chroma of 6 to 8.

Mabi series

The Mabi series consists of fine, montmorillonitic, isohyperthermic Vertic Eutropepts. These soils are deep, are somewhat poorly drained, and have a B2 horizon of yellowish brown clay. They formed in fine textured sediments derived from volcanic rocks. The Mabi soils are on alluvial fans and terraces above the river flood plains. Slopes range from 0 to 12 percent, but are dominantly 2 to 5 percent. The mean annual precipitation is 78 inches, and the mean annual temperature is 80 degrees F.

The Mabi soils are associated with the Montegrande, Rio Arriba, Juncos, and Mucara soils. They are clayey throughout and lack the gravelly subsurface layers of the Montegrande soils. They are darker colored than the Rio Arriba soils. They are not underlain by hard volcanic rocks as are the Juncos and Mucara soils.

Typical pedon of Mabi clay, 2 to 5 percent slopes, 800 feet north and 600 feet west of the Gurabo Experiment Substation Headquarters.

Ap—0 to 7 inches, very dark grayish brown (10YR 3/2) clay; few fine faint yellowish brown mottles; red (2.5YR 4/6) coatings along root channels; weak fine granular structure; hard, very firm, slightly sticky, plastic; common fine roots; common fine black nodules; few fine volcanic rock fragments; very strongly acid; clear smooth boundary.

B1—7 to 15 inches, dark yellowish brown (10YR 4/4) clay; few fine distinct gray (10YR 5/1) and common medium distinct yellowish brown (10YR 5/6) mottles; brown (10YR 4/3) when rubbed; weak fine and medium angular blocky structure with many pressure faces; very firm, slightly sticky, plastic; common fine roots; few fine black nodules; few fine volcanic rock fragments; strongly acid; clear wavy boundary.

B2—15 to 24 inches, yellowish brown (10YR 5/6) clay; many medium distinct gray (10YR 5/1) mottles; brown (10YR 4/3) when rubbed; weak fine and medium angular blocky structure with many pressure faces and slickensides that intersect; very firm, slightly sticky, plastic; few fine roots; few black nodules; few fine volcanic rock fragments; coatings along root channels; medium acid; clear wavy boundary.

C1—24 to 38 inches, yellowish brown (10YR 5/4) clay; few fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium and coarse angular blocky structure with many pressure faces and slickensides that intersect; very firm, slightly sticky, plastic; few fine black nodules; few fine volcanic rock fragments; few fine and medium carbonatic concretions; mildly alkaline; gradual smooth boundary.

C2—38 to 53 inches, yellowish brown (10YR 5/4) clay; common fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium angular blocky structure with common pressure faces and slickensides; very firm, slightly sticky, plastic; few fine black nodules; few fine volcanic rock fragments; few fine and medium carbonatic concretions; mildly alkaline; gradual smooth boundary.

C3—53 to 67 inches, yellowish brown (10YR 5/4) clay; common fine distinct gray (10YR 5/1) and few fine distinct greenish gray (5GY 6/1) mottles; weak medium angular blocky structure with few pressure faces and slickensides; very firm, slightly sticky, plastic; few fine black nodules; few fine and medium volcanic rock fragments; few fine carbonatic concretions; mildly alkaline; gradual wavy boundary.

The solum is 20 to 36 inches thick. Reaction throughout ranges from very strongly acid and medium acid in the upper horizons to mildly alkaline in the lower horizons.

The A horizon has hue of 10YR, value of 3 or less, and chroma of 2 or more.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 2 to 6.

Malaya series

The Malaya series consists of clayey, mixed, isohyperthermic Lithic Eutropepts. These soils are shallow, are well drained, and have a B horizon of dark brown gravelly clay. They formed in residuum of volcanic rocks. The Malaya soils are on side slopes of strongly dissected uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 77 degrees F.

The Malaya soils are associated with the Mucara and Caguabo soils. They have a thinner solum than the Mucara soils and are more alkaline than the Caguabo soils.

Typical pedon of Malaya clay loam, 40 to 60 percent slopes, 100 meters south from kilometer 61.6 of Highway 1.

A1—0 to 6 inches, dark brown (10YR 3/3) clay loam; weak medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; few black concretions; about 10 percent by volume, fine and medium rock fragments; slightly acid; clear smooth boundary.

B—6 to 13 inches, dark brown (10YR 4/3) gravelly clay, weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; common fine black concretions; about 20 percent by volume, fine and medium rock fragments; mildly alkaline; clear smooth boundary.

C—13 to 18 inches, dark yellowish brown (10YR 4/4) gravelly clay loam; massive; firm, slightly sticky, slightly plastic; black coatings on faces and on partially weathered rock fragments; about 20 percent by volume is rock fragments; moderately alkaline; gradual wavy boundary.

R—18 inches, semiconsolidated tuffaceous rocks.

The solum is 10 to 20 inches thick. Reaction throughout is slightly acid to moderately alkaline.

The A horizon has hue of 5YR to 10YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 10YR, value of 4, and chroma of 3 or 4. It has weak medium to coarse subangular blocky structure.

The C horizon is gravelly clay loam. Depth to the consolidated volcanic rock is less than 20 inches.

Maricao series

The Maricao series consists of clayey, mixed, isothermic Dystropeptic Tropudults. These soils are deep, are well drained, and have a B2t horizon of red clay. They formed in residuum of basic volcanic rocks. The Maricao soils are on side slopes and narrow hilltops of strongly dissected humid uplands. Slopes range from 20 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 74 degrees F.

The Maricao soils are associated with the Los Guineos soils. They have a thinner B2t horizon than the Los Guineos soils.

Typical pedon of Maricao clay, 20 to 60 percent slopes, 300 feet east from kilometer 21.8 of Highway 157, then 50 feet south along farm boundary.

A—0 to 6 inches, reddish brown (5YR 5/4) clay; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine roots; very strongly acid; clear smooth boundary.

B2t—6 to 14 inches, red (2.5YR 4/8) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; few patchy clay films; very strongly acid; clear smooth boundary.

B3—14 to 22 inches, red (2.5YR 5/6) silty clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; very strongly acid; clear smooth boundary.

C—22 to 60 inches, variegated red (2.5YR 4/6), strong brown (7.5YR 5/6 and 5/8), and pale brown (10YR 6/3) silty clay loam saprolite; massive; friable, slightly sticky, slightly plastic; very strongly acid.

The solum is 18 to 28 inches thick. Reaction throughout is very strongly acid.

The A horizon has hue of 2.5YR and 5YR, value of 4 or 5, and chroma of 4 or more.

The B2 horizon has hue of 2.5YR or 5YR, value of 4 or 5, and chroma of 6 or more.

Martin Pena series

The Martin Pena series consists of fine, mixed, nonacid, isohyperthermic Tropic Fluvaquents. These soils are deep, are very poorly drained, and have a black muck O horizon over silty clay loam and clay C horizons. They formed in organic materials from phanerogams such as reeds, sedges, and other water-loving grasses over fine textured sediments. The Martin Pena soils are in low depressional areas in the humid coastal plain and river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Martin Pena soils are associated with the Saladar, Bajura, and Coloso soils. They are underlain by mineral layers; whereas Saladar soils are organic throughout, and the Bajura and Coloso soils are mineral throughout.

Typical pedon of Martin Pena muck, 300 feet east of sentry box, entrance to the Sabana Seca Naval Communication Station, 30 feet north from center of paved unnumbered road.

Oa1—0 to 8 inches, black (10YR 2/1) muck; weak fine granular structure; slightly sticky, slightly plastic; many fine living and decayed roots; mildly alkaline; abrupt smooth boundary.

C1—8 to 18 inches, very dark brown (10YR 2/2) silty clay loam with thin lenses of brown to dark brown (10YR 4/3) organic materials; massive; slightly sticky, slightly plastic; few fine decayed roots; mildly alkaline; gradual smooth boundary.

C2—18 to 28 inches, very dark brown (10YR 2/2) clay; massive; slightly sticky, plastic; neutral; clear smooth boundary.

C3—28 to 55 inches, greenish gray (5G 5/1) clay; few fine faint very dark brown (10YR 2/2), dark greenish gray (5G 4/1), and greenish gray (5G 6/1) mottles; massive; slightly sticky, plastic; thin organic lenses; neutral; clear smooth boundary.

C4—55 to 63 inches, very dark brown (10YR 2/2) clay; few fine faint black (10YR 2/1) and greenish gray (5G 5/1) mottles; massive; slightly sticky, plastic; thin organic lenses; mildly alkaline.

The Oa1 horizon has hue of 10YR or 7.5YR, value of 2, and chroma of 2 or less.

The upper C horizon has hue of 10YR with value and chroma of 2 or 3. Thin organic lenses may occur in the lower C horizon. Reaction throughout the profile ranges from neutral to mildly alkaline.

Matanzas series

The Matanzas series consists of clayey, oxidic, isohyperthermic Tropeptic Eutrorthox. These soils are deep, are well drained, and have a B2 horizon of dark reddish brown and red clay. They formed in sediments derived from limestone. The Matanzas soils are on foot slopes and in small valleys between the limestone hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 64 inches, and the mean annual temperature is 77 degrees F.

The Matanzas soils are associated with the Bayamon and Tanama soils. They have a thinner solum and are shallower to hard limestone than the Bayamon soils. They are redder and deeper to the hard limestone than the Tanama soils.

Typical pedon of Matanzas clay, 2 to 5 percent slopes, 60 feet south and 100 feet west of Maguayo school, Bo. Maguayo, Toa Baja, P.R.

Ap—0 to 7 inches, dark reddish brown (5YR 3/4) clay; weak fine subangular blocky structure; slightly hard, firm, slightly sticky, slightly plastic; common fine roots; common fine quartz grains; common fine dark minerals; medium acid; clear smooth boundary.

B21—7 to 20 inches, dark reddish brown (2.5YR 3/4) clay; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; common fine pores; common fine quartz grains; medium acid; gradual smooth boundary.

B22—20 to 32 inches, red (2.5YR 4/6) clay; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; common fine quartz grains; slightly acid; gradual smooth boundary.

B23—32 to 40 inches, red (2.5YR 4/8) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; common fine quartz grains; few fine pores; slightly acid; gradual smooth boundary.

B3—40 to 53 inches, red (2.5YR 4/6) clay; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; common quartz grains; neutral; abrupt smooth boundary.

R—53 inches, limestone rock.

The solum thickness and depth to hard limestone is 40 to 60 inches. Reaction throughout ranges from medium acid to neutral.

The A horizon has hue of 5YR or 2.5YR, value of 2 or 3, and chroma of 2 to 4.

The B2 horizons have hue of 2.5YR, value of 3 or 4, and chroma of 3 to 8.

Montegrande series

The Montegrande series consists of fine, mixed, isohyperthermic Vertic Eutropepts. These soils are deep, are moderately well drained, and have B2 horizons of dark brown and grayish brown clay. They formed in fine textured sediments derived from volcanic rocks. The Montegrande soils are on foot slopes and alluvial fans. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Montegrande soils are associated with the Mabi, Rio Arriba, and Mucara soils. They have a thicker solum than the Mucara soils and are similar to the Mabi soils except for having very gravelly clay C horizons. They have a thinner solum and yellower color than the Rio Arriba soils.

Typical pedon of Montegrande clay, 2 to 5 percent slopes, 200 yards north from kilometer 5.65 of Highway 30, Gurabo Experiment Station, Gurabo, P.R.

Ap—0 to 7 inches, very dark grayish brown (10YR 3/2) clay; common fine faint reddish brown (5YR 4/4) mottles; weak fine granular structure; very hard, firm, slightly sticky, plastic; common fine black mineral grains; few fine rock fragments; common fine roots; strongly acid; clear smooth boundary.

B21—7 to 12 inches, dark brown (10YR 3/3) clay; mottles are common fine distinct yellowish brown (10YR 5/6), few fine faint gray (10YR 5/1), and common fine distinct greenish gray (5GY 5/1); weak medium angular blocky structure with few pressure faces; firm, slightly sticky, plastic; common fine black mineral grains; common fine roots; few fine rock fragments; slightly acid; clear wavy boundary.

B22—12 to 21 inches, grayish brown (10YR 5/2) clay; common medium distinct greenish gray (5GY 5/1) and common fine faint gray (10YR 5/1) mottles; weak coarse angular blocky structure with common pressure faces and slickensides; firm, slightly sticky, plastic; few fine black mineral grains; common fine roots; few fine rock fragments; slightly acid; gradual wavy boundary.

C1—21 to 29 inches, mixed dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/6) clay; weak medium and coarse angular blocky structure with common pressure faces and slickensides; firm, slightly sticky, plastic; few fine black mineral grains; few fine roots; neutral; clear wavy boundary.

IIC2—29 to 39 inches, brown (10YR 5/3) when rubbed very gravelly clay; massive with common pressure faces; firm, sticky, plastic; few fine black mineral grains; many sand size volcanic grains; about 55 percent of horizon is weathered and partially weathered volcanic rock fragments of mixed colors; neutral; gradual wavy boundary.

IIC3—39 to 48 inches, yellowish brown (10YR 5/4) when rubbed very gravelly clay; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; about 55 percent of horizon is weathered and partially weathered volcanic rock fragments of mixed colors; neutral; gradual wavy boundary.

The solum is 20 to 36 inches thick. Reaction throughout ranges from strongly acid in the A horizon to neutral in the lower horizons.

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 2 or 3.

The B2 horizon has hue of 7.5YR and 10YR, value of 3 to 5, and chroma of 2 to 4. It has weak medium to coarse angular to subangular blocky structure.

The C horizons are clay and very gravelly clay.

Morado series

The Morado series consists of fine-loamy, mixed, isohyperthermic Typic Eutropepts. These soils are moderately deep, are well drained, and have a mottled, reddish gray clay loam B2 horizon. They formed in residuum of volcanic rocks. The Morado soils are on side slopes, foot slopes, and hilltops of strongly dissected humid uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 76 degrees F.

The Morado soils are associated with the Mucara and Gaguabo series. They occupy similar positions in the landscape, but are deeper than the Caguabo soils. They have a thicker solum than the Mucara soils.

Typical pedon of Morado clay loam, 40 to 60 percent, eroded, 25 meters east from kilometer 2.9 of Highway 615, then 15 feet north.

Ap—0 to 8 inches, weak red (10R 4/2) clay loam; weak fine subangular blocky structure; friable, slightly sticky, plastic; common fine roots; neutral; clear smooth boundary.

B2—8 to 19 inches, reddish gray (5YR 5/2) clay loam; few fine faint red (2.5YR 4/6) mottles; weak fine subangular blocky structure; friable, slightly sticky, plastic; common fine roots; neutral; gradual wavy boundary.

B3—19 to 26 inches, variegated strong brown (7.5YR 5/6), dark reddish gray (5YR 4/2), weak red (2.5YR 4/2), and red (2.5YR 4/8) clay loam; massive; friable, slightly sticky, plastic; few fine roots; neutral; clear wavy boundary.

C—26 to 34 inches, variegated gray (5YR 5/1), light gray (7.5YR 7/0), and dark reddish gray (5YR 4/2) clay loam saprolite; massive; friable, slightly sticky, plastic; slightly acid; clear wavy boundary.

R—34 inches, reddish brown semiconsolidated rock.

The solum is 16 to 30 inches thick. Reaction throughout is neutral to slightly acid.

The A horizon has hue of 10R, 2.5YR, and 5YR; value of 4 or 5; and chroma of 1 to 3.

The B horizon has hue of 2.5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 8. It has weak fine subangular blocky structure.

Mucara series

The Mucara series consists of clayey, montmorillonitic, isohyperthermic, shallow Vertic Eutropepts. These soils are moderately deep, are well drained, and have a B horizon of dark brown clay. They formed in residuum of basic volcanic rocks. The Mucara soils are on foot slopes, side slopes, and rounded hilltops of strongly dissected humid uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Mucara soils are associated with the Caguabo, Morado, and Naranjito soils. They are deeper than the Caguabo soils, have a thinner solum than the Morado and Naranjito soils, and are yellower than the Naranjito soils.

Typical pedon of Mucara clay, 40 to 60 percent slopes, 0.6 mile from kilometer 67.2 of Highway 1, then 25 feet northwest along farm road.

Ap—0 to 5 inches, very dark grayish brown (10YR 3/2) clay; weak medium granular structure; firm, slightly sticky, plastic; many fine roots; slightly acid; clear smooth boundary.

B—5 to 12 inches, dark brown (10YR 3/3) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; thin patchy clay films along root channels and on faces of peds; few fine roots; common pressure faces; few fine dark concretions; few fine subrounded rock fragments; slightly acid; abrupt wavy boundary.

C—12 to 30 inches, highly weathered volcanic rocks, neutral.

R—30 inches, semiconsolidated volcanic rocks.

The solum is 10 to 20 inches thick. Reaction throughout is slightly acid to neutral. Depth to semiconsolidated volcanic rock ranges from 20 to 40 inches.

The A horizon has hue of 10YR and 2.5Y, value of 3 to 5, and chroma of 2 or 3.

The B horizon has hue of 7.5YR, 10YR, and 2.5Y; value of 3 to 5; and chroma of 2 to 4.

Naranjito series

The Naranjito series consists of clayey, mixed, isohyperthermic Typic Tropohumults. These soils are moderately deep, are well drained, and have a B horizon of reddish brown and yellowish red clay. They formed in residuum of volcanic rocks. The Naranjito soils occur on side slopes and hilltops of strongly dissected humid uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 76 degrees F.

The Naranjito soils are associated with the Mucara, Caguabo, Sabana, and Consumo soils. They have a thicker solum than the Mucara, Sabana, and Caguabo soils. They are on less weathered volcanic rock than the Consumo soils.

Typical pedon of Naranjito silty clay loam, 20 to 40 percent slopes, eroded, 100 feet east of intersection of Highway 833 with old trail to Fondo del Saco, Bo. Achiote, Naranjito, P.R.

Ap—0 to 4 inches, brown to dark brown (10YR 4/3) silty clay loam; moderate fine granular structure; friable, slightly sticky, slightly plastic; many fine roots; common fine rounded and subrounded rock fragments; very strongly acid; clear smooth boundary.

B2t—4 to 12 inches, reddish brown (5YR 4/4) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; thin patchy clay films; common fine dark concretions; very strongly acid; clear smooth boundary.

B3—12 to 24 inches, yellowish red (5YR 4/6) clay; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; common fine dark concretions; thin patchy clay films; very strongly acid; clear smooth boundary.

C—24 to 40 inches, variegated yellowish red (5YR 4/6), red (2.5YR 4/6), and light yellowish brown (10YR 6/4) clay loam saprolite; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; strongly acid; abrupt smooth boundary.

R—40 inches, consolidated volcanic rock.

The solum is 15 to 30 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 to 5, and chroma of 3 to 4.

The B horizon has hue of 5YR, 10YR, and 2.5YR; value of 4 or 5; and chroma of 3 to 6.

Pandura series

The Pandura series consists of loamy, mixed, isohyperthermic, shallow Typic Eutropepts. These soils are shallow, are well drained, and have a B horizon of dark, yellowish brown sandy loam. They formed in residuum of plutonic rocks. The Pandura soils are on side slopes and hilltops of dissected uplands. Slopes range from 12 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 80 degrees F.

The Pandura soils are associated with the Lirios, Jagueyes, Candelero, and Cayagua soils. They have a thinner solum and are coarser textured than the Lirios and Jagueyes soils. They are better drained, shallower, and coarser textured than the Candelero and Cayagua soils.

Typical pedon of Pandura sandy loam, 20 to 40 percent slopes, 90 feet southwest from kilometer 3.85 of Highway 181, San Lorenzo, P.R.

Ap—0 to 7 inches, dark brown (10YR 4/3) sandy loam; weak fine subangular blocky structure parting to granular; friable, nonsticky, nonplastic; common fine roots; few fine quartz grains; strongly acid; clear smooth boundary.

B—7 to 12 inches, dark yellowish brown (10YR 4/4) sandy loam; weak medium subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; common fine quartz grains; few dark minerals; few krotovinas; strongly acid; clear smooth boundary.

C1—12 to 26 inches, mixed very pale brown (10YR 7/4), pale brown (10YR 6/3), dark yellowish brown (10YR 4/4), and white (10YR 8/2) sandy loam saprolite; massive, but rock structure is evident; few fine roots; silty clay material with a dark grayish brown color (10YR 4/2) is deposited between rock cleavage; medium acid; gradual smooth boundary.

C2—26 inches, weathered granitic rock that can be penetrated with a spade.

The solum is 6 to 14 inches thick. Reaction throughout is medium acid to strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 or 4, and chroma of 3 or 4.

The B horizon has hue of 10YR, value of 4 or 5, and chroma of 4 to 6.

Pellejas series

The Pellejas series consists of fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Typic Dystropepts. These soils are deep, are somewhat excessively drained, and have a B2 horizon of dark yellowish brown clay loam. They formed in residuum of plutonic rocks. The Pellejas soils are on side slopes and narrow ridges of strongly dissected humid uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Pellejas soils are associated with the Mucara, Caguabo, Consumo, and Naranjito soils. They have a thicker solum than the Mucara and Caguabo soils. They have yellower hue and lack the argillic horizons of the Consumo and Naranjito soils.

Typical pedon of Pellejas clay loam, 40 to 60 percent slopes, 200 feet northwest from kilometer 17.0 of Highway 152, Bo. Cedro Abajo, Naranjito, P.R.

Ap—0 to 4 inches, dark brown (10YR 4/3) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine roots; few krotovinas; common quartz grains; few fine pores; subsurface material is mixed with surface horizon; very strongly acid; clear smooth boundary.

B2—4 to 12 inches, yellowish brown (10YR 5/4) clay loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; common fine and medium roots; common quartz grains; few krotovinas that have white mottles from the parent material; few dark minerals; very strongly acid; gradual smooth boundary.

B3—12 to 16 inches, yellowish brown (10YR 5/4) clay loam; weak fine subangular blocky structure; very friable, nonsticky, slightly plastic; few fine roots; some dead roots; few dark minerals; few krotovinas; common quartz grains; about 25 percent of this horizon is saprolite; very strongly acid; gradual smooth boundary.

C1—16 to 42 inches, pale brown (10YR 6/3) and light yellowish brown (10YR 6/4) sandy loam; massive; very friable, nonsticky, nonplastic; this horizon consists mostly of saprolite; strongly acid; gradual smooth boundary.

C2—42 to 60 inches, variegated gray (10YR 6/1), white (10YR 8/1), pinkish gray (5Y 6/2), and dark greenish gray (5GY 4/1), loamy sand saprolite; massive; very friable, loose; strongly acid.

The solum is 11 to 20 inches thick. Reaction throughout ranges from strongly acid to very strongly acid.

The A horizon has hue of 10YR, value of 2 or 4, and chroma of 2 or 3.

The B2 horizon has hue of 10YR, value of 4 to 6, and chroma of 3 or 4.

Reilly series

The Reilly series consists of sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls. These soils are shallow to gravel, are excessively drained, and have a dark brown sandy loam Ap horizon over dark brown gravelly sand and clean sand and gravel C horizons. They formed in sediments of mixed origin. The Reilly soils are on river flood plains adjacent to streams. Slopes range from 0 to 2 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Reilly soils are associated with the Toa, Coloso, Bajura, and Dique soils. They are better drained and are shallower and coarser textured than the Bajura and Coloso soils. They have gravelly subsurface layers that the Dique soils lack. They are coarser textured than the Toa soils.

Typical pedon of Reilly sandy loam, 400 feet northwest of the entrance to the Gurabo Experiment Station, north of Highway 941.

Ap—0 to 7 inches, dark brown (10YR 3/3) sandy loam; very weak fine granular structure; very friable, slightly sticky, nonplastic; many roots; medium acid; gradual smooth boundary.

C1—7 to 18 inches, dark brown (10YR 3/3) gravelly sand; massive; very friable; many roots; medium acid; gradual smooth boundary.

C2—18 to 55 inches, coarse clean sand and gravel; about 60 percent coarse gravel; slightly acid.

The A horizon is 7 to 15 inches thick. Reaction throughout is medium acid to slightly acid.

The A horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

Rio Arriba series

The Rio Arriba series consists of fine, mixed, isohyperthermic Vertic Paleudalfs. These soils are deep, are moderately well drained, and have a B22t horizon of yellowish brown clay. They formed in sediments of mixed origin. The Rio Arriba soils are on alluvial fans and terraces above the river flood plains. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Rio Arriba soils are associated with the Mabi, Montegrande, Mucara, and Caguabo soils. They have a thicker solum than the Mucara and Caguabo soils and are better drained than the Mabi soils. They lack the gravelly clay C horizon of the Montegrande soils.

Typical pedon of Rio Arriba clay, 5 to 12 percent slopes, eroded, 0.4 kilometers west of the town of Gurabo, P.R., then 800 feet east of the western boundary of the Gurabo Experiment Station farm, and 600 feet north of the railroad tracks.

Ap—0 to 8 inches, brown (10YR 4/3) clay; weak coarse granular structure; hard, firm, slightly sticky, plastic; many fine roots; neutral; clear smooth boundary.

B21t—8 to 16 inches, yellowish brown (10YR 5/8) clay; moderate coarse prismatic structure parting to weak medium subangular blocky; yellowish brown (10YR 5/4) thin continuous coatings on vertical ped surfaces, and patchy coatings on horizontal ped surfaces; hard, firm, slightly sticky, plastic; common fine roots; common fine black nodules; medium acid; clear smooth boundary.

B22t—16 to 28 inches, yellowish brown (10YR 5/6) clay; common medium distinct yellowish red (5YR 4/6) mottles; weak coarse angular blocky structure with few slickensides and pressure faces; firm, slightly sticky, plastic; many fine black nodules; few fine roots; neutral; clear wavy boundary.

B23t—28 to 60 inches, reddish yellow (7.5YR 6/6) clay; many medium distinct red (2.5YR 5/6) mottles; weak coarse angular blocky structure; pressure faces with discontinuous clay coatings on ped surfaces; firm, slightly sticky, plastic; many fine black nodules; mildly alkaline.

The solum is more than 60 inches thick. Reaction throughout ranges from medium acid to mildly alkaline.

The A horizon has hue of 10YR and 7.5YR, value of 3 and 4, and chroma of 2 to 4.

The B2t horizon has hue of 10YR, 7.5YR, and 2.5YR; value of 4 to 6; and chroma of 4 to 8.

Rio Piedras series

The Rio Piedras series consists of clayey kaolinitic isohyperthermic Typic Tropohumults. These soils are moderately deep, well drained, and have a B2t horizon of red clay. They formed in residuum of siltstone. The Rio Piedras soils are on side slopes of dissected uplands. Slopes range from 12 to 60 percent, but are dominantly 12 to 20 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Rio Piedras soils are associated with the Yunes soils. They are deeper and have thick argillic horizons which the Yunes soils lack.

Typical pedon of Rio Piedras clay, 12 to 20 percent slopes, eroded, 300 feet southwest from kilometer 1.1 of Guadalcanal road in an orchard at the Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 8 inches, dark brown (7.5YR 4/4) clay; moderate medium granular structure; hard, firm, slightly sticky, slightly plastic; very strongly acid; abrupt smooth boundary.

B2t—8 to 18 inches, red (10R 4/6) clay; few fine distinct yellowish brown (10YR 5/6) mottles; moderate coarse prismatic structure parting to moderate medium subangular blocky; continuous dark reddish brown (2.5YR 3/4) clay films on most peds and in root channels; clay films thicker on vertical ped faces; very hard, very firm, slightly sticky, slightly plastic; few small soft black concretions; common small shale fragments; roots mainly along cleavage planes; very strongly acid; gradual wavy boundary.

B3—18 to 28 inches, red (10R 4/6) clay; common fine and medium distinct red (2.5YR 4/6) and brownish yellow (10YR 6/6) mottles; weak medium subangular blocky structure; patchy reddish brown (5YR 4/4) clay films on peds and in root channels; very hard, very firm, slightly sticky, slightly plastic; many partially weathered shale fragments; original shale structure visible; very strongly acid; gradual wavy boundary.

C1—28 to 34 inches, mixed red (2.5YR 4/6) and brownish yellow (10YR 6/6) clay; common fine distinct light gray (10YR 7/1) and strong brown (7.5YR 5/6) mottles; massive; original structure of shale visible; many small shale fragments easily broken by fingers; very strongly acid; gradual wavy boundary.

C2—34 to 48 inches, bedded partially weathered clay shale that can be penetrated with soil auger; shale has mixed colors with light red (2.5YR 6/8), strong brown (7.5YR 5/8), and pink (7.5YR 7/4) predominating; very strongly acid.

R—48 inches, bedded cemented shale; beds range from 1 to 4 inches thick.

The solum is 20 to 34 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR and 5YR, value of 3 to 5, and chroma of 3 or 4.

The B2t horizon has hue of 5YR, 2.5YR, and 10R; value of 4 or 5; and chroma of 6 to 8.

Sabana series

The Sabana series consists of clayey, mixed, isohyperthermic Lithic Dystropepts. These soils are shallow, are well drained, and have a B2 horizon of dark brown silty clay. They formed in residuum of volcanic rocks. The Sabana soils are on side slopes and narrow ridgetops of humid volcanic uplands. Slopes range from 40 to 60 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 80 degrees F.

The Sabana soils are associated with the Mucara and Caguabo soils. They have a thinner solum than the Mucara soils. They are more acid than the Caguabo soils.

Typical pedon of Sabana silty clay loam, 40 to 60 percent slopes, 500 feet southeast from kilometer 53.5 of Highway 1, Cayey, P.R.

Ap—0 to 3 inches, very dark grayish brown (10YR 3/1) silty clay loam; weak fine granular structure; firm, slightly sticky, slightly plastic; about 5 percent volcanic rock fragments; common fine roots; strongly acid; clear wavy boundary.

B2—3 to 8 inches, dark brown (10YR 4/3) silty clay; moderate fine subangular blocky structure; friable, slightly sticky, slightly plastic; about 5 percent volcanic rock fragments; few fine pores; few fine patchy clay films; few fine roots; strongly acid; clear smooth boundary.

B3—8 to 15 inches, variegated light brownish gray (10YR 6/2) and strong brown (7.5YR 5/6) clay; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic, about 10 percent volcanic rock fragments; few fine roots; few fine patchy clay films; strongly acid; abrupt wavy boundary.

R—15 inches, semiconsolidated volcanic rock.

The solum thickness and depth to the rock is 10 to 20 inches. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3 or 4, and chroma of 1 to 3.

The B2 horizon has hue of 10YR, 7.5YR, and 5YR; value of 4 to 6; and chroma of 3 to 8.

Sabana Seca series

The Sabana Seca series consists of clayey, mixed, isohyperthermic Oxic Plinthaquults. These soils are deep, are poorly drained, and have a B22g horizon of light gray clay. They formed in sediments of mixed origin. The Sabana Seca series are on humid coastal plains. Slopes range from 2 to 8 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Sabana Seca soils are associated with the Almirante and Bajura soils. They have more plinthite than the Almirante soils and are poorly drained. They occupy higher positions and have thicker B horizons than the Bajura soils.

Typical pedon of Sabana Seca clay, 2 to 8 percent slopes, 400 meters east from kilometer 8.5 of Highway 866, Toa Baja, P.R.

Ap—0 to 10 inches, very dark grayish brown (10YR 3/2) clay; weak fine subangular blocky structure parting to weak fine granular; firm, slightly sticky, plastic; many fine roots; extremely acid; abrupt smooth boundary.

B1—10 to 13 inches, dark grayish brown (2.5Y 4/2) clay; many medium and coarse prominent yellowish brown (10YR 5/6) mottles; moderate fine subangular and angular blocky structure; firm, slightly sticky, plastic; common fine roots; thin patchy clay films on ped faces; dark gray (10YR 4/1) coloration on old root channels and in cracks; extremely acid; clear wavy boundary.

B21tg—13 to 28 inches, light gray (5Y 6/1) clay; many coarse prominent yellowish brown (10YR 5/6) and few fine prominent red (10R 4/6) mottles; very weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, plastic; common fine roots; thin patchy clay films on ped faces; dark gray (10YR 4/1) coloration on old root channels and on ped faces; extremely acid; gradual smooth boundary.

B22tg—23 to 36 inches, light gray (5Y 6/1) and (5Y 7/1) clay; many fine to coarse strong brown (7.5YR 5/6) and common medium and coarse prominent dark red (10R 3/6) mottles, and a few specks of red (2.5YR 4/6); very weak coarse prismatic structure parting to moderate medium subangular and angular blocky; firm, slightly sticky, plastic; few fine roots; common fine concretions; thin patchy clay films on ped faces; extremely acid; gradual smooth boundary.

B23tg—36 to 48 inches, white (5Y 8/1) and (5Y 8/2) clay; many fine, medium, and coarse prominent dusky red (10R 3/4) and strong brown (7.5YR 5/6) mottles and concretions; weak coarse prismatic structure parting to weak medium subangular and angular blocky; firm, slightly sticky, plastic; thin patchy clay films on vertical and horizontal ped faces; extremely acid; clear smooth boundary.

B24tg—48 to 56 inches, white (5Y 8/1) clay; many coarse prominent dusky red (10R 3/4) and common fine to coarse prominent strong brown (7.5YR 5/8) mottles and concretions; weak coarse prismatic structure; firm, slightly sticky, plastic; thin patchy clay films on vertical ped faces; extremely acid; clear smooth boundary.

B25g—56 to 70 inches, white (5Y 8/1) clay; many coarse prominent dusky red (10R 3/4) and dark red (10R 3/6), and few fine prominent red (10R 4/8) and strong brown (7.5YR 5/8) mottles and concretions; weak coarse prismatic structure; firm, slightly sticky, plastic; very few patchy clay films on vertical faces; extremely acid.

The solum is more than 60 inches thick. Reaction throughout is very strongly acid to extremely acid.

The A horizon has hue of 10YR and 2.5Y, value of 2 or 3, and chroma of 1 to 3.

The B2tg horizon has hue of 2.5Y and 5Y, value of 6 to 8, and chroma of 2 or less.

Saladar series

The Saladar series consists of euic, isohyperthermic Fluvaquentic Troposaprists. These soils are deep, are poorly drained, and have thick black muck O horizons. They formed in highly decomposed organic materials. The Saladar soils are in closed depressions and coastal marshes with restricted outlets. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Saladar soils are associated with the Martin Pena and Bajura soils. They lack mineral horizons and are slightly lower than the Martin Pena and Bajura soils.

Typical pedon of Saladar muck, 530 feet west of the corner of Dr. Joaquin Bosch Street and Dr. Colly Toste Street, Levittown Urbanization, Catano, P.R.

Oa1—0 to 10 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 30 percent fiber, about 10 percent when rubbed; weak fine granular structure; nonsticky; mildly alkaline; gradual smooth boundary.

Oa2—10 to 35 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 25 percent fiber, about 10 percent when rubbed; weak medium granular structure; nonsticky; neutral; gradual smooth boundary.

Oa3—35 to 51 inches, black (10YR 2/1) muck; black (10YR 2/1) when rubbed and pressed; about 25 percent fiber, 10 percent when rubbed; massive; nonsticky; neutral.

The organic portion of the control section has colors in hue of 10YR, value of 2, and chroma of 0 or 1. Reaction throughout ranges from mildly alkaline to neutral.

Soller series

The Soller series consists of clayey, mixed, isohyperthermic, shallow Eutropeptic Rendolls. These soils are shallow, are well drained, and have a B horizon of dark brown clay. They formed in residuum of limestone. The Soller soils are on side slopes and hilltops of low rounded hills. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 90 inches, and the mean annual temperature is 75 degrees F.

The Soller soils are associated with the Colinas and the Tanama soils. They have a thinner solum than the Colinas soils and are underlain by hard limestone. They are yellower and not as acid as the Tanama soils.

Typical pedon of Soller clay loam, 40 to 60 percent slopes, 400 feet south of Riverside Urbanization, then 250 feet southwest of water pump, Bayamon, P.R.

A1—0 to 5 inches, very dark grayish brown (10YR 3/2) clay loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; common fine roots; few quartz grains; common limestone rock fragments; mildly alkaline; clear smooth boundary.

B—5 to 12 inches, dark brown (10YR 3/3) clay; moderate coarse subangular blocky structure; firm, slightly sticky, plastic; common limestone rock fragments; common fine roots; moderately alkaline; gradual smooth boundary.

C—12 to 24 inches, yellow (10YR 7/6) weathered limestone; massive; friable, slightly sticky, slightly plastic; strongly alkaline; gradual smooth boundary.

R—24 inches, hard fragmental limestone.

The solum is 10 to 20 inches thick. Reaction throughout ranges from neutral to moderately alkaline.

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 1 or 2.

The B horizon has hue of 10YR, value of 3 or 4, and chroma of 2 to 4. It has weak to moderate medium to coarse subangular blocky structure.

Tanama series

The Tanama series consists of clayey, mixed, isohyperthermic, Lithic Tropudalfs. These soils are shallow, are well drained, and have a B2t horizon of reddish brown clay. They formed in residuum of limestone. The Tanama soils are on side slopes and foot slopes of limestone hills. Slopes range from 20 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Tanama soils are associated with the Juncal and Soller soils. They have a thinner solum and are shallower than the Juncal soils. They are redder and more acid than the Soller soils.

Typical pedon of Tanama clay in an area of Tanama-Rock outcrop complex, 20 to 60 percent slopes, 0.8 mile southwest from kilometer 0.95 of Highway 659, Bo. Santa Rosa, Dorado, P.R.

A1—0 to 4 inches, dark reddish brown (5YR 3/2) clay; weak fine subangular blocky structure; friable, slightly sticky, plastic; many fine roots; common fine and medium limestone fragments; few quartz grains; neutral; clear smooth boundary.

B2t—4 to 14 inches, reddish brown (5YR 4/4) clay; moderate medium subangular blocky structure; firm, slightly sticky, plastic; common fine and medium roots; thin patchy clay films; common fine and medium limestone fragments; mildly alkaline; abrupt wavy boundary.

R—14 inches, hard semiconsolidated limestone.

The solum thickness and depth to rock is 12 to 20 inches. Reaction throughout ranges from slightly acid to mildly alkaline.

The A horizon has hue of 7.5YR and 5YR, value of 3 or 4, and chroma of 2 to 4.

The B2t horizon has hue of 5YR and 2.5YR, value of 4 or 5, and chroma of 4 to 8.

Toa series

The Toa series consists of fine, mixed, isohyperthermic Fluventic Hapludolls. These soils are deep, are moderately well drained to well drained, and have a B horizon of dark brown silty clay loam. They formed in sediments of mixed origin. The Toa soils are on river flood plains in the humid portion of the island. Slopes range from 0 to 2 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Toa soils are associated with the Dique, Reilly, Coloso, and Bajura soils. They are better drained and coarser textured than the Bajura and Coloso soils. They are finer textured and have slower permeability than the Dique and Reilly soils.

Typical pedon of Toa silty clay loam, 250 feet southwest along fence next to old bridge and 100 feet southeast, which is west of the entrance to the Rio Piedras Experiment Station.

Ap—0 to 8 inches, dark brown (10YR 3/3) silty clay loam; moderate medium granular structure; slightly hard, friable, nonsticky, slightly plastic; many roots; slightly acid; clear smooth boundary.

B—8 to 16 inches, dark brown (10YR 3/3) silty clay loam; few fine faint pale brown (10YR 6/3) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many roots; slightly acid; gradual smooth boundary.

C1—16 to 56 inches, brown (10YR 5/3) silty clay loam, dark brown (10YR 4/3) when crushed; many fine distinct dark reddish brown (5YR 3/4) and few fine faint light gray mottles; weak medium and coarse subangular blocky structure; ped surfaces and root channels have a grayish brown (2.5YR 5/2) coating at lower depths; slightly hard, friable, slightly sticky, slightly plastic; common roots; common black concretions; thin lenses of sand; slightly acid; gradual smooth boundary.

C2—56 to 60 inches, dark brown (7.5YR 4/4) silty clay loam; many fine distinct gray and brown mottles; massive; friable, nonsticky, slightly plastic; common fine sand grains; slightly acid.

The mollic epipedon is 12 to 20 inches thick. Reaction throughout is slightly acid to neutral.

The A horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

The B horizon has hue of 10YR, value of 3, and chroma of 2 or 3.

Torres series

The Torres series consists of clayey, oxidic, isohyperthermic Plinthic Palehumults. These soils are deep, are excessively drained, and have a B2t horizon of yellowish brown clay. They formed in sediments of mixed origin. The Torres soils are on coastal plains and in trapped valleys between the haystack hills. Slopes range from 2 to 5 percent. The mean annual precipitation is 80 inches, and the mean annual temperature is 78 degrees F.

The Torres soils are associated with the Almirante, Bayamon, and Matanzas soils. They have a loamy sand A horizon that the Almirante, Bayamon, and Matanzas soils lack. They also lack the uniform red profiles of the Bayamon and Matanzas soils.

Typical pedon of Torres loamy sand, 2 to 5 percent slopes, 0.15 mile along a dirt road south from kilometer 25.5 of Highway 2, then 60 feet west of dirt road.

Ap—0 to 10 inches, very dark grayish brown (10YR 3/2) loamy sand; single grain; loose, nonsticky, nonplastic; common fine roots; few fine black concretions; strongly acid; gradual smooth boundary.

A11—10 to 21 inches, dark brown (10YR 3/3) loamy sand; weak coarse subangular blocky structure; very friable, nonsticky, nonplastic; few fine roots; few fine black concretions; strongly acid; gradual smooth boundary.

A12—21 to 28 inches, dark brown (10YR 3/3) sandy loam; weak coarse subangular blocky structure; very friable, nonsticky, nonplastic; common fine black concretions; strongly acid; abrupt smooth boundary.

B21t—28 to 36 inches, yellowish brown (10YR 5/8) clay; few fine prominent red (10R 4/8) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin clay films on ped faces; few sand sized quartz grains; strongly acid; gradual smooth boundary.

B22t—36 to 43 inches, yellowish brown (10YR 5/8) clay; common medium prominent red (10R 4/6) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin clay films on ped faces; few sand sized quartz grains; strongly acid; gradual smooth boundary.

B23t—43 to 64 inches, yellowish brown (10YR 5/8) clay; common medium prominent dark red (10R 3/6) and few medium prominent light gray (5Y 7/1) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; thin continuous clay films on ped faces; few fine quartz grains; strongly acid.

The solum is more than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR and 7.5YR, value of 3, and chroma of 2 to 4.

The B2t horizon has hue of 7.5YR and 10YR, value of 4 to 6, and chroma of 6 to 8.

Vega Alta series

The Vega Alta series consists of clayey, mixed, isohyperthermic Plinthic Tropudults. These soils are deep, are well drained, and have a B22t horizon of red and brownish yellow clay that contains plinthite. They formed in sediments of mixed origin. The Vega Alta soils are on coastal plains and terraces. Slopes range from 2 to 12 percent, but are dominantly 5 to 12 percent. The mean annual precipitation is 76 inches, and the mean annual temperature is 77 degrees F.

The Vega Alta soils are associated with the Almirante, Vega Baja, Bajura, and Coloso soils. They are on higher geomorphic positions and are better drained than the Bajura, Coloso, and Vega Baja soils. They have a thinner solum and are shallower to plinthite than the Almirante soils.

Typical pedon of Vega Alta clay loam, 2 to 5 percent slopes, 150 feet north of radio station, 50 feet south of trail east of Rum Pilot Plant; section of experimental farm north of Highway 1 to Caguas, Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 8 inches, dark yellowish brown (10YR 3/4) clay loam; moderate fine granular structure; friable, slightly sticky, slightly plastic; many fine black concretions; common fine roots; strongly acid; abrupt wavy boundary.

B1—8 to 14 inches, reddish yellow (7.5YR 6/8) and yellowish red (5YR 4/6) clay; weak medium and coarse subangular blocky structure parting to moderate fine granular structure; firm, slightly sticky, slightly plastic; thin patchy clay films on ped faces and in root channels; many fine black concretions; few fine roots; strongly acid; clear wavy boundary.

B21t—14 to 25 inches, red (2.5YR 4/8) and strong brown (7.5YR 5/8) clay; moderate medium and coarse subangular blocky structure parting to weak medium angular blocky; firm, slightly sticky, slightly plastic; thick patchy clay films on ped faces; few fine black concretions; few fine roots; strongly acid; gradual wavy boundary.

B22t—25 to 36 inches, red (2.5YR 4/8) and brownish yellow (10YR 6/8) clay; weak medium and coarse subangular blocky structure; firm, nonsticky, slightly plastic; brownish yellow clay films in root channels; nodules of plinthite; few fine quartz grains; very strongly acid; gradual wavy boundary.

B23t—36 to 52 inches, dark red (10R 3/6), strong brown (7.5YR 5/8), and light gray (5Y 7/1) clay; weak coarse subangular blocky structure; friable, nonsticky, slightly plastic; thin patchy clay films; lenses of plinthite; very strongly acid; gradual wavy boundary.

BC—52 to 84 inches, dark red (10R 3/6), brownish yellow (10YR 6/8), and light gray (5Y 7/1) clay; massive; friable, nonsticky, slightly plastic; very strongly acid.

The solum is less than 60 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 7.5YR and 10YR, value of 3 or 4, and chroma of 2 or 3.

The B2t horizon has hue of 10R, 2.5YR, 7.5YR, and 10YR; value of 3 to 6; and chroma of 6 to 8.

Vega Baja series

The Vega Baja series consists of fine, mixed, isohyperthermic Aeric Tropaqualfs. These soils are deep, are poorly drained, and have a B22t horizon of strong brown and gray silty clay. They formed in sediments of mixed origin. The Vega Baja soils are on coastal plains and alluvial fans. Slopes range from 0 to 2 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 80 degrees F.

The Vega Baja soils are associated with the Coloso, Bajura, Toa, and Vega Alta soils. They are at slightly higher elevations above the flood plain than the Bajura and Coloso soils and are underlain by mottled coastal plains clays. They are more poorly drained than the Vega Alta and Toa soils. They lack the plinthite layers of the Vega Alta soils.

Typical pedon of Vega Baja silty clay, 200 feet north on road to Food Technology Laboratory and 200 feet to the right of the road (section of farm north of Highway 1 to Caguas, P.R.), Rio Piedras Experiment Station, Rio Piedras, P.R.

Ap—0 to 7 inches, dark brown (10YR 4/3) silty clay; weak fine granular structure; firm, slightly sticky, slightly plastic; few fine black concretions; many fine roots; very strongly acid; gradual wavy boundary.

A12—7 to 12 inches, mixed dark grayish brown (10YR 4/2) and yellowish brown (10YR 5/8) silty clay; weak coarse subangular blocky structure; firm, sticky, plastic; few fine black concretions; many fine roots; strongly acid; abrupt wavy boundary.

B21t—12 to 17 inches, dark grayish brown (10YR 4/2) and yellowish brown (10YR 5/8) silty clay; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few fine black concretions; black coatings on ped faces and in root channels; few fine roots; very strongly acid; abrupt wavy boundary.

B22t—17 to 32 inches, mixed strong brown (7.5YR 5/8) and gray (5Y 6/1) clay; weak medium subangular blocky structure; firm, slightly sticky, plastic; seams between peds and root channels filled with gray clay; few fine black concretions; very strongly acid; gradual wavy boundary.

B3—32 to 50 inches, brownish yellow (10YR 6/8) and gray (N 7/0) silty clay loam with pockets of yellowish brown (10YR 5/4) clay loam; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few peds and fracture planes coated with black; root channels and worm burrows filled with gray clay; strongly acid; abrupt wavy boundary.

C1—50 to 55 inches, light gray (N 7/0) silty clay; many fine distinct strong brown (7.5YR 5/8) mottles; massive; firm, sticky, plastic; medium acid; abrupt wavy boundary.

C2—55 to 60 inches, light gray (N 7/0) and strong brown (7.5YR 5/8) silty clay; massive; firm, sticky, plastic; medium acid.

The solum is 30 to 60 inches thick. Reaction throughout is medium acid to very strongly acid, and acidity decreases with depth.

The Ap horizon has hue of 7.5YR or 10YR, value of 3 or 4, and chroma of 3 or 4.

The B2t horizon has matrix colors in hue of 7.5YR to 2.5Y, value of 4 to 6, and chroma of 1 to 8.

Via series

The Via series consists of fine-loamy, mixed, isohyperthermic Typic Tropudalfs. These soils are deep, are well drained, and have a B22t horizon of yellowish brown clay loam. They formed in sediments of mixed origin. The Via soils are on high bottom terraces. Slopes range from 5 to 12 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is 78 degrees F.

The Via soils are associated with the Rio Arriba, Mabi, and Mucara soils. They occupy similar terrace positions to the Rio Arriba soils, but are coarser textured and lack their Vertic properties. They are coarser textured and better drained than the Mabi soils and do not have their expansive clays. They are deeper than the Mucara soils and are not underlain by volcanic rocks.

Typical pedon of Via clay loam, 5 to 12 percent slopes, eroded, 0.6 mile northwest of kilometer 32.8 from Highway 1 along farm road, then 600 feet north to a pangolagrass field, Bo. Bairoa, Caguas, P.R.

Ap—0 to 9 inches, dark brown (10YR 4/3) clay loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; common fine roots; common fine pores; about 5 percent rock fragments and rounded pebbles; few coated quartz grains; few fine black concretions; strongly acid; abrupt smooth boundary.

B21t—9 to 17 inches, strong brown (7.5YR 5/8) clay loam; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; about 10 percent rock fragments and rounded pebbles; thin patchy clay films on vertical ped faces; common dark minerals; medium acid; clear smooth boundary.

B22t—17 to 26 inches, yellowish brown (10YR 5/6) clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 10 percent weathered rock fragments; few fine dark minerals; few fine pebbles; thin patchy clay films; medium acid; clear smooth boundary.

B23t—26 to 36 inches, strong brown (7.5YR 5/8) clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 10 percent weathered rock fragments; few fine dark minerals; few fine rounded pebbles; medium acid; clear smooth boundary.

IIC—36 to 60 inches, strong brown (7.5YR 5/8) very gravelly clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; about 60 percent weathered and unweathered rock fragments; many dark minerals; medium acid.

The solum is 30 to 60 inches thick. Reaction throughout ranges from medium acid to strongly acid.

The A horizon has hue of 10YR to 5YR, value of 4 or 5, and chroma of 2 to 4.

The B2t horizon has hue of 10YR and 7.5YR, value of 4 to 6, and chroma of 4 to 8.

Vivi series

The Vivi series consists of coarse-loamy, mixed, isohyperthermic Fluventic Eutropepts. These soils are deep, are well drained, and have a B horizon of dark yellowish brown loam. They formed in sediments derived from plutonic rocks. The Vivi soils are on river flood plains. Slopes range from 0 to 2 percent. The mean annual precipitation is 85 inches, and the mean annual temperature is 80 degrees F.

The Vivi soils are associated with the Pandura soils. They have a thicker solum and are not underlain by plutonic rocks as the Pandura soils are.

Typical pedon of Vivi loam, 90 feet east from kilometer 2.1 from highway 745, Bo. Espino, San Lorenzo, P.R.

Ap—0 to 9 inches, dark brown (10YR 3/3) loam; weak fine granular structure; very friable, nonsticky, nonplastic; common fine roots; few fine black minerals; fine quartz grains; few fine black concretions; strongly acid; clear smooth boundary.

B—9 to 22 inches, dark yellowish brown (10YR 3/4) loam; weak fine subangular blocky structure; friable, nonsticky, slightly plastic; few fine black minerals; common fine quartz grains; strongly acid; clear smooth boundary.

C1—22 to 34 inches, dark yellowish brown (10YR 4/4) loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; few fine black minerals; common fine quartz grains; very strongly acid; clear smooth boundary.

C2—34 to 47 inches, yellowish brown (10YR 5/4) very fine sandy loam; massive; very friable, nonsticky, nonplastic; few fine black minerals; common fine quartz grains; very strongly acid; clear smooth boundary.

C3—47 to 58 inches, yellowish brown (10YR 5/4) loamy sand; massive; very friable, nonsticky, nonplastic; many fine black minerals; very strongly acid.

The solum is 10 to 22 inches thick. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 10YR to 2.5Y, value of 2 and 3, and chroma of 2 and 3.

The B horizon has hue of 10YR and 2.5Y, value of 3 to 6, and chroma of 2 to 4.

The C horizons are stratified loam, sandy loam, very fine sandy loam, and loamy sand.

Yunes series

The Yunes series consists of loamy-skeletal, mixed, isohyperthermic, shallow Typic Dystropepts. These soils are shallow, are well drained, and have B horizons of dark brown and brown very shaly silty clay loam. They formed in residuum of thin bedded shale. The Yunes soils are on side slopes and tops of strongly dissected uplands. Slopes range from 20 to 60 percent, but are dominantly 40 to 60 percent. The mean annual precipitation is 75 inches, and the mean annual temperature is about 80 degrees F.

The Yunes soils are associated with the Rio Piedras soils. They have a thinner solum and lack the well developed argillic horizons of the Rio Piedras soils.

Typical pedon of Yunes silty clay loam, 20 to 40 percent slopes, 50 feet south of kilometer 2.3 from highway 847, Rio Piedras Experiment station, Rio Piedras, P.R.

A1—0 to 2 inches, dark reddish brown (5YR 3/2) silty clay loam, reddish gray (5YR 5/2) when dry; moderate medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; about 10 percent fine shale fragments; strongly acid; abrupt smooth boundary.

B2—2 to 11 inches, dark brown (7.5YR 3/2) very shaly silty clay loam; weak medium subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; about 60 percent shale fragments; strongly acid; abrupt smooth boundary.

B3—11 to 16 inches, brown (7.5YR 4/4) very shaly silty clay loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; about 80 percent shale fragments; strongly acid; abrupt smooth boundary.

R—16 inches, mixed light red (2.5YR 6/8), strong brown (7.5YR 5/8), and pink (7.5YR 7/4) bedded fragmental shale with thickness of beds from 1 to 4 inches; when moist, shale can be penetrated with difficulty by a spade.

The solum thickness and depth to rock is 10 to 20 inches. Reaction throughout is strongly acid to very strongly acid.

The A horizon has hue of 5YR or 7.5YR, value of 3 to 5, and chroma of 2 or 3.

The B horizon has hue of 2.5YR to 7.5YR, value of 3 to 6, and chroma of 3 to 6. It has weak medium to coarse subangular blocky structure. Shale fragments in the B horizons range from 50 to 80 percent.

Classification

The system of soil classification currently used was adopted by the National Cooperative Soil Survey in 1965. Readers interested in further details about the system should refer to "Soil taxonomy" (*4*).

The system of classification has six categories. Beginning with the broadest, these categories are the order, suborder, great group, subgroup, family, and series. In this system the classification is based on the different soil properties that can be observed in the field or those that can be inferred either from other properties that are observable in the field or from the combined data of soil science and other disciplines. The properties selected for the higher categories are the result of soil genesis or of factors that affect soil genesis. In table 16, the soils of the survey area are classified according to the system. Categories of the system are discussed in the following paragraphs.

ORDER. Ten soil orders are recognized as classes in the system. The properties used to differentiate among orders are those that reflect the kind and degree of dominant soil-forming processes that have taken place. Each order is identified by a word ending in *sol.* An example is Ultisol.

SUBORDER. Each order is divided into suborders based primarily on properties that influence soil genesis and are important to plant growth or that are selected to reflect the most important variables within the orders. The last syllable in the name of a suborder indicates the order. An example is Humult (*Hum*, meaning humus, plus *ult*, from Ultisol).

GREAT GROUP. Each suborder is divided into great groups on the basis of close similarities in kind, arrangement, and degree of expression of pedogenic horizons; soil moisture and temperature regimes; and base status. Each great group is identified by the name of a suborder and a prefix that suggests something about the properties of the soil. An example is Tropohumults (*Tropo*, meaning tropical, plus *humults*, the suborder of Ultisols that have high humus content).

SUBGROUP. Each great group may be divided into three subgroups: the central (typic) concept of the great groups, which is not necessarily the most extensive subgroup; the intergrades, or transitional forms to other orders, suborders, or great groups; and the extragrades, which have some properties that are representative of the great groups but do not indicate transitions to any other known kind of soil. Each subgroup is identified by one or more adjectives preceding the name of the great group. The adjective *Typic* identifies the subgroup that is thought to typify the great group. An example is Typic Tropohumults.

FAMILY. Families are established within a subgroup on the basis of similar physical and chemical properties that affect management. Among the properties considered in horizons of major biological activity below plow depth are particle-size distribution, mineral content, temperature regime, thickness of the soil penetrable by roots, consistence, moisture equivalent, soil slope, and permanent cracks. A family name consists of the name of a subgroup and a series of adjectives. The adjectives are the class names for the soil properties used as family differentiae. An example is clayey, kaolinitic, isohyperthermic Typic Tropohumults.

SERIES. The series consists of soils that formed in a particular kind of material and have horizons that, except for texture of the surface soil or of the underlying substratum, are similar in differentiating characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineral and chemical composition.

Formation of the soils

This section describes the five major factors of soil formation and tells how these factors have affected the soils of the San Juan Area.

Factors of soil formation

Soils are formed by the action of soils forming processes on material deposited or accumulated by geologic forces. The characteristics of the soil at any given point are determined by 1) the physical and mineralogical composition of the parent material; 2) the climate under which the material has accumulated and has existed since accumulation; 3) the plant and animal life on and in the soil; 4) the relief, or lay of the land; and 5) the length of time the forces of soil formation have acted on the soil material.

Climate and plant and animal life are active factors of soil genesis. They act on the parent material that has accumulated through the weathering of rocks and slowly change it to a natural body that has genetically related horizons. The effects of the climate and plant and animal life are conditioned by relief. The parent material also affects the kind of profile that can be formed and, in extreme cases, determines it almost entirely. Finally, time is needed for the changing of the parent material into a mature soil. The amount of time can be short or long, but some time is always required for soil horizons to develop.

The factors of soil formation are so closely interrelated in their effects on the soil that few generalizations can be made about the effect of any one unless conditions are specified for the other four.

Parent material

Parent material is the unconsolidated mass from which the soil forms. It largely determines the chemical and mineralogical composition of the soil. To a large extent, the minerals in the parent material determine the kinds and amounts of clay in the soil. Many of the soils in the San Juan Area formed in place material derived from plutonic rocks, mainly granodiorite and quartz diorite, and from extrusive volcanic rocks such as lava, tuff, breccia, and dune deposits, swamp and marsh deposits, and blanket pre-weathered deposits.

Climate

A soil forms rapidly in the San Juan Area because of the warm tropical climate. This warm climate is favorable throughout the year for rapid chemical and physical reactions, for the decomposition of organic material from plants and animals, and for other soil-forming processes.

The variations in temperature are relatively small within the area, but rainfall varies from place to place and this accounts for some differences in the soils.

Temperature and rainfall govern the rate of weathering of the rocks and the decomposition of minerals. They also influence leaching, eluviation, and illuviation. For example, soils in areas of lower rainfall are not so leached as soils in other parts of the area that originated from the same parent material, but have lost bases and nutrients because of the amount of rainfall.

For more specific information about climate of the San Juan Area, refer to the climate section.

Plants and animals

Plants, animals, fungi, and bacteria are important to soil formation. The changes they bring about depend mainly on the kinds of life processes peculiar to each.

Originally, the San Juan Area was covered by fairly dense tropical forest. A large part was cleared for cultivation. When it was later left idle, low brush and native pasture became dominant. Most of the original native vegetation has been destroyed or seriously disturbed, but its effect on soil formation is visible.

The vegetation is generally responsible for the amount of organic matter in the soil, the color of the surface layer, and the amount of nutrients. Growing plants provide a cover that helps to reduce erosion and stabilize the surface so that the soil-forming processes can continue. Leaves, twigs, and entire plants accumulate on the surface of forest soils and then decompose as a result of percolating water and of microorganisms, earthworms, and other forms of animal life acting on the soil. The roots of plants widen cracks on the rocks and thus permit more water to enter the soil. Also, the uprooting of trees influences soil formation by mixing the soil layers and loosening the underlying material.

Earthworms, ants, and many other burrowing animals are extremely active in the San Juan Area and help to keep the soil open and porous. They mix the layers of the soil, mix organic matter into the soil, and help break down the remains of plants. Earthworms and other small invertebrates feed on organic matter in the upper few inches of the soil. They slowly but continually mix the soil material and in places alter it chemically.

Bacteria, fungi, and other microorganisms hasten the weathering of rock minerals and the decay of organic matter.

Relief

The shape of the land surface, the slope, and the depth of the water table have had great influence on the formation of the soils in the survey area. Strongly sloping to steep soils, where runoff is moderate to rapid, generally are well drained, have bright colored, unmottled subsoil and are leached to a greater depth than wet soils in the same general area. About 73 percent of the soils of the San Juan Area are steep to very steep.

In level areas or slight depressions, where the water table is at or near the surface for long periods of time, the soils show marked evidence of wetness, as is the case of the Bajura and Martin Pena soils.

Time

In the formation of soils, time is needed for changes to take place in the parent material, and this is usually a long time when measured in years.

The soils of the San Juan Area range from those that show little or no development to older soils that show pronounced development.

Vivi and Dique soils are examples of young soils that formed from sediment that washed from the hills and was deposited on river flood plains. Bayamon, Matanzas, and Vega Alta are three of the older soils of the stable coastal plains, where the parent material has weathered in place for a long time.

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Glossary

ABC soil. A soil having an A, a B, and a C horizon.

AC soil. A soil having only an A and a C horizon. Commonly such soil formed in recent alluvium or on steep rocky slopes.

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.

Alluvial fan. A fan-shaped deposit of sand, gravel, and fine material dropped by a stream where its gradient lessens abruptly.

Alluvium. Material, such as sand, silt, or clay, deposited on land by streams.

Area reclaim. An area difficult to reclaim after the removal of soil for construction and other uses. Revegetation and erosion control are extremely difficult.

Association, soil. A group of soils geographically associated in a characteristic repeating pattern and defined and delineated as a single mapping unit.

Available water capacity (available moisture capacity). The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field moisture capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. The capacity, in inches, in a 60-inch profile or to a limiting layer is expressed as—

	Inches
Very low	0 to 3
Low	3 to 6
Moderate	6 to 9
High	More than 9

Badland. Steep or very steep, commonly nonstony barren land dissected by many intermittent drainage channels. Badland is most common in semiarid and arid regions where streams are entrenched in soft geologic material. Local relief generally ranges from 25 to 500 feet. Runoff potential is very high, and geologic erosion is active.

Base saturation. The degree to which material having base exchange properties is saturated with exchangeable bases (sum of Ca, Mg, Na, K), expressed as a percentage of the exchange capacity.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Bottom land. The normal flood plain of a stream, subject to frequent flooding.

Boulders. Rock fragments larger than 2 feet (60 centimeters) in diameter.

Calcareous soil. A soil containing enough calcium carbonate (commonly with magnesium carbonate) to effervesce (fizz) visibly when treated with cold, dilute hydrochloric acid. A soil having measurable amounts of calcium carbonate or magnesium carbonate.

Cation. An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation-exchange capacity. The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. The term, as applied to soils, is synonymous with base-exchange capacity, but is more precise in meaning.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Clay film. A thin coating of oriented clay on the surface of a soil aggregate or lining pores or root channels. Synonyms: clay coat, clay skin.

Coarse fragments. Mineral or rock particles up to 3 inches (2 millimeters to 7.5 centimeters) in diameter.

Coarse textured (light textured) soil. Sand or loamy sand.

Cobblestone (or cobble). A rounded or partly rounded fragment of rock 3 to 10 inches (7.5 to 25 centimeters) in diameter.

Colluvium. Soil material, rock fragments, or both moved by creep, slide, or local wash and deposited at the bases of steep slopes.

Complex, soil. A mapping unit of two or more kinds of soil occurring in such an intricate pattern that they cannot be shown separately on a soil map at the selected scale of mapping and publication.

Concretions. Grains, pellets, or nodules of various sizes, shapes, and colors consisting of concentrated compounds or cemented soil grains. The composition of most concretions is unlike that of the surrounding soil. Calcium carbonate and iron oxide are common compounds in concretions.

Consistence, soil. The feel of the soil and the ease with which a lump can be crushed by the fingers. Terms commonly used to describe consistence are—

Loose.—Noncoherent when dry or moist; does not hold together in a mass.

Friable.—When moist, crushes easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.

Firm.—When moist, crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

Plastic.—When wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.

Sticky.—When wet, adheres to other material and tends to stretch somewhat and pull apart rather than to pull free from other material.

Hard.—When dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.

Soft.—When dry, breaks into powder or individual grains under very slight pressure.

Cemented.—Hard; little affected by moistening.

Contour stripcropping (or contour farming). Growing crops in strips that follow the contour. Strips of grass or close-growing crops are alternated with strips of clean-tilled crops or summer fallow.

Control section. The part of the soil on which classification is based. The thickness varies among different kinds of soil, but for many it is 40 or 80 inches (1 or 2 meters).

Corrosive. High risk of corrosion to uncoated steel or deterioration of concrete.

Cutbanks cave. Unstable walls of cuts made by earthmoving equipment. The soil sloughs easily.

Deferred grazing. A delay in grazing until range plants have reached a specified stage of growth. Grazing is deferred in order to increase the vigor of forage and to allow desirable plants to produce seed. Contrasts with continuous grazing and rotation grazing.

Depth to rock. Bedrock at a depth that adversely affects the specified use.

Diversion (or diversion terrace). A ridge of earth, generally a terrace, built to protect downslope areas by diverting runoff from its natural course.

Drainage class (natural). Refers to the frequency and duration of periods of saturation or partial saturation during soil formation, as opposed to altered drainage, which is commonly the result of artificial drainage or irrigation but may be caused by the sudden deepening of channels or the blocking of drainage outlets. Seven classes of natural soil drainage are recognized:

Excessively drained.—Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of the mottling related to wetness.

Somewhat excessively drained.—Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep that much of the water they receive is lost as runoff. All are free of the mottling related to wetness.

Well drained.—Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured. They are mainly free of mottling.

Moderately well drained.—Water is removed from the soil somewhat slowly during some periods. Moderately well drained soils are wet for only a short time during the growing season, but periodically for long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the solum, or periodically receive high rainfall, or both.

Somewhat poorly drained.—Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a high water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly drained.—Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated in layers directly below plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

Very poorly drained.—Water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. Unless the soil is artificially drained, most mesophytic crops cannot be grown. Very poorly drained soils are commonly level or depressed and are frequently ponded. Yet, where rainfall is high and nearly continuous, they can have moderate or high slope gradients, as for example in "hillpeats" and "climatic moors."

Drainage, surface. Runoff, or surface flow of water, from an area.

Eluviation. The movement of material in true solution or colloidal suspension from one place to another within the soil. Soil horizons that have lost material through eluviation are eluvial; those that have received material are illuvial.

Erosion. The wearing away of the land surface by running water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (geologic). Erosion caused by geologic processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of such landscape features as flood plains and coastal plains. Synonym: natural erosion.

Erosion (accelerated). Erosion much more rapid than geologic erosion, mainly as a result of the activities of man or other animals or of a catastrophe in nature, for example, fire, that exposes a bare surface.

Excess fines. Excess silt and clay. The soil does not provide a source of gravel or sand for construction purposes.

Fast intake. The rapid movement of water into the soil.

Favorable. Favorable soil features for the specified use.

Fertility, soil. The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable.

Field moisture capacity. The moisture content of a soil, expressed as a percentage of the ovendry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called *normal field capacity, normal moisture capacity,* or *capillary capacity.*

Fibric soil material (peat). The least decomposed of all organic soil material. Peat contains a large amount of well preserved fiber that is readily identifiable according to botanical origin. Peat has the lowest bulk density and the highest water content at saturation of all organic soil material.

Fine textured (heavy textured) soil. Sandy clay, silty clay, and clay.

Flooding. The temporary covering of soil with water from overflowing streams, runoff from adjacent slopes, and tides. Frequency, duration, and probable dates of occurrence are estimated. Frequency is expressed as none, rare, occasional, and frequent. *None* means that flooding is not probable; *rare* that it is unlikely but possible under unusual weather conditions; *occasional* that it occurs on an average of once or less in 2 years; and *frequent* that it occurs on an average of more than once in 2 years. Duration is expressed as *very brief* if less than 2 days, *brief* if 2 to 7 days, and *long* if more than 7 days. Probable dates are expressed in months; *November-May*, for example, means that flooding can occur during the period November through May. Water standing for short periods after rainfall or commonly covering swamps and marshes is not considered flooding.

Flood plain. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

Foot slope. The inclined surface at the base of a hill.

Forage. Plant material used as feed by domestic animals. Forage can be grazed or cut for hay.

Genesis, soil. The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum, or true soil, from the unconsolidated parent material.

Gleyed soil. A soil having one or more neutral gray horizons as a result of waterlogging and lack of oxygen. The term "gleyed" also designates gray horizons and horizons having yellow and gray mottles as a result of intermittent waterlogging.

Grassed waterway. A natural or constructed waterway, typically broad and shallow, seeded to grass as protection against erosion. Conducts surface water away from cropland.

Gravel. Rounded or angular fragments of rock up to 3 inches (2 millimeters to 7.5 centimeters) in diameter. An individual piece is a pebble.

Gravelly soil material. Material from 15 to 50 percent, by volume, rounded or angular rock fragments, not prominently flattened, up to 3 inches (7.5 centimeters) in diameter.

Ground water (geology). Water filling all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

Gully. A miniature valley with steep sides cut by running water and through which water ordinarily runs only after rainfall. The distinction between a gully and a rill is one of depth. A gully generally is an obstacle to farm machinery and is too deep to be obliterated by ordinary tillage; a rill is of lesser depth and can be smoothed over by ordinary tillage.

Hemic soil material (mucky peat). Organic soil material intermediate in degree of decomposition between the less decomposed fibric and the more decomposed sapric material.

Horizon, soil. A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. The major horizons of mineral soil are as follows:

O horizon.—An organic layer, fresh and decaying plant residue, at the surface of a mineral soil.

A horizon.—The mineral horizon, formed or forming at or near the surface, in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon most of which was originally part of a B horizon.

A2 horizon.—A mineral horizon, mainly a residual concentration of sand and silt high in content of resistant minerals as a result of the loss of silicate clay, iron, aluminum, or a combination of these.

B horizon.—The mineral horizon below an A horizon. The B horizon is in part a layer of change from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics caused (1) by accumulation of clay, sesquioxides, humus, or a combination of these; (2) by prismatic or blocky structure; (3) by redder or browner colors than those in the A horizon; or (4) by a combination of these. The combined A and B horizons are generally called the solum, or true soil. If a soil lacks a B horizon, the A horizon alone is the solum.

C horizon.—The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the A or B horizon. The material of a C horizon may be either like or unlike that from which the solum is presumed to have formed. If the material is known to differ from that in the solum the Roman numeral II precedes the letter C.

R layer.—Consolidated rock beneath the soil. The rock commonly underlies a C horizon, but can be directly below an A or a B horizon.

Humus. The well decomposed, more or less stable part of the organic matter in mineral soils.

Hydrologic soil groups. Refers to soils grouped according to their runoff-producing characteristics. The chief consideration is the inherent capacity of soil bare of vegetation to permit infiltration. The slope and the kind of plant cover are not considered, but are separate factors in predicting runoff. Soils are assigned to four groups. In group A are soils having a high infiltration rate when thoroughly wet and having a low runoff potential. They are mainly deep, well drained, and sandy or gravelly. In group D, at the other extreme, are soils having a very slow infiltration rate and thus a high runoff potential. They have a claypan or clay layer at or near the surface, have a permanent high water table, or are shallow over nearly impervious bedrock or other material. A soil is assigned to two hydrologic groups if part of the acreage is artificially drained and part is undrained.

Impervious soil. A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

Infiltration. The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or material.

Infiltration rate. The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.

Karst (topography). The relief of an area underlain by limestone that dissolves in differing degrees, thus forming numerous depressions or small basins.

Landslide. The rapid downhill movement of a mass of soil and loose rock generally when wet or saturated. The speed and distance of movement, as well as the amount of soil and rock material, vary greatly.

Large stones. Rock fragments 10 inches (25 centimeters) or more across. Large stones adversely affect the specified use.

Leaching. The removal of soluble material from soil or other material by percolating water.

Light textured soil. Sand and loamy sand.

Liquid limit. The moisture content at which the soil passes from a plastic to a liquid state.

Loam. Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Low strength. Inadequate strength for supporting loads.

Medium textured soil. Very fine sandy loam, loam, silt loam, or silt.

Metamorphic rock. Rock of any origin altered in mineralogical composition, chemical composition, or structure by heat, pressure, and movement. Nearly all such rocks are crystalline.

Mineral soil. Soil that is mainly mineral material and low in organic material. Its bulk density is greater than that of organic soil.

Minimum tillage. Only the tillage essential to crop production and prevention of soil damage.

Miscellaneous areas. Areas that have little or no natural soil, are too nearly inaccessible for orderly examination, or cannot otherwise be feasibly classified.

Moderately coarse textured (moderately light textured) soil. Sandy loam and fine sandy loam.

Moderately fine textured (moderately heavy textured) soil. Clay loam, sandy clay loam, and silty clay loam.

Morphology, soil. The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile.

Mottling, soil. Irregular spots of different colors that vary in number and size. Mottling generally indicates poor aeration and impeded drainage. Descriptive terms are as follows: abundance—*few*, *common*, and *many*; size—*fine*, *medium*, and *coarse*; and contrast—*faint*, *distinct*, and *prominent*. The size measurements are of the diameter along the greatest dimension. *Fine* indicates less than 5 millimeters (about 0.2 inch); *medium*, from 5 to 15 millimeters (about 0.2 to 0.6 inch); and *coarse*, more than 15 millimeters (about 0.6 inch).

Muck. Dark colored, finely divided, well decomposed organic soil material mixed with mineral soil material. The content of organic matter is more than 20 percent.

Munsell notation. A designation of color by degrees of the three single variables—hue, value, and chroma. For example, a notation of 10YR 6/4 is a color of 10YR hue, value of 6, and chroma of 4.

Neutral soil. A soil having a pH value between 6.6 and 7.3.

Nutrient, plant. Any element taken in by a plant, essential to its growth, and used by it in the production of food and tissue. Plant nutrients are nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, zinc, and perhaps other elements obtained from the soil; and carbon, hydrogen, and oxygen obtained largely from the air and water.

Parent material. The great variety of unconsolidated organic and mineral material in which soil forms. Consolidated bedrock is not yet parent material by this concept.

Peat. Unconsolidated material, largely undecomposed organic matter, that has accumulated under excess moisture.

Ped. An individual natural soil aggregate, such as a granule, a prism, or a block.

Pedon. The smallest volume that can be called "a soil." A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from about 10 to 100 square feet (1 square meter to 10 square meters), depending on the variability of the soil.

Percolation. The downward movement of water through the soil.

Percs slowly. The slow movement of water through the soil adversely affecting the specified use.

Permeability. The quality that enables the soil to transmit water or air, measured as the number of inches per hour that water moves through the soil. Terms describing permeability are *very slow* (less than 0.06 inch), *slow* (0.06 to 0.20 inch), *moderately slow* (0.2 to 0.6 inch), *moderate* (0.6 to 2.0 inches), *moderately rapid* (2.0 to 6.0 inches), *rapid* (6.0 to 20 inches), and *very rapid* (more than 20 inches).

Phase, soil. A subdivision of a soil series or other unit in the soil classification system based on differences in the soil that affect its management. A soil series, for example, may be divided into phases on the bases of differences in slope, stoniness, thickness, or some other characteristic that affects management. These differences are too small to justify separate series.

pH value. (See Reaction, soil). A numerical designation of acidity and alkalinity in soil.

Piping. Moving water of subsurface tunnels or pipelike cavities in the soil.

Plasticity index. The numerical difference between the liquid limit and the plastic limit; the range of moisture content within which the soil remains plastic.

Plastic limit. The moisture content at which a soil changes from a semisolid to a plastic state.

Plinthite. The sesquioxide-rich, humus-poor, highly weathered mixture of clay with quartz and other diluents that commonly appears as red mottles, usually in platy, polygonal, or reticulate patterns. Plinthite changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying, especially if it is exposed also to heat from the sun. In a moist soil, plinthite can be cut with a spade, whereas ironstone cannot be cut but can be broken or shattered with a spade. Plinthite is one form of the material that has been called laterite.

Plutonic rock. A general term applied to the class of igneous rocks that have crystallized at great depths and are generally granitoid in texture.

Polypedon. A volume of soil having properties within the limits of a soil series, the lowest and most homogeneous category of soil taxonomy. A "soil individual."

Poorly graded. Refers to soil material consisting mainly of particles of nearly the same size. Because there is little difference in size of the particles, density can be increased only slightly by compaction.

Poor outlets. Surface or subsurface drainage outlets difficult or expensive to install.

Pressure faces. Structural faces that show more evidence of clay than the natural ped surfaces but that do not have clay films. Probably caused by the shrinking and swelling of the soil.

Productivity (soil). The capability of a soil for producing a specified plant or sequence of plants under a specified system of management. Productivity is measured in terms of output, or harvest, in relation to input.

Profile, soil. A vertical section of the soil extending through all its horizons and into the parent material.

Reaction, soil. The degree of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline. The degree of acidity or alkalinity is expressed as—

	pH
Extremely acid	Below 4.5
Very strongly acid	4.5 to 5.0
Strongly acid	5.1 to 5.5
Medium acid	5.6 to 6.0
Slightly acid	6.1 to 6.5
Neutral	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	9.1 and higher

Relief. The elevations or inequalities of a land surface, considered collectively.

Residuum (residual soil material). Unconsolidated, weathered, or partly weathered mineral material that accumulates over disintegrating rock.

Rock fragments. Rock or mineral fragments having a diameter of 2 millimeters or more; for example, pebbles, cobbles, stones, and boulders.

Rooting depth. Shallow root zone. The soil is shallow over a layer that greatly restricts roots. See Root zone.

Root zone. The part of the soil that can be penetrated by plant roots.

Runoff. The precipitation discharged in stream channels from a drainage area. The water that flows off the land surface without sinking in is called surface runoff; that which enters the ground before reaching surface streams is called ground-water runoff or seepage flow from ground water.

Saline soil. A soil containing soluble salts in an amount that impairs growth of plants. A saline soil does not contain excess exchangeable sodium.

Sand. As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.

Sandstone. Sedimentary rock containing dominantly sand-size particles.

Sapric soil material (muck). The most highly decomposed of all organic soil material. Muck has the least amount of plant fiber, the highest bulk density, and the lowest water content at saturation of all organic soil material.

Saprolite (geology). Soft, earthy, clay-rich, thoroughly decomposed rock formed in place by chemical weathering of igneous and metamorphic rock. In soil survey, the term saprolite is applied to any unconsolidated residual material underlying the soil and grading to hard bedrock below.

Sedimentary rock. Rock made up of particles deposited from suspension in water. The chief kinds of sedimentary rock are conglomerate, formed from gravel; sandstone, formed from sand; shale, formed from clay; and limestone, formed from soft masses of calcium carbonate. There are many intermediate types. Some wind-deposited sand is consolidated into sandstone.

Seepage. The rapid movement of water through the soil. Seepage adversely affects the specified use.

Series, soil. A group of soils, formed from a particular type of parent material, having horizons that, except for the texture of the A or surface horizon, are similar in all profile characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineralogical and chemical composition.

Sheet erosion. The removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and runoff water.

Shrink-swell. The shrinking of soil when dry and the swelling when wet. Shrinking and swelling can damage roads, dams, building foundations, and other structures. It can also damage plant roots.

Silica. A combination of silicon and oxygen. The mineral form is called quartz.

Silt. As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.

Siltstone. Sedimentary rock made up of dominantly silt-sized particles.

Sinkhole. A depression in a landscape where limestone has been locally dissolved.

Slickensides. Polished and grooved surfaces produced by one mass sliding past another. In soils, slickensides may occur at the bases of slip surfaces on the steeper slopes; on faces of blocks, prisms, and columns; and in swelling clayey soils, where there is marked change in moisture content.

Slope. The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.

Slow intake. The slow movement of water into the soil.

Small stones. Rock fragments 3 to 10 inches (7.5 to 25 centimeters) in diameter. Small stones adversely affect the specified use.

Soil. A natural, three-dimensional body at the earth's surface that is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.

Soil separates. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes of separates recognized in the United States are as follows: *very coarse sand* (2.0 millimeters to 1.0 millimeter); *coarse sand* (1.0 to 0.5 millimeter); *medium sand* (0.5 to 0.25 millimeter); *fine sand* (0.25 to 0.10 millimeter); *very fine sand* (0.10 to 0.05 millimeter); *silt* (0.005 to 0.002 millimeter); and *clay* (less than 0.002 millimeter).

Solum. The upper part of a soil profile, above the C horizon, in which the processes of soil formation are active. The solum in mature soil consists of the A and B horizons. Generally, the characteristics of the material in these horizons are unlike those of the underlying material. The living roots and other plant and animal life characteristics of the soil are largely confined to the solum.

Stones. Rock fragments 10 to 24 inches (25 to 60 centimeters) in diameter.

Stony. Refers to a soil containing stones in numbers that interfere with or prevent tillage.

Stratified. Arranged in strata, or layers. The term refers to geologic material. Layers in soils that result from the processes of soil formation are called horizons; those inherited from the parent material are called strata.

Stripcropping. Growing crops in a systematic arrangement of strips or bands which provide vegetative barriers to wind and water erosion.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates that are separated from adjoining aggregates. The principal forms of soil structure are—*platy* (laminated), *prismatic* (vertical axis of aggregates longer than horizontal), *columnar* (prisms with rounded tops), *blocky* (angular or subangular), and *granular*. *Structureless* soils are either *single grained* (each grain by itself, as in dune sand) or *massive* (the particles adhering without any regular cleavage, as in many hardpans).

Stubble mulch. Stubble or other crop residue left on the soil, or partly worked into the soil, to provide protection from soil blowing and water erosion after harvest, during preparation of a seedbed for the next crop, and during the early growing period of the new crop.

Subsoil. Technically, the B horizon; roughly, the part of the solum below plow depth.

Substratum. The part of the soil below the solum.

Subsurface layer. Technically, the A2 horizon. Generally refers to a leached horizon lighter in color and lower in content of organic matter than the overlying surface layer.

Surface soil. The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from 4 to 10 inches (10 to 25 centimeters). Frequently designated as the "plow layer," or the "Ap horizon."

Terrace. An embankment, or ridge, constructed across sloping soils on the contour or at a slight angle to the contour. The terrace intercepts surface runoff so that it can soak into the soil or flow slowly to a prepared outlet without harm. A terrace in a field is generally built so that the field can be farmed. A terrace intended mainly for drainage has a deep channel that is maintained in permanent sod.

Terrace (geologic). An old alluvial plain, ordinarily flat or undulating, bordering a river, a lake, or the sea. A stream terrace is frequently called a second bottom, in contrast with a flood plain, and is seldom subject to overflow. A marine terrace, generally wide, was deposited by the sea.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are *sand, loamy sand, sandy loam, loam, silt, silt loam, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay*, and *clay*. The sand, loamy sand, and sandy loam classes may be further divided by specifying "coarse," "fine," or " very fine."

Thin layer. Otherwise suitable soil material too thin for the specified use.

Tilth, soil. The condition of the soil, especially the soil structure, as related to the growth of plants. Good tilth refers to the friable state and is associated with high noncapillary porosity and stable structure. A soil in poor tilth is nonfriable, hard, nonaggregated, and difficult to till.

Topsoil (engineering). Presumably a fertile soil or soil material, or one that responds to fertilization, ordinarily rich in organic matter, used to topdress roadbanks, lawns, and gardens.

Tuff. A compacted deposit 50 percent or more volcanic ash and dust.

Upland (geology). Land at a higher elevation, in general, than the alluvial plain or stream terrace; land above the lowlands along streams.

Unstable fill. Risk of caving or sloughing in banks of fill material.

Variegation. Refers to patterns of contrasting colors assumed to be inherited from the parent material rather than to be the result of poor drainage.

Volcanic rock. The class of igneous rocks that have been poured out or ejected at or near the surface. The form is synonymous with extrusive rock and effusive rock.

Water table. The upper limit of the soil or underlying rock material that is wholly saturated with water.

Illustrations

Figure 1.—Adequate drainage is essential in producing high yields of sugarcane on poorly drained Bajura clay.

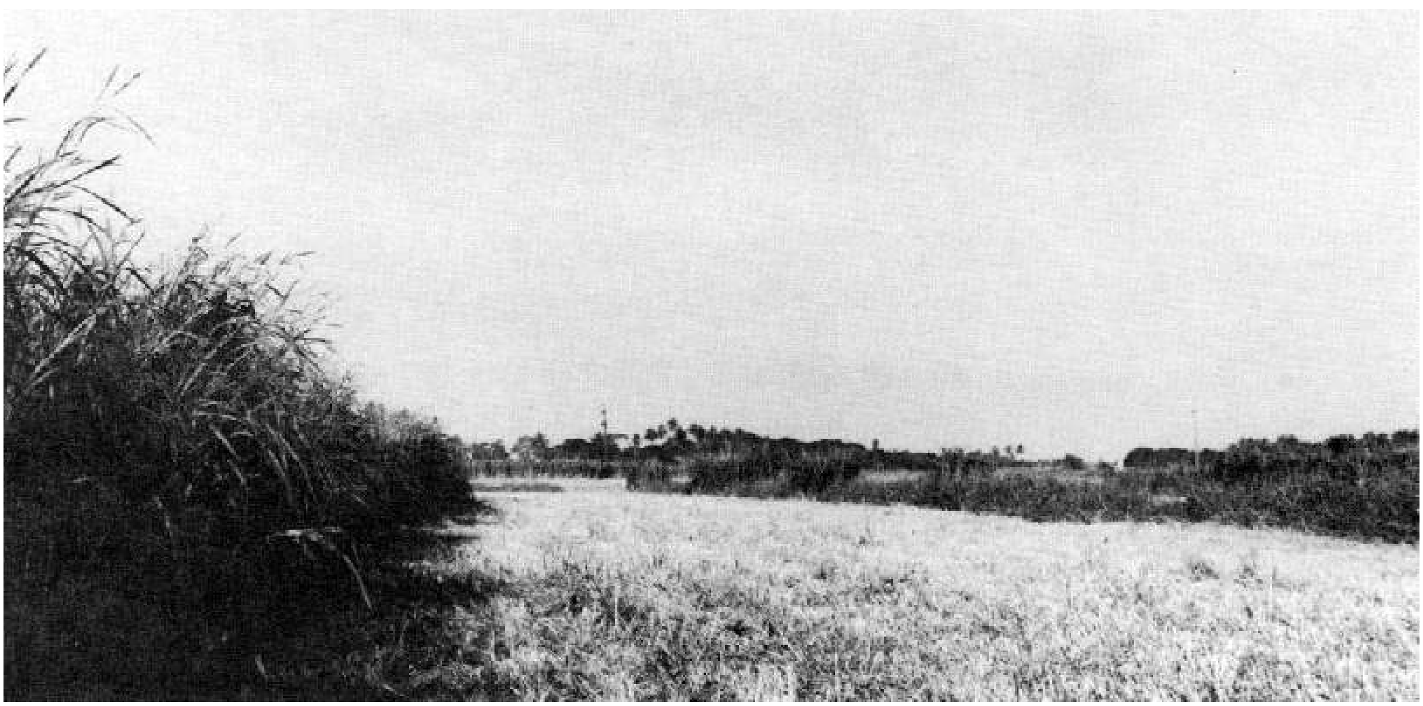

Figure 2.—High yields of Merker grass are produced on Bayamon clay, 2 to 5 percent slopes, a deep, red, acid soil on the coastal plains.

Figure 3.—Drainage ditch lowers water table and improves drainage of Coloso silty clay loam. This field is planted to sugarcane.

Figure 4.—Field of Daguey clay, 12 to 20 percent slopes, is prepared for planting to taniers and plantains.

Figure 5.—Sugarcane grown on Dique loam. This nearly level, well drained soil is on flood plains.

Figure 6.—Controlling erosion is the major concern of management in this field of Humatas clay, 20 to 40 percent slopes, planted to plantains. Hillside ditches break the length of slope and take excess runoff water slowly out of the field.

Figure 7.—Proper stocking rates and deferred grazing, as well as liming and fertilizing, are the chief management needs of this pasture on Lares clay, 5 to 12 percent slopes, eroded, planted to pangolagrass.

Figure 8.—Contour furrows and hillside ditches help overcome the rapid runoff and erosion hazard on Limones clay, 20 to 40 percent slopes.

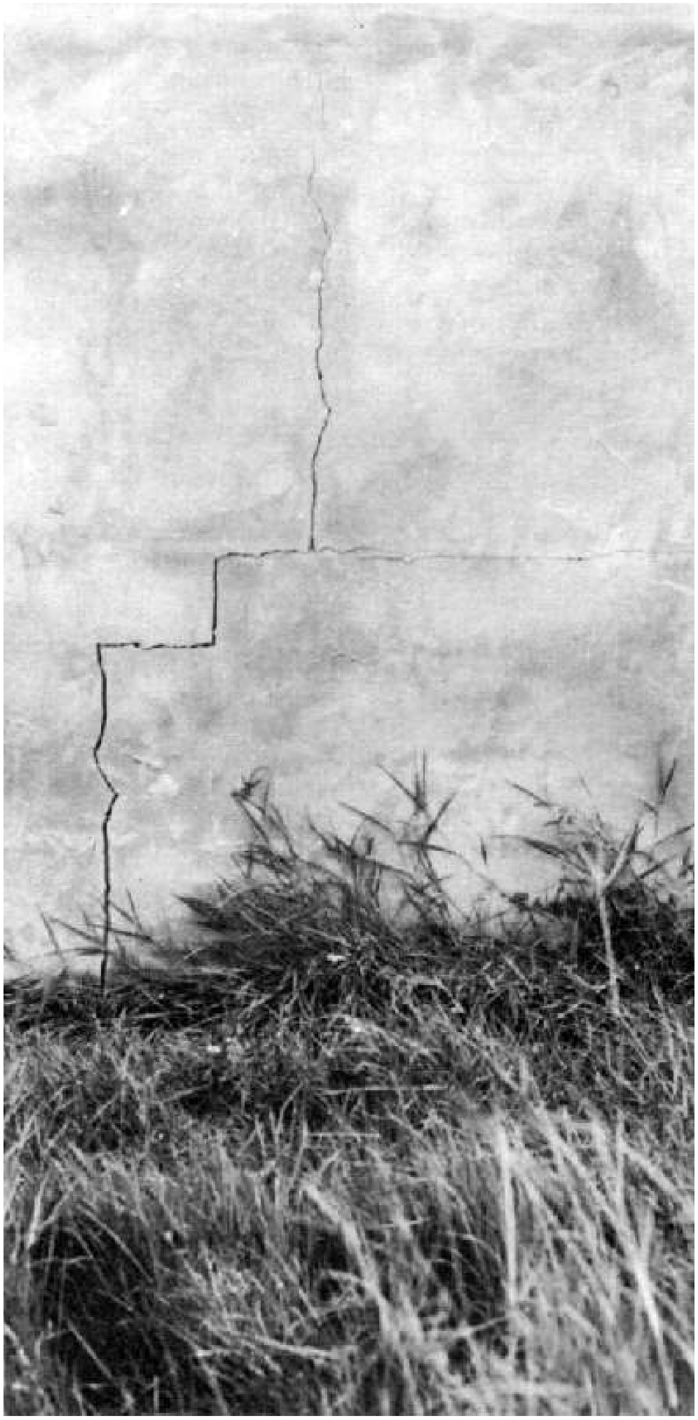

Figure 9.—High shrink-swell potential has caused cracks in this wall on Mabi clay, 0 to 2 percent slopes. This soil is severely limited for most urban uses.

Figure 10.—Crop residue management in this field of Toa silty clay loam helps maintain moisture and recycles nutrients back into the soil.

Figure 11.—Harvest of Merker grass on Vega Alta clay loam, 5 to 12 percent slopes, eroded.

Figure 12.—Hillside ditches shorten the slope and reduce runoff and erosion in field of plantains.

Tables

TABLE 1.--TEMPERATURE AND PRECIPITATION DATA

Month	Temperature[1]						Precipitation[1]				
	Average daily maximum	Average daily minimum	Average daily	2 years in 10 will have-- Maximum temperature higher than--	2 years in 10 will have-- Minimum temperature lower than--	Average number of growing degree days[2]	Average	2 years in 10 will have-- Less than--	2 years in 10 will have-- More than--	Average number of days with 0.10 inch or more	Average snowfall
	°F	°F	°F	°F	°F	Units	In	In	In		In
January----	82.5	69.8	76.2	88	64	502	3.21	1.98	4.31	9	.0
February---	82.9	69.5	76.2	89	64	454	2.15	1.13	2.99	5	.0
March------	84.2	70.4	77.3	91	64	536	2.59	1.29	3.64	5	.0
April------	84.9	72.0	78.5	92	66	555	3.52	1.52	5.13	7	.0
May--------	86.3	73.5	79.9	93	69	617	5.89	2.20	8.85	10	.0
June-------	87.7	74.8	81.3	93	71	639	5.11	2.67	7.09	10	.0
July-------	87.6	75.7	81.7	92	72	673	4.82	2.78	6.47	11	.0
August-----	88.1	75.7	81.9	93	72	679	6.27	4.49	7.90	12	.0
September--	88.2	75.1	81.7	93	72	651	5.19	3.48	6.75	11	.0
October----	87.7	74.4	81.1	93	70	654	5.88	3.36	7.93	10	.0
November---	85.4	72.9	79.2	91	67	576	5.14	3.28	6.82	11	.0
December---	83.3	71.3	77.3	89	66	536	4.86	2.77	6.56	10	.0
Year-----	85.7	72.9	79.4	94	63	7,072	54.63	44.96	63.50	111	.0

[1]Recorded in the period 1955-74 at San Juan, P. R.

[2]A growing degree day is a unit of heat available for plant growth. It can be calculated by adding the maximum and minimum daily temperatures, dividing the sum by 2, and subtracting the temperature below which growth is minimal for the principal crops in the area (60° F).

TABLE 2.--TEMPERATURE AND PRECIPITATION DATA

Month	Temperature[1]						Precipitation[1]				
	Average daily maximum	Average daily minimum	Average daily	2 years in 10 will have-- Maximum temperature higher than--	2 years in 10 will have-- Minimum temperature lower than--	Average number of growing degree days[2]	Average	2 years in 10 will have-- Less than--	2 years in 10 will have-- More than--	Average number of days with 0.10 inch or more	Average snowfall
	°F	°F	°F	°F	°F	Units	In	In	In		In
January----	76.1	60.2	68.2	82	56	254	3.80	2.12	5.17	10	.0
February---	77.5	59.8	68.7	83	55	244	2.13	1.35	2.83	6	.0
March------	78.9	60.7	69.8	84	56	304	3.29	1.85	4.46	6	.0
April------	80.1	61.6	70.9	85	56	327	4.27	1.68	6.36	7	.0
May--------	81.0	63.5	72.3	87	59	381	6.50	2.65	9.61	9	.0
June-------	82.0	65.4	73.7	86	62	411	3.39	1.88	4.62	8	.0
July-------	82.5	66.1	74.3	87	62	443	3.31	2.00	4.47	7	.0
August-----	82.5	66.5	74.5	88	61	450	5.18	3.43	6.77	8	.0
September--	82.7	66.0	74.4	86	61	432	5.22	3.74	6.58	9	.0
October----	81.9	66.2	74.1	88	61	437	9.03	3.80	13.27	12	.0
November---	79.7	64.2	71.9	84	59	357	6.95	3.28	9.93	10	.0
December---	77.1	61.6	69.4	84	57	291	4.03	1.77	5.85	7	.0
Year-----	80.2	63.5	71.9	89	55	4,331	57.10	39.74	73.55	99	.0

[1]Recorded in the period 1963-74 at Barranquitas, P. R.

[2]A growing degree day is a unit of heat available for plant growth. It can be calculated by adding the maximum and minimum daily temperatures, dividing the sum by 2, and subtracting the temperature below which growth is minimal for the principal crops in the area (60° F).

TABLE 3.--MAP UNITS AND THEIR POTENTIAL AND LIMITATIONS FOR SPECIFIED USE

Map unit	Extent of area	Cultivated farm crops	Specialty crops	Woodland	Urban Uses	Intensive recreation areas	Extensive recreation areas
	Pct						
1. Maricao-Los Guineos	10	Poor: slope.	Poor: slope.	Good-------	Poor: slope, too clayey.	Poor: slope, too clayey.	Good.
2. Humatas-Naranjito-Consumo	29	Poor: slope.	Poor: slope.	Good-------	Poor: slope, too clayey.	Poor: slope, too clayey.	Good.
3. Mucara-Caguabo	39	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
4. Descalabrado	1	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
5. Pandura-Lirios	7	Poor: slope.	Poor: slope.	Good-------	Poor: slope.	Poor: slope.	Good.
6. Tanama-Colinas-Soller	4	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Poor: depth to rock.	Poor: slope, depth to rock.	Poor: slope, depth to rock.	Good.
7. Almirante-Vega Alta-Matanzas	3	Good-------	Good-------	Good-------	Good-------	Good--------	Good.
8. Toa-Bajura-Coloso	4	Good-------	Good-------	Good-------	Poor: wetness, flooding.	Poor: wetness, flooding.	Good.
9. Mabi-Rio Arriba	2	Fair: wetness.	Fair: wetness.	Good-------	Poor: wetness, shrink-swell.	Poor: wetness, too clayey.	Good.
10. Martin Pena-Saladar-Hydraquents	1	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Poor: wetness, flooding.	Good.

TABLE 4.--ACREAGE AND PROPORTIONATE EXTENT OF THE SOILS

Map symbol	Soil name	Acres	Percent
AaB	Aceitunas clay, 2 to 5 percent slopes	575	0.1
AaC	Aceitunas clay, 5 to 12 percent slopes	4,328	1.0
AbD	Aibonito clay, 12 to 20 percent slopes	276	0.1
AbE	Aibonito clay, 20 to 40 percent slopes	803	0.2
AmB	Almirante clay, 2 to 5 percent slopes	4,280	1.0
AmC	Almirante clay, 5 to 12 percent slopes	1,098	0.2
Ba	Bajura clay	4,148	0.9
BmB	Bayamon clay, 2 to 5 percent slopes	647	0.1
CaE	Caguabo clay loam, 20 to 40 percent slopes	3,674	0.8
CaF	Caguabo clay loam, 40 to 60 percent slopes	51,494	11.5
CbF	Caguabo-Rock outcrop complex, 40 to 60 percent slopes	2,324	0.5
Ce	Candelero loam	607	0.1
ClC	Catalina clay, 4 to 12 percent slopes	267	0.1
Cn	Catano loamy sand	252	0.1
Co	Cayagua sandy loam	1,822	0.4
CrD2	Colinas clay loam, 12 to 20 percent slopes, eroded	1,165	0.3
CrE2	Colinas clay loam, 20 to 40 percent slopes, eroded	2,802	0.6
CrF2	Colinas clay loam, 40 to 60 percent slopes, eroded	894	0.2
Cs	Coloso silty clay loam	2,640	0.6
CuE	Consumo clay, 20 to 40 percent slopes	2,382	0.5
CuF	Consumo clay, 40 to 60 percent slopes	17,118	3.8
CzC	Corozal clay, 5 to 12 percent slopes	219	0.1
DaC	Daguey clay, 2 to 12 percent slopes	106	([1])
DaD	Daguey clay, 12 to 20 percent slopes	6,729	1.5
DeF	Descalabrado clay loam, 40 to 60 percent slopes	1,785	0.4
DgF	Descalabrado-Rock outcrop complex, 40 to 60 percent slopes	1,239	0.3
Dm	Dique loam	296	0.1
Dr	Durados sandy loam	448	0.1
Es	Estacion silty clay loam	1,624	0.4
GuF	Guayama clay loam, 20 to 60 percent slopes	266	0.1
Hm	Humacao loam	78	([1])
HtE	Humatas clay, 20 to 40 percent slopes	19,364	4.3
HtF	Humatas clay, 40 to 60 percent slopes	21,105	4.7
HuF	Humatas-Rock outcrop complex, 20 to 60 percent slopes	1,022	0.2
Hy	Hydraquents, saline	624	0.1
JaE2	Jagueyes loam, 20 to 40 percent slopes, eroded	200	([1])
JnD2	Juncal clay, 5 to 20 percent slopes, eroded	524	0.1
JuC	Juncos clay, 5 to 12 percent slopes	754	0.2
JuD	Juncos clay, 12 to 20 percent slopes	1,272	0.3
LaB	Lares clay, 2 to 5 percent slopes	205	([1])
LaC2	Lares clay, 5 to 12 percent slopes, eroded	1,841	0.4
LmE	Limones clay, 20 to 40 percent slopes	384	0.1
LmF	Limones clay, 40 to 60 percent slopes	314	0.1
LoF2	Lirios silty clay loam, 20 to 60 percent slopes, eroded	7,346	1.6
LsE	Los Guineos clay, 20 to 40 percent slopes	3,474	0.8
LsF	Los Guineos clay, 40 to 60 percent slopes	14,588	3.3
MaA	Mabi clay, 0 to 2 percent slopes	274	0.1
MaB	Mabi clay, 2 to 5 percent slopes	2,440	0.5
MaC	Mabi clay, 5 to 12 percent slopes	2,785	0.6
Md	Made land	245	0.1
MlF	Malaya clay loam, 40 to 60 percent slopes	480	0.1
MoF	Maricao clay, 20 to 60 percent slopes	22,515	5.0
Mp	Martin Pena muck	2,339	0.5
MsB	Matanzas clay, 2 to 5 percent slopes	1,031	0.2
MtB	Montegrande clay, 2 to 5 percent slopes	72	([1])
MtC	Montegrande clay, 5 to 12 percent slopes	390	0.1
MuF2	Morado clay loam, 40 to 60 percent slopes, eroded	2,471	0.6
MxD	Mucara clay, 12 to 20 percent slopes	2,442	0.5
MxE	Mucara clay, 20 to 40 percent slopes	16,920	3.8
MxF	Mucara clay, 40 to 60 percent slopes	70,480	15.8
NaD2	Naranjito silty clay loam, 12 to 20 percent slopes, eroded	1,148	0.3
NaE2	Naranjito silty clay loam, 20 to 40 percent slopes, eroded	5,594	1.3
NaF2	Naranjito silty clay loam, 40 to 60 percent slopes, eroded	25,999	5.8
PaD	Pandura sandy loam, 12 to 20 percent slopes	1,524	0.3
PaE	Pandura sandy loam, 20 to 40 percent slopes	2,967	0.7
PaF	Pandura sandy loam, 40 to 60 percent slopes	13,171	2.9
PeF	Pellejas clay loam, 40 to 60 percent slopes	617	0.1
Re	Reilly sandy loam	539	0.1
RoB	Rio Arriba clay, 2 to 5 percent slopes	1,693	0.4
RoC2	Rio Arriba clay, 5 to 12 percent slopes, eroded	2,479	0.6

See footnote at end of table.

TABLE 4.--ACREAGE AND PROPORTIONATE EXTENT OF THE SOILS--Continued

Map symbol	Soil name	Acres	Percent
RpD2	Rio Piedras clay, 12 to 20 percent slopes, eroded	1,276	0.3
RpE2	Rio Piedras clay, 20 to 40 percent slopes, eroded	869	0.2
RpF2	Rio Piedras clay, 40 to 60 percent slopes, eroded	1,209	0.3
SaF	Sabana silty clay loam, 40 to 60 percent slopes	799	0.2
ScB	Sabana Seca clay, 2 to 8 percent slopes	590	0.1
Sm	Saladar muck	2,719	0.6
SoE	Soller clay loam, 20 to 40 percent slopes	673	0.2
SoF	Soller clay loam, 40 to 60 percent slopes	4,070	0.9
TaF	Tanama-Rock outcrop complex, 20 to 60 percent slopes	6,575	1.5
Tc	Toa silty clay loam	4,983	1.1
TrB	Torres loamy sand, 2 to 5 percent slopes	694	0.2
Ts	Tropopsamments	61	([1])
Ud	Urban land-Durados complex	3,461	0.8
Um	Urban land-Mucara complex	4,142	0.9
Us	Urban land-Sabana Seca complex	5,040	1.1
Uv	Urban land-Vega Alta complex	14,048	3.1
VaB	Vega Alta clay loam, 2 to 5 percent slopes	365	0.1
VaC2	Vega Alta clay loam, 5 to 12 percent slopes, eroded	1,696	0.4
Vg	Vega Baja silty clay	48	([1])
VkC2	Via clay loam, 5 to 12 percent slopes, eroded	413	0.1
Vv	Vivi loam	165	([1])
YeE	Yunes silty clay loam, 20 to 40 percent slopes	462	0.1
YeF	Yunes silty clay loam, 40 to 60 percent slopes	778	0.2
	Riverwash	524	0.1
	Urban areas	20,614	4.6
	Water	987	0.2
	Total	447,279	100.0

[1]Less than 0.1 percent.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE

[All yields were estimated for a high level of management in 1974. Absence of a yield figure indicates the crop is seldom grown or is not suited]

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Aceitunas:							
AaB	60	50	40	35	---	24	19
AaC	60	50	40	35	---	24	17
Aibonito:							
AbD	---	---	---	25	5	21	14
AbE	---	---	---	20	4	21	---
Almirante:							
AmB	60	50	40	35	---	---	19
AmC	60	50	40	35	---	---	17
Bajura:							
Ba	---	45	30	---	---	---	15
Bayamon:							
BmB	60	50	40	35	---	24	19
Caguabo:							
CaE, CaF	---	---	---	---	---	6	---
[2]CbF	---	---	---	---	---	---	---
Candelero:							
Ce	45	35	30	---	---	24	17
Catalina:							
ClC	60	50	40	35	12	21	17
Catano:							
Cn	---	---	---	---	---	20	12
Cayagua:							
Co	50	40	35	---	---	24	16
Colinas:							
CrD2	45	35	30	---	---	17	13
CrE2	---	---	---	---	---	17	---
CrF2	---	---	---	---	---	12	---
Coloso:							
Cs	60	50	40	---	---	---	18
Consumo:							
CuE	---	---	---	25	8	21	---
CuF	---	---	---	---	6	14	---
Corozal:							
CzC	60	50	40	35	12	24	17
Daguey:							
DaC, DaD	45	40	30	35	12	24	16
Descalabrado:							
DeF	---	---	---	---	---	---	---
[2]DgF	---	---	---	---	---	---	---
Dique:							
Dm	80	60	40	---	---	24	20

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Durados:							
Dr	---	---	---	---	---	20	12
Estacion:							
Es	60	50	40	---	---	2	17
Guayama:							
GuF	---	---	---	---	---	---	---
Humacao:							
Hm	60	50	40	35	---	24	19
Humatas:							
HtE	---	---	---	30	10	21	---
HtF	---	---	---	---	8	21	---
[2]HuF	---	---	---	---	---	---	---
Hydraquents:							
Hy	---	---	---	---	---	---	---
Jagueyes:							
JaE2	---	---	---	30	10	---	---
Juncal:							
JnD2	---	45	35	35	---	17	15
Juncos:							
JuC	---	40	35	35	7	24	15
JuD	---	35	30	30	7	24	14
Lares:							
LaB	45	40	35	35	12	24	19
LaC2	45	40	35	35	12	24	17
Limones:							
LmE	---	---	---	30	10	---	---
LmF	---	---	---	---	8	---	---
Lirios:							
LoF2	---	---	---	---	6	24	---
Los Guineos:							
LsE	---	---	---	25	8	20	---
LsF	---	---	---	---	6	---	---
Mabi:							
MaA	55	45	35	---	---	24	16
MaB	55	45	35	---	---	24	16
MaC	50	40	35	30	---	24	15
Made land:							
Md.							
Malaya:							
MlF	---	---	---	---	---	12	---
Maricao:							
MoF	---	---	---	---	6	20	---
Martin Pena:							
Mp	---	---	---	---	---	---	---

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Matanzas:							
MsB	60	50	40	35	---	24	19
Montegrande:							
MtB	55	45	35	---	---	---	16
MtC	55	45	35	30	---	---	15
Morado:							
MuF2	---	---	---	---	5	12	---
Mucara:							
MxD	---	35	30	30	7	24	14
MxE	---	---	---	25	6	12	---
MxF	---	---	---	---	5	12	---
Naranjito:							
NaD2	---	35	30	30	7	21	14
NaE2	---	---	---	25	6	21	---
NaF2	---	---	---	---	5	15	---
Pandura:							
PaD	---	35	30	25	---	11	12
PaE, PaF	---	---	---	---	---	8	---
Pellejas:							
PeF	---	---	---	---	6	11	---
Reilly:							
Re	---	35	30	---	---	24	15
Rio Arriba:							
RoB	55	45	35	---	---	---	16
RoC2	50	40	35	30	---	---	15
Rio Piedras:							
RpD2	---	35	30	30	10	24	13
RpE2	---	---	---	25	8	21	---
RpF2	---	---	---	---	6	21	---
Sabana:							
SaF	---	---	---	---	---	12	---
Sabana Seca:							
ScB	---	---	---	---	---	2	14
Saladar:							
Sm	---	---	---	---	---	---	---
Soller:							
SoE, SoF	---	---	---	---	---	12	---
Tanama:							
[2]TaF	---	---	---	---	---	---	---
Toa:							
To	80	60	50	---	---	24	20
Torres:							
TrB	---	---	---	---	---	1.6	10

See footnotes at end of table.

TABLE 5.--YIELDS PER ACRE OF CROPS AND PASTURE--Continued

Soil name and map symbol	Sugarcane, 18 month	Sugarcane, spring	Sugarcane, ratoon	Plantains	Coffee	Pangola-grass	Merker grass
	Ton	Ton	Ton	Thousand	Cwt	Ton[1]	Ton[1]
Tropopsamments:							
Ts	---	---	---	---	---	---	---
Urban land:							
[2]Ud	---	---	---	---	---	---	---
[2]Um	---	---	---	---	---	---	---
[2]Us	---	---	---	---	---	---	---
[2]Uv	---	---	---	---	---	---	---
Vega Alta:							
VaB	60	50	40	35	---	---	19
VaC2	60	50	40	35	---	---	17
Vega Baja:							
Vg	55	45	40	---	---	---	16
Via:							
VkC2	50	45	40	---	---	24	17
Vivi:							
Vv	60	50	40	---	---	---	16
Yunes:							
YeE, YeF	---	---	---	---	6	20	---

[1]Dry weight per acre per year.
[2]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 6.--CAPABILITY CLASSES AND SUBCLASSES

[Miscellaneous areas excluded. Absence of an entry means no acreage]

Class	Total acreage	Major management concerns (Subclass)		
		Erosion (e)	Wetness (w)	Soil problem (s)
		Acres	Acres	Acres
I	5,279	---	---	---
II	14,513	7,181	5,474	1,858
III	32,420	26,058	4,738	1,624
IV	29,590	29,051	---	539
V	---	---	---	---
VI	65,970	64,576	---	1,394
VII	244,718	173,805	2,339	68,574
VIII	5,728	---	3,343	2,385

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY

[Only the soils suitable for production of commercial trees are listed in this table. Absence of an entry in a column means the information was not available]

Soil name and map symbol	Ordination symbol	Management concerns: Erosion hazard	Management concerns: Equipment limitation	Management concerns: Seedling mortality	Potential productivity: Important trees	Potential productivity: Average yearly growth per acre	Trees to plant
						Bd ft	
Aibonito:							
AbD	2c	Slight	Moderate	Slight	Honduras pine	1200	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
AbE	2c	Moderate	Moderate	Slight	Honduras pine	1200	Honduras pine, robusta eucalyptus.
Caguabo:							
CaE	3d	Severe	Severe	Slight	Honduras pine	800	Honduras pine, robusta eucalyptus.
CaF	4d	Severe	Severe	Severe	Honduras pine	700	Honduras pine.
[1]CbF:							
Caguabo part	4d	Severe	Severe	Severe	Honduras pine	700	Honduras pine.
Rock outcrop part.							
Catalina:							
ClC	2c	Slight	Moderate	Slight	Honduras pine	1100	Honduras pine, honduras mahogany, kadam, robusta eucalyptus, mahoe.
Colinas:							
CrD2	2d	Slight	Slight	Slight	Honduras mahogany	450	Honduras pine, honduras mahogany, mahoe, teak.
CrE2	3d	Moderate	Moderate	--------	Honduras mahogany	350	Honduras mahogony.
Consumo:							
CuE	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
CuF	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
Daguey:							
DaC, DaD	2c	Slight	Moderate	Slight	Honduras pine	1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
Descalabrado:							
DeF	4d	Severe	Severe	Severe	Honduras pine	<800	Honduras pine.
[1]DgF:							
Descalabrado part	4d	Severe	Severe	Severe	Honduras pine	<800	Honduras pine.
Rock outcrop part.							
Guayama:							
GuF	4d	Moderate	Moderate	Severe	Honduras pine	<800	Honduras pine.

See footnote at end of table.

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY--Continued

Soil name and map symbol	Ordination symbol	Management concerns: Erosion hazard	Management concerns: Equipment limitation	Management concerns: Seedling mortality	Potential productivity: Important trees	Potential productivity: Average yearly growth per acre	Trees to plant
						Bd ft	
Humatas:							
HtE	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
HtF	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
[1]HuF:							
Humatas part	3c	Severe	Severe	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus.
Rock outcrop part.							
Jagueyes:							
JaE2	2r	Moderate	Moderate	Moderate	Honduras pine	1200	Honduras pine.
Juncal:							
JnD2	2c	Slight	Slight	Slight	Honduras pine Honduras mahogany	1200 450	Honduras pine, honduras mahogany.
Juncos:							
JuC	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.
JuD	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.
Lares:							
LaB, LaC2	2c	Slight	Moderate	Slight	Honduras pine	1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
Limones:							
LmE	2c	Moderate	Moderate	Moderate	Honduras pine	1300	Honduras pine.
LmF	3c	Severe	Severe	Moderate	Honduras pine	1000	Honduras pine.
Lirios:							
LoF2	2c	Moderate	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus.
Los Guineos:							
LsE, LsF	2c	Moderate	Moderate	Slight	Honduras pine	1400	Honduras pine, robusta eucalyptus.
Malaya:							
MlF	4d	Moderate	Moderate	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.
Maricao:							
MoF	2c	Moderate	Moderate	Slight	Honduras pine	1300	Honduras pine, robusta eucalyptus.
Morado:							
MuF2	3d	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Mucara:							
MxD	3d	Slight	Moderate	Slight	Honduras pine	1000	Honduras pine, robusta eucalyptus, honduras mahogany.

See footnote at end of table.

TABLE 7.--WOODLAND MANAGEMENT AND PRODUCTIVITY--Continued

Soil name and map symbol	Ordination symbol	Management concerns: Erosion hazard	Management concerns: Equipment limitation	Management concerns: Seedling mortality	Potential productivity: Important trees	Potential productivity: Average yearly growth per acre	Trees to plant
						Bd ft	
Mucara:							
MxE	3d	Moderate	Moderate	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
MxF	3d	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Naranjito:							
NaD2, NaE2	2c	Slight	Moderate	Slight	Honduras pine	1100	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
NaF2	3c	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Pandura:							
PaD	2o	Moderate	Slight	Slight	Honduras pine	1200	Honduras pine, robusta eucalyptus, mahoe.
PaE	2r	Severe	Moderate	Slight	Honduras pine	1100	Honduras pine, robusta eucalyptus, mahoe.
PaF	3r	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Pellejas:							
PeF	3r	Severe	Severe	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Rio Piedras:							
RpD2	2c	Slight	Moderate	Slight	Honduras pine Honduras pine	1300 1300	Honduras pine, honduras mahogany, kadam, mahoe, robusta eucalyptus.
RpE2	2c	Moderate	Moderate	Slight	Honduras pine Honduras pine	1100 1000	Honduras pine, robusta eucalyptus.
RpF2	3c	Severe	Severe	Slight	Honduras pine Honduras pine	1100 1000	Honduras pine, robusta eucalyptus.
Sabana:							
SaF	4d	Moderate	Severe	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.
Soller:							
SoE	4d	Moderate	Moderate	Slight	Honduras mahogany	350	Honduras mahogany.
SoF	4d	Severe	Severe	Severe	Honduras mahogany	350	Honduras mahogany.
Urban land:							
[1]Um: Urban land part.							
Mucara part	3d	Moderate	Moderate	Slight	Honduras pine	900	Honduras pine, robusta eucalyptus.
Yunes:							
YeE, YeF	4d	Moderate	Severe	Slight	Honduras pine	700	Honduras pine, robusta eucalyptus.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 8.--BUILDING SITE DEVELOPMENT

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," and "severe." Absence of an entry means soil was not rated]

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Aceitunas:				
AaB	Moderate: too clayey.	Moderate: low strength.	Moderate: corrosive, low strength.	Moderate: low strength.
AaC	Moderate: slope, too clayey.	Moderate: slope, low strength.	Severe: slope.	Moderate: slope, low strength.
Aibonito:				
AbD, AbE	Severe: slope.	Severe: slope.	Severe: slope, corrosive, low strength.	Severe: slope.
Almirante:				
AmB	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: low strength, shrink-swell.	Moderate: low strength, shrink-swell.
AmC	Moderate: slope, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Bajura:				
Ba	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell, wetness.	Severe: floods, shrink-swell, wetness.	Severe: floods, shrink-swell, wetness.
Bayamon:				
BmB	Moderate: too clayey.	Slight	Slight	Moderate: low strength.
Caguabo:				
CaE, CaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
[1]CbF:				
Caguabo part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Rock outcrop part.				
Candelero:				
Ce	Severe: wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Moderate: wetness, low strength.
Catalina:				
ClC	Moderate: slope, too clayey.	Moderate: slope, low strength.	Severe: slope.	Moderate: slope, low strength.
Catano:				
Cn	Severe: cutbanks cave.	Slight	Slight	Slight.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Cayagua:				
Co	Moderate: slope, wetness.	Moderate: slope, wetness.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Colinas:				
CrD2, CrE2, CrF2	Severe: slope, cutbanks cave.	Severe: slope.	Severe: slope.	Severe: slope, low strength.
Coloso:				
Cs	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell, corrosive.	Severe: floods, shrink-swell, low strength.
Consumo:				
CuE, CuF	Severe: slope, too clayey.	Severe: slope, low strength.	Severe: slope, low strength, corrosive.	Severe: slope, low strength.
Corozal:				
CzC	Severe: too clayey, wetness.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, shrink-swell, wetness.
Daguey:				
DaC	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: slope, corrosive, shrink-swell.	Moderate: low strength, shrink-swell.
DaD	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Descalabrado:				
DeF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
[1]DgF:				
Descalabrado part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Rock outcrop part.				
Dique:				
Dm	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Durados:				
Dr	Severe: cutbanks cave.	Severe: floods.	Severe: floods.	Moderate: floods.
Estacion:				
Es	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Guayama:				
GuF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Humacao:				
Hm	Slight	Moderate: shrink-swell, low strength.	Moderate: slope, shrink-swell, low strength.	Moderate: shrink-swell, low strength.
Humatas:				
HtE, HtF	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
[1]HuF:				
Humatas part	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
Rock outcrop part.				
Hydraquents:				
Hy	Severe: floods, wetness.	Severe: floods, low strength, wetness.	Severe: corrosive, floods, low strength.	Severe: floods, low strength, wetness.
Jagueyes:				
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Juncal:				
JnD2	Moderate: slope, hard to pack, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Juncos:				
JuC	Severe: too clayey.	Severe: low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.	Severe: low strength, shrink-swell.
JuD	Severe: slope, too clayey.	Severe: slope, low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.	Severe: slope, low strength, shrink-swell.
Lares:				
LaB	Severe: too clayey, wetness.	Moderate: low strength, shrink-swell, wetness.	Moderate: low strength, shrink-swell, corrosive.	Severe: low strength.
LaC2	Severe: too clayey, wetness.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Severe: low strength.
Limones:				
LmE, LmF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Lirios:				
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Los Guineos:				
LsE, LsF	Severe: slope, too clayey.	Severe: slope, low strength.	Severe: slope, low strength.	Severe: slope, low strength.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Mabi:				
MaA, MaB	Severe: too clayey, wetness.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell, wetness.	Severe: shrink-swell.
MaC	Severe: too clayey, wetness.	Severe: floods, shrink-swell.	Severe: slope, shrink-swell, wetness.	Severe: shrink-swell.
Made land: Md.				
Malaya:				
MlF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Maricao:				
MoF	Severe: slope.	Severe: slope.	Severe: slope, corrosive.	Severe: slope.
Martin Pena:				
Mp	Severe: floods, too clayey, wetness.	Severe: floods, shrink-swell, wetness.	Severe: corrosive, floods, shrink-swell.	Severe: floods, shrink-swell, wetness.
Matanzas:				
MsB	Moderate: depth to rock, too clayey.	Slight	Slight	Moderate: low strength.
Montegrande:				
MtB	Severe: too clayey, small stones.	Severe: floods, shrink-swell, low strength.	Severe: floods, shrink-swell, corrosive.	Severe: low strength, shrink-swell.
MtC	Severe: too clayey, small stones.	Severe: floods, shrink-swell, low strength.	Severe: slope, shrink-swell, corrosive.	Severe: low strength, shrink-swell.
Morado:				
MuF2	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
Mucara:				
MxD, MxE, MxF	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
Naranjito:				
NaD2, NaE2, NaF2	Severe: slope.	Severe: slope, low strength.	Severe: slope, low strength.	Severe: slope, low strength, shrink-swell.
Pandura:				
PaD, PaE, PaF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pellejas:				
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Reilly:				
Re	Severe: cutbanks cave, floods, small stones.	Severe: floods.	Severe: floods.	Severe: floods.
Rio Arriba:				
RoB, RoC2	Severe: too clayey.	Severe: floods, shrink-swell.	Severe: floods, shrink-swell.	Severe: shrink-swell.
Rio Piedras:				
RpD2, RpE2, RpF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Sabana:				
SaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.
Sabana Seca:				
ScB	Severe: too clayey, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.
Saladar:				
Sm	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.
Soller:				
SoE, SoF	Severe: slope, depth to rock, too clayey.	Severe: slope.	Severe: slope.	Severe: slope, low strength, depth to rock.
Tanama:				
[1]TaF:				
Tanama part	Severe: slope, depth to rock, too clayey.	Severe: slope, depth to rock, low strength.	Severe: slope, depth to rock, corrosive.	Severe: slope, depth to rock, low strength.
Rock outcrop part.				
Toa:				
To	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Torres:				
TrB	Moderate: too clayey.	Slight	Moderate: corrosive.	Slight.
Tropopsamments:				
Ts	Severe: cutbanks cave, floods, wetness.	Severe: floods, wetness.	Severe: corrosive, floods, wetness.	Severe: floods, wetness.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Severe: cutbanks cave.	Severe: floods.	Severe: floods.	Moderate: floods.
[1]Um:				
Urban land part.				

See footnote at end of table.

TABLE 8.--BUILDING SITE DEVELOPMENT--Continued

Soil name and map symbol	Shallow excavations	Dwellings without basements	Small commercial buildings	Local roads and streets
Urban land:				
Mucara part	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.
[1]Us:				
Urban land part.				
Sabana Seca part	Severe: too clayey, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.	Severe: low strength, wetness.
[1]Uv:				
Urban land part.				
Vega Alta part	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: corrosive, low strength, shrink-swell.	Moderate: low strength, shrink-swell.
Vega Alta:				
VaB	Moderate: too clayey.	Moderate: low strength, shrink-swell.	Moderate: corrosive, low strength, shrink-swell.	Moderate: low strength, shrink-swell.
VaC2	Moderate: slope, too clayey.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Vega Baja:				
Vg	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Via:				
VkC2	Moderate: slope, too clayey, small stones.	Moderate: slope, low strength, shrink-swell.	Severe: slope.	Moderate: slope, low strength, shrink-swell.
Vivi:				
Vv	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.
Yunes:				
YeE, YeF	Severe: slope, depth to rock.	Severe: slope.	Severe: slope.	Severe: slope.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 9.--SANITARY FACILITIES

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," "good," "fair," and other terms used to rate soils. Absence of an entry means soil was not rated]

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Aceitunas:					
AaB	Slight	Moderate: slope, seepage.	Moderate: too clayey.	Slight	Fair: too clayey.
AaC	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Fair: slope, too clayey.
Aibonito:					
AbD	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
AbE	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Almirante:					
AmB	Slight	Moderate: slope.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
AmC	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Poor: slope, hard to pack, too clayey.
Bajura:					
Ba	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey, wetness.	Severe: floods, wetness.	Poor: hard to pack, too clayey, wetness.
Bayamon:					
BmB	Slight	Moderate: slope, seepage.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
Caguabo:					
CaE, CaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, small stones.
[1]CbF:					
Caguabo part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, small stones.
Rock outcrop part.					
Candelero:					
Ce	Severe: wetness, percs slowly.	Severe: slope, floods.	Severe: wetness.	Severe: wetness.	Fair: too clayey.
Catalina:					
ClC	Moderate: slope.	Severe: slope, seepage.	Severe: seepage.	Severe: seepage.	Fair: hard to pack, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Catano:					
Cn	Slight	Severe: seepage.	Severe: too sandy, seepage.	Severe: seepage.	Poor: seepage, too sandy.
Cayagua:					
Co	Moderate: slope, wetness.	Severe: slope, seepage.	Severe: seepage.	Severe: seepage, wetness.	Fair: slope.
Colinas:					
CrD2	Severe: slope.	Severe: slope, seepage.	Severe: seepage.	Severe: slope, seepage.	Poor: slope.
CrE2, CrF2	Severe: slope.	Severe: slope, seepage.	Severe: slope, seepage.	Severe: slope, seepage.	Poor: slope.
Coloso:					
Cs	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey.	Severe: floods.	Fair: too clayey, area reclaim.
Consumo:					
CuE, CuF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Corozal:					
CzC	Severe: percs slowly, wetness.	Severe: slope.	Severe: too clayey, wetness.	Moderate: wetness.	Poor: hard to pack, too clayey.
Daguey:					
DaC	Slight	Severe: slope.	Moderate: too clayey.	Slight	Fair: hard to pack, too clayey.
DaD	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
Descalabrado:					
DeF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
[1]DgF:					
Descalabrado part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Rock outcrop part.					
Dique:					
Dm	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Good.
Durados:					
Dr	Moderate: floods.	Severe: seepage.	Severe: seepage, too sandy.	Severe: seepage.	Poor: seepage, too sandy, area reclaim.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Estacion:					
Es	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Poor: area reclaim, thin layer.
Guayama:					
GuF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, area reclaim.
Humacao:					
Hm	Slight	Moderate: slope, seepage.	Slight	Slight	Good.
Humatas:					
HtE, HtF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope.
[1]HuF:					
Humatas part	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope.
Rock outcrop part.					
Hydraquents:					
Hy	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Poor: wetness.
Jagueyes:					
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Juncal:					
JnD2	Moderate: slope.	Severe: slope.	Moderate: too clayey.	Moderate: slope.	Fair: slope, hard to pack, too clayey.
Juncos:					
JuC	Severe: percs slowly, depth to rock.	Severe: slope.	Severe: too clayey, depth to rock.	Moderate: slope.	Poor: too clayey, hard to pack.
JuD	Severe: slope, percs slowly, depth to rock.	Severe: slope.	Severe: too clayey, depth to rock.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Lares:					
LaB	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Poor: too clayey.
LaC2	Moderate: percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope.	Poor: too clayey.
Limones:					
LmE, LmF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Lirios:					
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Los Guineos:					
LsE, LsF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, too clayey, hard to pack.
Mabi:					
MaA	Severe: percs slowly.	Slight	Severe: too clayey.	Moderate: floods, wetness.	Poor: hard to pack, too clayey.
MaB	Severe: percs slowly.	Moderate: slope.	Severe: too clayey.	Moderate: floods, wetness.	Poor: hard to pack, too clayey.
MaC	Severe: percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope, floods, wetness.	Poor: hard to pack, too clayey.
Made land:					
Md.					
Malaya:					
MlF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Maricao:					
MoF	Severe: slope.	Severe: slope.	Severe: slope, too clayey.	Severe: slope.	Poor: slope, hard to pack, too clayey.
Martin Pena:					
Mp	Severe: floods, percs slowly, wetness.	Severe: floods, wetness.	Severe: floods, too clayey, wetness.	Severe: floods, wetness.	Poor: hard to pack, too clayey, wetness.
Matanzas:					
MsB	Severe: depth to rock.	Moderate: slope, depth to rock.	Severe: depth to rock.	Slight	Fair: hard to pack, too clayey.
Montegrande:					
MtB	Moderate: floods, percs slowly.	Moderate: slope, seepage.	Severe: too clayey.	Moderate: floods.	Poor: hard to pack, too clayey.
MtC	Moderate: slope, floods, percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope, floods.	Poor: hard to pack, too clayey.
Morado:					
MuF2	Severe: slope, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage.	Poor: slope.
Mucara:					
MxD	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Mucara:					
MxE, MxF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.
Naranjito:					
NaD2	Severe: slope, depth to rock.	Severe: slope.	Severe: depth to rock.	Severe: slope.	Poor: slope, too clayey.
NaE2, NaF2	Severe: slope, depth to rock.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, too clayey.
Pandura:					
PaD	Severe: slope.	Severe: slope, seepage.	Severe: depth to rock, seepage.	Severe: slope, seepage.	Poor: slope, thin layer.
PaE, PaF	Severe: slope.	Severe: slope, seepage.	Severe: slope, depth to rock, seepage.	Severe: slope, seepage.	Poor: slope, thin layer.
Pellejas:					
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Reilly:					
Re	Severe: floods.	Severe: floods, seepage, small stones.	Severe: floods, seepage, small stones.	Severe: floods, seepage.	Poor: seepage, small stones, thin layer.
Rio Arriba:					
RoB, RoC2	Severe: percs slowly.	Severe: floods.	Severe: too clayey.	Moderate: floods.	Poor: hard to pack, too clayey.
Rio Piedras:					
RpD2	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.	Severe: slope.	Poor: slope.
RpE2, RpF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.	Poor: slope.
Sabana:					
SaF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer.
Sabana Seca:					
ScB	Severe: percs slowly, wetness.	Moderate: slope.	Severe: too clayey, wetness.	Severe: wetness.	Poor: too clayey, wetness.
Saladar:					
Sm	Severe: floods, percs slowly, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: floods, wetness.	Poor: excess humus, wetness.
Soller:					
SoE, SoF	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock, too clayey.	Severe: slope.	Poor: slope, thin layer, area reclaim.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Tanama:					
[1]TaF:					
Tanama part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock, too clayey.	Severe: slope.	Poor: slope, thin layer, area reclaim.
Rock outcrop part.					
Toa:					
To	Severe: floods.	Severe: floods.	Severe: floods.	Severe: floods.	Fair: too clayey.
Torres:					
TrB	Moderate: percs slowly.	Moderate: slope.	Moderate: too clayey.	Slight	Fair: too clayey.
Tropopsamments:					
Ts	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, too sandy, wetness.	Severe: floods, wetness.	Poor: too sandy.
Urban land:					
[1]Ud:					
Urban land part.					
Durados part	Moderate: floods.	Severe: seepage.	Severe: seepage, too sandy.	Severe: seepage.	Poor: seepage, too sandy, area reclaim.
[1]Um:					
Urban land part.					
Mucara part	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope, depth to rock.	Severe: slope.	Poor: slope, thin layer, too clayey.
[1]Us:					
Urban land part.					
Sabana Seca part	Severe: percs slowly, wetness.	Moderate: slope.	Severe: too clayey, wetness.	Severe: wetness.	Poor: too clayey, wetness.
[1]Uv:					
Urban land part.					
Vega Alta part	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Fair: hard to pack, too clayey.
Vega Alta:					
VaB	Moderate: percs slowly.	Moderate: slope.	Severe: too clayey.	Slight	Fair: hard to pack, too clayey.
VaC2	Moderate: slope, percs slowly.	Severe: slope.	Severe: too clayey.	Moderate: slope.	Fair: slope, hard to pack, too clayey.
Vega Baja:					
Vg	Severe: floods, wetness, percs slowly.	Severe: floods, wetness.	Severe: floods, too clayey.	Severe: floods, wetness.	Poor: area reclaim, hard to pack, too clayey.

See footnote at end of table.

TABLE 9.--SANITARY FACILITIES--Continued

Soil name and map symbol	Septic tank absorption fields	Sewage lagoon areas	Trench sanitary landfill	Area sanitary landfill	Daily cover for landfill
Via:					
VkC2	Moderate: slope.	Severe: slope.	Severe: seepage.	Severe: seepage.	Fair: slope, too clayey, small stones.
Vivi:					
Vv	Severe: floods.	Severe: floods, seepage.	Severe: floods, seepage.	Severe: floods, seepage.	Good.
Yunes:					
YeE, YeF	Severe: slope, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage, depth to rock.	Severe: slope, seepage.	Poor: slope, thin layer, area reclaim.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 10.--CONSTRUCTION MATERIALS

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "good," "fair," "poor," and "unsuited." Absence of an entry means soil was not rated]

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Aceitunas:				
AaB	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
AaC	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Aibonito:				
AbD	Fair: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
AbE	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Almirante:				
AmB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: low strength, shrink-swell.
AmC	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, low strength, shrink-swell.
Bajura:				
Ba	Poor: shrink-swell, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
Bayamon:				
BmB	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: low strength.
Caguabo:				
CaE, CaF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer.
[1]CbF:				
Caguabo part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer.
Rock outcrop part.				
Candelero:				
Ce	Fair: shrink-swell, wetness, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Catalina:				
ClC	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Catano:				
Cn	Good	Good	Unsuited: excess fines.	Poor: too sandy.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Cayagua:				
Co	Fair: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope.
Colinas:				
CrD2	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
CrE2, CrF2	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Coloso:				
Cs	Poor: area reclaim, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Consumo:				
CuE, CuF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Corozal:				
CzC	Fair: low strength, shrink-swell, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey, wetness.
Daguey:				
DaC	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
DaD	Fair: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Descalabrado:				
DeF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
[1]DgF:				
Descalabrado part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Rock outcrop part.				
Dique:				
Dm	Good	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Durados:				
Dr	Good	Good	Unsuited excess fines.	Poor: too sandy.
Estacion:				
Es	Good	Unsuited: excess fines.	Good	Poor: thin layer, small stones.
Guayama:				
GuF	Poor: slope, area reclaim, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Humacao:				
Hm	Fair: low strength, shrink-swell.	Unsuited excess fines.	Unsuited excess fines	Good.
Humatas:				
HtE, HtF	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
[1]HuF:				
Humatas part	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Rock outcrop part.				
Hydraquents:				
Hy	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: excess salt, wetness.
Jagueyes:				
JaE2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Juncal:				
JnD2	Fair: area reclaim, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, area reclaim, low strength.
Juncos:				
JuC	Poor: low strength, shrink-swell, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, area reclaim.
JuD	Poor: low strength, shrink-swell, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, area reclaim.
Lares:				
LaB, LaC2	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Limones:				
LmE, LmF	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Lirios:				
LoF2	Poor: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Los Guineos:				
LsE, LsF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey.
Mabi:				
MaA, MaB, MaC	Poor: shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Made land:				
Md.				

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Malaya:				
MlF	Poor: slope, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Maricao:				
MoF	Poor: slope, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Martin Pena:				
Mp	Poor: excess humus, low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: wetness.
Matanzas:				
MsB	Fair: area reclaim, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Montegrande:				
MtB, MtC	Poor: shrink-swell, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Morado:				
MuF2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Mucara:				
MxD	Poor: shrink-swell, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
MxE, MxF	Poor: slope, shrink-swell, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
Naranjito:				
NaD2	Poor: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
NaE2, NaF2	Poor: slope, low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Pandura:				
PaD	Poor: thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
PaE, PaF	Poor: slope, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
Pellejas:				
PeF	Poor: slope.	Poor: excess fines.	Unsuited: excess fines.	Poor: slope.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Reilly:				
Re	Good	Fair: excess fines.	Fair: excess fines.	Poor: small stones, thin layer.
Rio Arriba:				
RoB, RoC2	Poor: shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey.
Rio Piedras:				
RpD2	Fair: slope, area reclaim, low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
RpE2, RpF2	Poor: slope.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope.
Sabana:				
SaF	Poor: slope, low strength, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim, thin layer.
Sabana Seca:				
ScB	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
Saladar:				
Sm	Poor: excess humus, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: wetness.
Soller:				
SoE, SoF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, area reclaim.
Tanama:				
[1]TaF:				
Tanama part	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, area reclaim.
Rock outcrop part.				
Toa:				
To	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Torres:				
TrB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Tropopsamments:				
Ts	Poor: area reclaim, wetness.	Good	Unsuited: excess fines.	Poor: excess lime, excess salt, too sandy.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Good	Good	Unsuited: excess fines.	Poor: too sandy.

See footnote at end of table.

TABLE 10.--CONSTRUCTION MATERIALS--Continued

Soil name and map symbol	Roadfill	Sand	Gravel	Topsoil
Urban land:				
[1]Um:				
Urban land part.				
Mucara part	Poor: slope, shrink-swell, thin layer.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, too clayey, thin layer.
[1]Us:				
Urban land part.				
Sabana Seca part	Poor: low strength, wetness.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: too clayey, wetness.
[1]Uv:				
Urban land part.				
Vega Alta part	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Vega Alta:				
VaB	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
VaC2	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey.
Vega Baja:				
Vg	Poor: low strength.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: too clayey.
Via:				
VkC2	Fair: low strength, shrink-swell.	Unsuited: excess fines.	Unsuited: excess fines.	Fair: slope, too clayey, small stones.
Vivi:				
Vv	Good	Unsuited: excess fines.	Unsuited: excess fines.	Good.
Yunes:				
YeE, YeF	Poor: slope, thin layer, area reclaim.	Unsuited: excess fines.	Unsuited: excess fines.	Poor: slope, thin layer, small stones.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 11.--WATER MANAGEMENT

["Seepage," and some of the other terms that describe restrictive soil features are defined in the Glossary. Absence of an entry means soil was not evaluated]

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Aceitunas: AaB, AaC	Seepage, slope.	Compressible, low strength.	Not needed	Slope	Favorable.
Aibonito: AbD, AbE	Seepage, slope.	Compressible, low strength.	Not needed	Slope	Slope.
Almirante: AmB, AmC	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Bajura: Ba	Slight	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, poor outlets, wetness.	Not needed.
Bayamon: BmB	Seepage	Compressible, low strength, seepage.	Not needed	Slope	Favorable.
Caguabo: CaE, CaF	Depth to rock, slope.	Thin layer, low strength.	Not needed	Depth to rock, slope.	Erodes easily, slope.
[1]CbF: Caguabo part	Depth to rock, slope.	Thin layer, low strength.	Not needed	Depth to rock, slope.	Erodes easily, slope.
Rock outcrop part.					
Candelero: Ce	Slope	Low strength, compressible.	Percs slowly, wetness.	Percs slowly, slope, wetness.	Percs slowly, wetness.
Catalina: ClC	Seepage, slope.	Compressible, hard to pack, unstable fill.	Not needed	Complex slope	Favorable.
Catano: Cn	Seepage	Seepage, piping.	Not needed	Too sandy, piping.	Not needed.
Cayagua: Co	Seepage, slope.	Low strength, piping.	Complex slope	Slope	Slope.
Colinas: CrD2, CrE2, CrF2	Slope, seepage, cutbanks cave.	Hard to pack, seepage, piping, cutbanks cave.	Not needed	Piping, slope.	Slope.
Coloso: Cs	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, wetness.	Percs slowly, wetness.
Consumo: CuE, CuF	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Corozal:					
CzC	Favorable	Compressible, hard to pack, low strength.	Percs slowly, wetness.	Percs slowly, wetness.	Percs slowly, wetness.
Daguey:					
DaC, DaD	Seepage, slope.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Descalabrado:					
DeF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
[1]DgF:					
Descalabrado part	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
Rock outcrop part.					
Dique:					
Dm	Seepage	Seepage, piping.	Not needed	Not needed	Favorable.
Durados:					
Dr	Seepage	Seepage, piping, unstable fill.	Not needed	Too sandy, piping.	Droughty.
Estacion:					
Es	Seepage	Seepage	Not needed	Not needed	Favorable.
Guayama:					
GuF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth, droughty.
Humacao:					
Hm	Favorable	Favorable	Not needed	Favorable	Favorable.
Humatas:					
HtE, HtF	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
[1]HuF:					
Humatas part	Slope, seepage.	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Rock outcrop part.					
Hydraquents:					
Hy	Seepage	Hard to pack, low strength, unstable fill.	Excess salt, floods, wetness.	Not needed	Not needed.
Jagueyes:					
JaE2	Seepage, slope.	Low strength, piping, seepage.	Not needed	Slope	Slope.
Juncal:					
JnD2	Favorable	Compressible, low strength, shrink-swell.	Not needed	Slope	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Juncos:					
JuC, JuD	Slope	Compressible, hard to pack, shrink-swell.	Percs slowly	Complex slope, depth to rock, percs slowly.	Percs slowly.
Lares:					
LaB, LaC2	Favorable	Compressible, low strength, shrink-swell.	Not needed	Complex slope	Favorable.
Limones:					
LmE, LmF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Lirios:					
LoF2	Slope	Compressible, hard to pack, shrink-swell.	Not needed	Slope	Slope.
Los Guineos:					
LsE, LsF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Mabi:					
MaA, MaB, MaC	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly.	Percs slowly, slope, wetness.	Percs slowly, slope, wetness.
Made land:					
Md.					
Malaya:					
MlF	Slope, depth to rock.	Thin layer	Not needed	Slope, depth to rock, rooting depth.	Slope, rooting depth.
Maricao:					
MoF	Slope	Compressible, hard to pack, low strength.	Not needed	Slope	Slope.
Martin Pena:					
Mp	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly, poor outlets.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
Matanzas:					
MsB	Depth to rock, seepage.	Compressible, hard to pack, thin layer.	Not needed	Not needed	Favorable.
Montegrande:					
MtB, MtC	Slope	Compressible, hard to pack, shrink-swell.	Not needed	Slope	Slope.
Morado:					
MuF2	Slope, depth to rock.	Compressible, hard to pack, thin layer.	Not needed	Slope, depth to rock.	Slope.
Mucara:					
MxD, MxE, MxF	Slope, depth to rock.	Shrink-swell, compressible, thin layer.	Not needed	Depth to rock, slope.	Slope, depth to rock.
Naranjito:					
NaD2, NaE2, NaF2	Slope, depth to rock.	Compressible, hard to pack, low strength.	Not needed	Depth to rock, slope.	Slope.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Pandura:					
PaD, PaE, PaF	Slope, depth to rock.	Seepage, thin layer.	Not needed	Depth to rock, slope.	Droughty, slope.
Pellejas:					
PeF	Seepage, slope.	Seepage	Not needed	Slope	Droughty, erodes easily, slope.
Reilly:					
Re	Seepage	Seepage	Not needed	Not needed	Not needed.
Rio Arriba:					
RoB, RoC2	Favorable	Compressible, hard to pack, shrink-swell.	Floods, percs slowly.	Percs slowly	Percs slowly.
Rio Piedras:					
RpD2, RpE2, RpF2	Slope	Compressible, hard to pack, low strength.	Not needed	Slope, rooting depth.	Slope.
Sabana:					
SaF	Slope, depth to rock.	Thin layer	Not needed	Depth to rock, slope, rooting depth.	Erodes easily, slope.
Sabana Seca:					
ScB	Favorable	Compressible, hard to pack, low strength.	Percs slowly, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
Saladar:					
Sm	Excess humus	Excess humus, hard to pack, seepage.	Floods, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, rooting depth, wetness.
Soller:					
SoE, SoF	Slope, depth to rock.	Compressible, low strength, thin layer.	Not needed	Depth to rock, slope.	Slope, rooting depth.
Tanama:					
[1]TaF:					
Tanama part	Depth to rock, slope.	Compressible, low strength, thin layer.	Not needed	Depth to rock, slope.	Rooting depth, slope.
Rock outcrop part.					
Toa:					
To	Favorable	Favorable	Floods	Not needed	Favorable.
Torres:					
TrB	Favorable	Compressible, low strength.	Not needed	Too sandy, slope.	Droughty.
Tropopsamments:					
Ts	Seepage	Seepage, unstable fill.	Cutbanks cave, excess salt, floods.	Not needed	Not needed.
Urban land:					
[1]Ud:					
Urban land part.					
Durados part	Seepage	Seepage, piping, unstable fill.	Not needed	Too sandy, piping.	Droughty.

See footnote at end of table.

TABLE 11.--WATER MANAGEMENT--Continued

Soil name and map symbol	Pond reservoir areas	Embankments, dikes, and levees	Drainage	Terraces and diversions	Grassed waterways
Urban land:					
[1]Um:					
Urban land part.					
Mucara part	Slope, depth to rock.	Shrink-swell, compressible, thin layer.	Not needed	Depth to rock, slope.	Slope, depth to rock.
[1]Us:					
Urban land part.					
Sabana Seca part	Favorable	Compressible, hard to pack, low strength.	Percs slowly, poor outlets, wetness.	Percs slowly, poor outlets, wetness.	Percs slowly, wetness.
[1]Uv:					
Urban land part.					
Vega Alta part	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Vega Alta: VaB, VaC2	Favorable	Compressible, hard to pack, low strength.	Not needed	Slope	Favorable.
Vega Baja: Vg	Slight	Compressible, hard to pack, low strength.	Floods, percs slowly.	Complex slope, percs slowly.	Not needed.
Via: VkC2	Slope, seepage.	Compressible, low strength.	Not needed	Slope	Favorable.
Vivi: Vv	Seepage	Piping, low strength, hard to pack.	Not needed	Not needed	Not needed.
Yunes: YeE, YeF	Slope, seepage, depth to rock.	Thin layer	Not needed	Depth to rock, slope.	Slope, rooting depth.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 12.--RECREATIONAL DEVELOPMENT

["Shrink-swell" and some of the other terms that describe restrictive soil features are defined in the Glossary. See text for definitions of "slight," "moderate," and "severe"]

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Aceitunas:				
AaB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
AaC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Aibonito:				
AbD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
AbE	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Almirante:				
AmB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
AmC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Bajura:				
Ba	Severe: floods, wetness, too clayey.	Severe: floods, too clayey, wetness.	Severe: floods, wetness, too clayey.	Severe: too clayey, wetness.
Bayamon:				
BmB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Caguabo:				
CaE, CaF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock, too clayey.	Severe: slope.
[1]CbF:				
Caguabo part	Severe: slope.	Severe: slope.	Severe: slope, depth to rock, too clayey.	Severe: slope.
Rock outcrop part.				
Candelero:				
Ce	Severe: wetness.	Severe: wetness.	Severe: slope, wetness.	Severe: wetness.
Catalina:				
ClC	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Catano:				
Cn	Moderate: too sandy.	Moderate: too sandy.	Severe: too sandy.	Moderate: too sandy.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Cayagua:				
Co	Severe: wetness.	Severe: wetness.	Severe: slope, wetness.	Severe: wetness.
Colinas:				
CrD2	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.
CrE2, CrF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Coloso:				
Cs	Severe: floods, wetness.	Moderate: too clayey, wetness.	Moderate: too clayey, wetness.	Moderate: too clayey, wetness.
Consumo:				
CuE, CuF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Corozal:				
CzC	Severe: too clayey, percs slowly.	Severe: too clayey.	Severe: slope, too clayey, wetness.	Severe: too clayey.
Daguey:				
DaC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
DaD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Descalabrado:				
DeF	Severe: slope.	Severe: slope.	Severe: slope; depth to rock.	Severe: slope.
[1]DgF:				
Descalabrado part	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Rock outcrop part.				
Dique:				
Dm	Severe: floods.	Moderate: floods.	Moderate: floods.	Slight.
Durados:				
Dr	Slight	Slight	Slight	Slight.
Estacion:				
Es	Severe: floods.	Moderate: floods, too clayey.	Moderate: floods, too clayey.	Moderate: too clayey.
Guayama:				
GuF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Humacao:				
Hm	Slight	Slight	Moderate: slope.	Slight.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Humatas:				
HtE, HtF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
[1]HuF:				
Humatas part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Rock outcrop part.				
Hydraquents:				
Hy	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.	Severe: floods, wetness.
Jagueyes:				
JaE2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Juncal:				
JnD2	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Juncos:				
JuC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
JuD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Lares:				
LaB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.
LaC2	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Limones:				
LmE, LmF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Lirios:				
LoF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Los Guineos:				
LsE, LsF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Mabi:				
MaA, MaB	Severe: percs slowly, too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
MaC	Severe: percs slowly, too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Made land:				
Md.				

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Malaya:				
MlF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Maricao:				
MoF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Martin Pena:				
Mp	Severe: floods, percs slowly, wetness.	Severe: floods, wetness, excess humus.	Severe: floods, wetness, excess humus.	Severe: floods, wetness, excess humus.
Matanzas:				
MsB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Montegrande:				
MtB	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
MtC	Severe: too clayey.	Severe: too clayey.	Severe: slope, too clayey.	Severe: too clayey.
Morado:				
MuF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Mucara:				
MxD	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: too clayey.
MxE, MxF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Naranjito:				
NaD2	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope, too clayey.
NaE2, NaF2	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pandura:				
PaD	Severe: slope.	Severe: slope.	Severe: slope.	Moderate: slope.
PaE, PaF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Pellejas:				
PeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope.
Reilly:				
Re	Moderate: floods, small stones.	Moderate: floods, small stones.	Severe: floods, small stones.	Moderate: small stones.
Rio Arriba:				
RoB, RoC2	Severe: too clayey, percs slowly.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Rio Piedras:				
RpD2, RpE2, RpF2	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Sabana:				
SaF	Severe: slope.	Severe: slope.	Severe: slope, depth to rock.	Severe: slope.
Sabana Seca:				
ScB	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.
Saladar:				
Sm	Severe: excess humus, floods, percs slowly.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.	Severe: excess humus, floods, wetness.
Soller:				
SoE, SoF	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
Tanama:				
[1]TaF:				
Tanama part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, depth to rock, too clayey.	Severe: slope, too clayey.
Rock outcrop part.				
Toa:				
To	Severe: floods.	Moderate: floods, too clayey.	Moderate: floods, too clayey.	Moderate: too clayey.
Torres:				
TrB	Slight	Slight	Moderate: slope.	Slight.
Tropopsamments:				
Ts	Severe: floods, too sandy.	Severe: floods, too sandy.	Severe: floods, too sandy.	Severe: too sandy, floods.
Urban land:				
[1]Ud:				
Urban land part.				
Durados part	Slight	Slight	Slight	Slight.
[1]Um:				
Urban land part.				
Mucara part	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.	Severe: slope, too clayey.
[1]Us:				
Urban land part.				
Sabana Seca part	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.	Severe: percs slowly, too clayey, wetness.	Severe: too clayey, wetness.

See footnote at end of table.

TABLE 12.--RECREATIONAL DEVELOPMENT--Continued

Soil name and map symbol	Camp areas	Picnic areas	Playgrounds	Paths and trails
Urban land:				
[1]Uv:				
Urban land part.				
Vega Alta part	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
Vega Alta:				
VaB	Moderate: too clayey.	Moderate: too clayey.	Moderate: slope, too clayey.	Moderate: too clayey.
VaC2	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Vega Baja:				
Vg	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.	Severe: too clayey.
Via:				
VkC2	Moderate: slope, too clayey.	Moderate: slope, too clayey.	Severe: slope.	Moderate: too clayey.
Vivi:				
Vv	Severe: floods.	Moderate: floods.	Moderate: floods.	Slight.
Yunes:				
YeE, YeF	Severe: slope.	Severe: slope.	Severe: slope.	Severe: slope, small stones.

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS

[The symbol < means less than; > means greater than. Absence of an entry means data were not estimated]

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number--: 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Aceitunas:											
AaB, AaC----------	0-8	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	8-60	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
Aibonito:											
AbD, AbE----------	0-7	Clay------------	MH	A-7	0	100	100	90-100	75-100	60-70	20-30
	7-43	Clay------------	MH	A-7	0	100	100	95-100	90-100	60-70	20-30
	43-99	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
Almirante:											
AmB, AmC----------	0-60	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	20-30
Bajura:											
Ba----------------	0-60	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	45-55
Bayamon:											
BmB---------------	0-66	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-60	10-20
Caguabo:											
CaE, CaF----------	0-4	Clay loam-------	CL, SC	A-7	0	75-100	55-100	50-100	40-80	40-50	20-30
	4-10	Very gravelly clay loam, very gravelly silty clay loam.	GC, SC	A-2	0	40-80	25-35	22-35	18-30	30-40	10-15
	10-16	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	16	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]CbF:											
Caguabo part-----	0-4	Clay loam-------	CL, SC	A-7	0	75-100	55-100	50-100	40-80	40-50	20-30
	4-10	Very gravelly clay loam, very gravelly silty clay loam.	GC, SC	A-2	0	40-80	25-35	22-35	18-30	30-40	10-15
	10-16	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	16	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Candelero:											
Ce----------------	0-6	Loam------------	ML, SM	A-4, A-2	0	100	100	60-95	30-75	15-25	2-7
	6-35	Sandy clay loam	SC	A-6	0	100	100	80-90	35-50	30-40	15-25
	35-58	Sandy clay loam, sandy clay.	SC, CL	A-6	0	100	100	80-95	35-60	30-40	15-25
Catalina:											
ClC---------------	0-6	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	6-84	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	84-99	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
Catano:											
Cn----------------	0-7	Loamy sand------	SP-SM	A-2, A-3	0	100	100	50-70	5-15	<20	NP
	7-58	Sand------------	SP-SM	A-2, A-3	0	100	100	50-70	5-15	<20	NP
Cayagua:											
Co----------------	0-8	Sandy loam------	SM, ML	A-2, A-4	0	100	100	60-90	30-60	30-40	2-7
	8-22	Clay, sandy clay	MH	A-7	0	100	100	85-100	50-95	60-70	20-30
	22-60	Sandy loam, sandy clay loam.	SM, ML	A-2, A-4	0	100	100	60-90	30-60	30-40	2-7
Colinas:											
CrD2, CrE2, CrF2--	0-26	Clay loam-------	CL	A-6	0	90-100	75-100	70-100	55-80	30-40	15-20
	26-52	Marl------------	CL, CL-ML	A-4	0	90-100	75-90	70-85	65-70	20-30	4-10

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification		Frag- ments > 3 inches	Percentage passing sieve number--				Liquid limit	Plas- ticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
Coloso:											
Cs----------------	0-16	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	20-30
	16-70	Silty clay loam, silty clay, clay.	CL, MH, CH	A-7	0	100	100	95-100	85-95	40-70	20-35
Consumo:											
CuE, CuF----------	0-20	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	25-35
	20-46	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	70-80	25-35
Corozal:											
CzC---------------	0-9	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	9-40	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-70	15-25
	40-60	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-35	10-15
Daguey:											
DaC, DaD----------	0-10	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	10-72	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	72-90	Silty clay loam	MH	A-7	0	100	100	85-95	70-90	70-80	25-35
Descalabrado:											
DeF---------------	0-5	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-40	15-20
	5-17	Gravelly clay, gravelly clay loam, gravelly sandy clay loam.	SC, CL	A-6	0	100	50-75	45-75	38-70	30-40	12-20
	17	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]DgF:											
Descalabrado part	0-5	Clay loam-------	CL	A-6	0	100	100	90-100	70-80	30-40	15-20
	5-17	Gravelly clay, gravelly clay loam, gravelly sandy clay loam.	SC, CL	A-6	0	100	50-75	45-75	38-70	30-40	12-20
	17	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Dique:											
Dm----------------	0-54	Loam------------	ML	A-4	0	100	100	85-100	60-90	30-40	5-10
Durados:											
Dr----------------	0-14	Sandy loam------	SM	A-2	0	100	100	60-70	25-35	---	NP
	14-23	Loamy sand------	SM	A-2	0	100	100	50-75	15-30	---	NP
	23-60	Sand------------	SP-SM, SM	A-2, A-3	0	95-100	75-100	50-70	5-15	---	NP
Estacion:											
Es----------------	0-8	Silty clay loam	CL	A-6	0	95-100	70-95	65-95	50-90	30-40	15-20
	8-20	Gravelly clay loam, gravelly silty clay loam.	GM-GC, GC, CL, CL-ML	A-4	0	65-80	55-75	50-75	40-70	20-30	5-10
	20-50	Gravelly sand---	GP, GP-GM, SP, SP-SM	A-1	15-65	30-55	25-50	15-35	1-8	---	NP

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Frag- ments > 3 inches	Percentage passing sieve number-- 4	10	40	200	Liquid limit	Plas- ticity index
	In				Pct					Pct	
Guayama:											
GuF----------------	0-4	Clay loam--------	CL	A-6	0	100	75-100	70-100	55-80	30-40	15-20
	4-20	Gravelly clay, gravelly silty clay loam, clay.	GC, CL, SC	A-6, A-2	0	50-100	50-100	40-100	20-80	30-40	15-20
	20	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Humacao:											
Hm-----------------	0-8	Loam------------	ML	A-4	0	100	100	85-95	60-75	30-40	5-10
	8-60	Sandy clay loam, clay loam.	CL	A-7	0	100	100	80-90	70-80	40-50	20-30
Humatas:											
HtE, HtF----------	0-5	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	5-24	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	24-60	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	60-70	25-30
[1]HuF:											
Humatas part-----	0-5	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	5-24	Clay------------	MH	A-7	0	100	100	90-100	85-95	70-80	30-35
	24-60	Clay, silty clay, silty clay loam.	MH	A-7	0	100	100	95-100	85-95	60-70	25-30
Rock outcrop part.											
Hydraquents:											
Hy-----------------	0-60	Variable--------	---	---	0	---	---	---	---	---	---
Jagueyes:											
JaE2---------------	0-5	Loam------------	SM, ML	A-2, A-4	0	100	100	60-95	30-75	---	NP
	5-41	Clay loam, sandy clay loam.	CL, SC	A-6	0	100	100	80-100	35-80	35-40	15-20
	41-62	Sandy clay loam, clay loam.	SC, SM, ML, CL	A-4	0	100	100	80-100	35-80	25-35	5-10
Juncal:											
JnD2---------------	0-10	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
	10-48	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
	48-60	Silty clay loam	MH	A-7	0	100	100	95-100	85-95	60-70	20-25
Juncos:											
JuC, JuD----------	0-31	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	31-40	Clay------------	CH	A-7	0	95-100	75-100	70-100	60-95	70-80	40-50
	40	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Lares:											
LaB, LaC2---------	0-36	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	36-60	Clay------------	MH	A-7	0	85-100	85-100	75-95	60-80	60-70	20-30
Limones:											
LmE, LmF----------	0-79	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	30-40
Lirios:											
LoF2---------------	0-4	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	15-25
	4-34	Clay, silty clay	MH	A-7	0	100	100	90-100	75-95	60-70	25-30
	34-60	Silty clay loam	CL	A-7	0	100	100	95-100	85-95	40-50	15-25
Los Guineos:											
LsE, LsF----------	0-5	Clay------------	MH, CH	A-7	0	100	100	90-100	75-95	60-80	25-35
	5-60	Clay------------	MH, CH	A-7	0	100	100	90-100	75-95	60-80	25-35
Mabi:											
MaA, MaB, MaC-----	0-24	Clay------------	CH	A-7	0	100	90-100	85-100	70-95	55-75	40-60
	24-99	Clay------------	CH	A-7	0	100	90-100	85-100	70-95	55-75	40-60

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Frag- ments > 3 inches	Percentage passing sieve number-- 4	10	40	200	Liquid limit	Plas- ticity index
	In				Pct					Pct	
Made land: Md.											
Malaya:											
MlF---------------	0-6	Clay loam-------	CL, ML	A-7	0	100	100	90-100	70-90	40-50	15-20
	6-13	Gravelly clay---	SC, CL, GC	A-7	0	60-80	55-75	50-75	40-70	40-50	20-30
	13-18	Gravelly clay loam.	SC, CL, SM, ML, GM, GC	A-2, A-7	0	60-80	55-75	50-75	30-60	40-50	15-20
	18	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Maricao:											
MoF---------------	0-14	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	25-30
	14-60	Silty clay loam, silty clay.	MH	A-7	0	100	100	95-100	85-95	50-60	15-20
Martin Pena:											
Mp----------------	0-8	Muck------------	OH	---	0	---	---	---	---	---	NP
	8-18	Silty clay loam, clay.	CH	A-7	0	100	100	95-100	85-95	50-60	30-40
	18-63	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
Matanzas:											
MsB---------------	0-20	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	20-53	Clay------------	MH	A-7	0	100	100	90-100	75-95	60-70	20-30
	53	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Montegrande:											
MtB, MtC----------	0-7	Clay------------	CH, MH	A-7	0	100	100	90-100	75-95	70-80	35-45
	7-29	Clay------------	CH, MH	A-7	0	100	100	90-100	75-95	70-80	35-45
	29-48	Very gravelly clay.	GC	A-2	0	40-50	20-35	18-20	15-19	30-40	15-20
Morado:											
MuF2--------------	0-34	Clay loam-------	CL	A-7	0	100	100	90-100	70-80	40-50	20-30
	34	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Mucara:											
MxD, MxE, MxF-----	0-5	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	5-12	Clay, silty clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	12-30	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	30	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Naranjito:											
NaD2, NaE2, NaF2--	0-4	Silty clay loam	MH	A-7	0	80-95	75-95	70-95	65-90	60-70	20-30
	4-24	Clay------------	MH	A-7	0	80-95	75-90	70-90	55-85	70-80	25-35
	24-40	Clay loam-------	CL	A-7	0	80-90	75-90	70-90	55-70	40-50	20-30
	40	Weathered bedrock.	---	---	---	---	---	---	---	---	---
Pandura:											
PaD, PaE, PaF-----	0-7	Sandy loam------	SM, ML	A-2, A-4	0	100	100	60-95	30-75	<35	NP-10
	7-26	Sandy loam, loam	SM, ML	A-2, A-4	0	100	100	60-95	30-75	<35	NP-10
	26	Weathered bedrock.	---	---	---	---	---	---	---	---	---
Pellejas:											
PeF---------------	0-16	Clay loam-------	CL	A-7	0	100	100	85-100	60-80	40-50	20-30
	16-60	Sandy loam, loamy sand.	SM	A-2	0	100	100	50-75	25-35	---	---

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification		Frag- ments > 3 inches	Percentage passing sieve number--				Liquid limit	Plas- ticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
Reilly:											
Re	0-18	Sandy loam	SM	A-2-4	0	100	100	60-70	30-35	---	---
	18-55	Stratified very gravelly sand to sand.	SP-SM, GW	A-1	0	20-55	10-50	5-35	0-8	---	---
Rio Arriba:											
RoB, RoC2	0-8	Clay	CH	A-7	0	100	100	90-100	75-95	55-75	40-60
	8-60	Clay	CH	A-7	0	100	100	90-100	75-95	55-75	40-60
Rio Piedras:											
RpD2, RpE2, RpF2	0-8	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	8-28	Clay	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
	28-48	Clay	MH	A-7	0	100	100	85-95	70-95	70-80	25-35
	48	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Sabana:											
SaF	0-3	Silty clay loam	CL	A-6	0	80-100	75-100	70-100	60-95	30-40	10-20
	3-15	Silty clay, clay	CH	A-7	0	80-100	75-100	65-100	55-95	70-80	40-50
	15	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Sabana Seca:											
ScB	0-70	Clay	MH	A-7	0	100	100	90-100	75-95	50-60	15-20
Saladar:											
Sm	0-51	Muck	OH	---	0	---	---	---	---	---	NP
Soller:											
SoE, SoF	0-5	Clay loam	CL	A-6	0-10	100	100	90-100	70-80	30-40	15-20
	5-12	Clay	CH	A-7	0-35	95-100	90-100	80-100	60-95	70-80	40-50
	12-24	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	24	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Tanama:											
[1]TaF:											
Tanama part	0-14	Clay	MH	A-7	0-15	100	100	90-100	75-95	70-80	30-40
	14	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
Rock outcrop part.											
Toa:											
To	0-60	Silty clay loam	CL	A-6	0	100	100	90-100	70-95	30-40	15-20
Torres:											
TrB	0-28	Loamy sand	SM, SP-SM	A-2, A-3, A-4	0	100	100	50-70	5-40	---	NP
	28-64	Clay	MH	A-7	0	100	100	90-100	75-95	50-60	12-20
Tropopsamments:											
Ts	0-60	Sand	SP, SM, SM-SC	A-2, A-3, A-4	0	100	100	52-70	2-40	---	---
Urban land:											
[1]Ud:											
Urban land part.											
Durados part	0-14	Sandy loam	SM	A-2	0	100	100	60-70	25-35	---	NP
	14-23	Loamy sand	SM	A-2	0	100	100	50-75	15-30	---	NP
	23-60	Sand	SP-SM, SM	A-2, A-3	0	95-100	75-100	50-70	5-15	---	NP
[1]Um:											
Urban land part.											

See footnote at end of table.

TABLE 13.--ENGINEERING PROPERTIES AND CLASSIFICATIONS--Continued

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Fragments > 3 inches	Percentage passing sieve number-- 4	10	40	200	Liquid limit	Plasticity index
	In				Pct					Pct	
Urban land:											
Mucara part------	0-6	Clay------------	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	6-12	Clay, silty clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
	12-22	Weathered bedrock.	---	---	---	---	---	---	---	---	---
	22	Unweathered bedrock.	---	---	---	---	---	---	---	---	---
[1]Us:											
Urban land part.											
Sabana Seca part-	0-70	Clay------------	MH	A-7	0	100	100	90-100	75-95	50-60	15-20
[1]Uv:											
Urban land part.											
Vega Alta part---	0-8	Clay loam-------	MH	A-7	0	100	100	90-100	70-95	60-70	20-30
	8-84	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
Vega Alta:											
VaB, VaC2---------	0-8	Clay loam-------	MH	A-7	0	100	100	90-100	70-95	60-70	20-30
	8-84	Clay------------	MH	A-7	0	100	100	90-100	75-95	70-80	25-35
Vega Baja:											
Vg----------------	0-7	Silty clay------	CH	A-7	0	100	95-100	90-100	75-95	70-80	40-50
	7-50	Silty clay, clay, silty clay loam.	CH	---	0	100	95-100	90-100	75-95	70-80	40-50
	50-60	Silty clay, clay	CH	A-7	0	100	100	90-100	75-95	70-80	40-50
Via:											
VkC2--------------	0-9	Clay loam-------	CL	A-7	0-5	100	85-95	80-95	60-90	40-50	20-30
	9-36	Clay loam, gravelly clay loam.	CL, GC, SC	A-6	0	65-95	50-90	45-90	35-70	30-40	15-20
	36-52	Very gravelly clay loam.	GP-GC, SP-SC, GC, SC	A-2, A-6	0	25-70	10-65	9-65	7-50	30-40	15-20
Vivi:											
Vv----------------	0-9	Loam------------	ML, SM	A-2, A-4	0	100	100	60-95	30-75	---	---
	9-47	Very fine sandy loam, loam.	ML	A-4	0	100	100	85-95	50-75	---	---
	47-58	Loamy sand------	SP-SM, SM	A-1, A-2	0	100	85-100	45-65	5-15	---	---
Yunes:											
YeE, YeF----------	0-2	Silty clay loam	MH	A-7	0	100	75-100	70-100	60-95	60-70	20-30
	2-16	Very shaly silty clay loam.	GC, GP-GC	A-2	0	15-40	10-35	5-30	5-30	20-30	7-12
	16	Fragmental material.	---	---	---	---	---	---	---	---	---

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

[Dashes indicate data were not available. The symbol < means less than; > means greater than. The erosion tolerance factor (T) is for the entire profile. Absence of an entry means data were not estimated]

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Aceitunas:									
AaB, AaC	0-8	0.6-2.0	0.10-0.15	4.5-5.5	Low	High	High	0.10	5
	8-60	0.6-2.0	0.10-0.15	4.5-5.5	Low	High	High	0.10	
Aibonito:									
AbD, AbE	0-7	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	4
	7-43	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	
	43-99	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High	High	0.10	
Almirante:									
AmB, AmC	0-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High	High	0.17	4
Bajura:									
Ba	0-60	0.06-0.2	0.15-0.20	5.6-6.5	High	High	Moderate	---	---
Bayamon:									
BmB	0-66	0.6-2.0	0.10-0.15	4.5-5.0	Low	High	Moderate	0.10	5
Caguabo:									
CaE, CaF	0-4	0.6-2.0	0.10-0.15	6.1-6.5	Moderate	Moderate	Low	0.24	3
	4-10	0.6-2.0	0.05-0.07	6.1-6.5	Low	Low	Low	0.17	
	10-16	---	---	---	---	---	---	---	
	16	---	---	---	---	---	---	---	
[1]CbF:									
Caguabo part	0-4	0.6-2.0	0.10-0.15	6.1-6.5	Moderate	Moderate	Low	0.24	3
	4-10	0.6-2.0	0.05-0.07	6.1-6.5	Low	Low	Low	0.17	
	10-16	---	---	---	---	---	---	---	
	16	---	---	---	---	---	---	---	
Rock outcrop part.									
Candelero:									
Ce	0-6	2.0-6.0	0.05-0.10	4.5-6.0	Low	High	High	0.24	4
	6-35	0.06-0.2	0.10-0.15	4.5-6.0	Moderate	High	High	---	
	35-58	0.06-0.2	0.10-0.15	4.5-6.0	Moderate	High	Low	---	
Catalina:									
ClC	0-6	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	Moderate	0.10	5
	6-84	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	High	0.10	
	84-99	2.0-6.0	0.10-0.15	4.5-6.0	Moderate	High	Moderate	0.10	
Catano:									
Cn	0-7	>20.0	<0.05	7.9-8.4	Very low	Low	Low	---	---
	7-58	>20.0	<0.05	7.9-8.4	Very low	Low	Low	---	
Cayagua:									
Co	0-8	0.6-2.0	0.11-0.13	4.5-5.5	Very low	Low	High	0.24	4
	8-22	0.6-2.0	0.13-0.15	4.5-5.5	Moderate	High	High	0.20	
	22-60	2.0-6.0	0.11-0.13	4.5-7.3	Very low	Low	High	0.24	
Colinas:									
CrD2, CrE2, CrF2	0-26	0.6-2.0	0.18-0.20	7.4-7.8	Moderate	Moderate	Low	0.17	3
	26-52	2.0-6.0	0.05-0.10	7.4-7.8	Low	Low	Low	0.10	
Coloso:									
Cs	0-16	0.2-0.6	0.14-0.18	5.6-6.0	Moderate	High	Low	---	---
	16-70	0.06-0.2	0.12-0.18	5.6-6.0	High	High	Low	---	
Consumo:									
CuE, CuF	0-20	0.6-2.0	0.12-0.18	4.5-5.0	Moderate	High	High	0.17	3
	20-46	0.6-2.0	0.10-0.16	4.5-5.0	Moderate	High	High	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea- bility	Available water capacity	Soil reaction	Shrink- swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
Corozal:									
CzC---------------	0-9	0.06-0.2	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	0.24	5
	9-40	0.06-0.2	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	---	
	40-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High----------	High-----------	---	
Daguey:									
DaC, DaD----------	0-10	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	0.10	4
	10-72	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	0.10	
	72-90	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	High----------	High-----------	0.10	
Descalabrado:									
DeF---------------	0-5	0.6-2.0	0.15-0.20	6.6-7.3	Low-------	Moderate------	Low------------	0.24	3
	5-17	0.6-2.0	0.10-0.15	6.6-7.3	Low-------	Moderate------	Low------------	---	
	17	---	---	---	----------	--------------	---------------	---	
[1]DgF:									
Descalabrado part	0-5	0.6-2.0	0.15-0.20	6.6-7.3	Low-------	Moderate------	Low------------	0.24	3
	5-17	0.6-2.0	0.10-0.15	6.6-7.3	Low-------	Moderate------	Low------------	---	
	17	---	---	---	----------	--------------	---------------	---	
Rock outcrop part.									
Dique:									
Dm----------------	0-54	2.0-6.0	0.10-0.15	5.6-6.0	Low-------	Low-----------	Moderate-------	---	---
Durados:									
Dr----------------	0-14	6.0-20	0.05-0.10	6.6-7.3	Low-------	Low-----------	Low------------	---	---
	14-23	6.0-20	0.05-0.10	7.9-8.4	Low-------	Low-----------	Low------------	---	
	23-60	>20	<0.05	7.9-8.4	Low-------	Low-----------	Low------------	---	
Estacion:									
Es----------------	0-8	0.6-2.0	0.12-0.15	5.6-6.5	Moderate	Moderate------	Moderate-------	---	---
	8-20	2.0-6.0	0.12-0.15	5.6-6.5	Low-------	Moderate------	Moderate-------	---	
	20-50	>6.0	0.02-0.05	5.6-6.5	Low-------	Low-----------	Moderate-------	---	
Guayama:									
GuF---------------	0-4	0.6-2.0	0.10-0.15	6.6-7.8	Moderate	Moderate------	Low------------	0.24	3
	4-20	0.6-2.0	0.10-0.15	6.6-7.8	Moderate	Moderate------	Low------------	0.20	
	20	---	---	---	----------	--------------	---------------	---	
Humacao:									
Hm----------------	0-8	2.0-6.0	0.05-0.10	5.1-6.0	Low-------	Low-----------	Moderate-------	0.17	5
	8-60	0.6-2.0	0.10-0.15	5.1-6.0	Moderate	Moderate------	Moderate-------	---	
Humatas:									
HtE, HtF----------	0-5	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High----------	High-----------	0.10	4
	5-24	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High----------	High-----------	---	
	24-60	0.6-2.0	0.10-0.16	4.5-5.5	Moderate	High----------	High-----------	---	
[1]HuF:									
Humatas part-----	0-5	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High----------	High-----------	0.10	4
	5-24	0.6-2.0	0.12-0.18	4.5-5.5	Moderate	High----------	High-----------	---	
	24-60	0.6-2.0	0.10-0.16	4.5-5.5	Moderate	High----------	High-----------	---	
Rock outcrop part.									
Hydraquents:									
Hy----------------	0-60	---	---	7.9-9.0	----------	High----------	High-----------	---	---
Jagueyes:									
JaE2--------------	0-5	2.0-6.0	0.02-0.05	4.5-5.0	Low-------	Low-----------	High-----------	0.02	4
	5-41	0.6-2.0	0.05-0.10	4.5-5.0	Low-------	Low-----------	High-----------	---	
	41-62	0.6-2.0	0.05-0.10	4.5-5.0	Low-------	Low-----------	High-----------	---	
Juncal:									
JnD2--------------	0-10	0.6-2.0	0.15-0.20	5.6-6.5	Moderate	High----------	Moderate-------	0.17	3
	10-48	0.6-2.0	0.15-0.20	6.6-7.8	Moderate	High----------	Low------------	---	
	48-60	0.6-2.0	0.15-0.20	7.4-7.8	Moderate	Moderate------	Low------------	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Juncos:									
JuC, JuD----------	0-31	0.06-0.2	0.15-0.17	6.1-7.3	High------	High----------	Low------------	0.17	3
	31-40	0.06-0.2	0.13-0.16	6.1-7.3	High------	High----------	Low------------	0.17	
	40	---	---	6.1-7.3	----------	--------------	---------------	---	
Lares:									
LaB, LaC2---------	0-36	0.6-2.0	0.07-0.13	4.5-5.0	Moderate	High----------	High-----------	0.10	5
	36-60	0.2-0.6	0.07-0.13	4.5-5.0	Moderate	High----------	High-----------	---	
Limones:									
LmE, LmF----------	0-79	0.6-2.0	0.15-0.20	3.6-5.0	Moderate	High----------	High-----------	0.02	4
Lirios:									
LoF2--------------	0-4	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate------	High-----------	0.17	4
	4-34	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	---	
	34-60	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate------	High-----------	---	
Los Guineos:									
LsE, LsF----------	0-5	0.6-2.0	0.15-0.17	4.5-5.5	Moderate	High----------	High-----------	0.10	4
	5-60	0.6-2.0	0.15-0.17	4.5-5.5	Moderate	High----------	High-----------	0.01	
Mabi:									
MaA, MaB, MaC-----	0-24	0.06-0.2	0.15-0.20	4.5-6.0	High------	High----------	Moderate-------	0.32	4
	24-99	0.06-0.2	0.15-0.20	7.4-7.8	High------	High----------	Low------------	---	
Made land:									
Md.									
Malaya:									
MlF---------------	0-6	0.6-2.0	0.15-0.20	5.6-6.5	Moderate	High----------	Low------------	0.24	3
	6-13	0.6-2.0	0.10-0.20	6.6-8.4	Moderate	Moderate------	Low------------	---	
	13-18	0.6-2.0	0.10-0.20	6.6-8.4	Moderate	Moderate------	Low------------	---	
	18	---	---	---	----------	--------------	---------------	---	
Maricao:									
MoF---------------	0-14	0.6-2.0	0.15-0.20	4.5-5.0	Moderate	High----------	High-----------	0.17	3
	14-60	0.6-2.0	0.10-0.15	4.5-5.0	Moderate	Moderate------	High-----------	---	
Martin Pena:									
Mp----------------	0-8	0.6-2.0	0.15-0.20	6.6-7.8	Low-------	Moderate------	Low------------	---	---
	8-18	0.6-2.0	0.12-0.15	6.6-7.8	Moderate	High----------	Low------------	---	
	18-63	<0.06	0.15-0.20	6.6-7.8	High------	High----------	Low------------	---	
Matanzas:									
MsB---------------	0-20	0.6-2.0	0.15-0.20	5.6-7.3	Moderate	High----------	Low------------	0.10	4
	20-53	0.6-2.0	0.15-0.20	5.6-7.3	Moderate	High----------	Low------------	0.10	
	53	---	---	---	----------	--------------	---------------	---	
Montegrande:									
MtB, MtC----------	0-7	0.2-0.6	0.15-0.17	5.1-6.5	High------	High----------	Moderate-------	0.17	4
	7-29	0.2-0.6	0.15-0.17	6.1-7.3	High------	High----------	Moderate-------	---	
	29-48	0.6-2.0	0.10-0.15	6.6-7.3	Moderate	Moderate------	Low------------	---	
Morado:									
MuF2--------------	0-34	0.6-2.0	0.10-0.15	6.1-7.3	Moderate	Moderate------	Low------------	0.17	3
	34	---	---	---	----------	--------------	---------------	---	
Mucara:									
MxD, MxE, MxF-----	0-5	0.6-2.0	0.15-0.17	6.1-6.5	High------	High----------	Low------------	0.17	3
	5-12	0.6-2.0	0.15-0.17	6.1-6.5	High------	High----------	Low------------	---	
	12-30	---	---	6.6-7.3	----------	--------------	---------------	---	
	30	---	---	---	----------	--------------	---------------	---	
Naranjito:									
NaD2, NaE2, NaF2--	0-4	0.6-2.0	0.16-0.20	4.5-5.5	Moderate	High----------	High-----------	0.17	3
	4-12	0.6-2.0	0.15-0.17	4.5-5.5	High------	High----------	High-----------	0.17	
	12-40	0.6-2.0	0.15-0.19	4.5-5.5	Moderate	High----------	High-----------	0.17	
	40	---	---	---	----------	--------------	---------------	---	

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permea-bility	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion		Erosion factors	
						Uncoated steel	Concrete	K	T
	In	In/hr	In/in	pH					
Pandura:									
PaD, PaE, PaF-----	0-7	2.0-6.0	0.02-0.10	5.1-6.0	Very low	Low-----------	Moderate-------	0.24	3
	7-26	2.0-6.0	0.02-0.10	5.1-6.0	Low-------	Low-----------	Moderate-------	---	
	26	2.0-20	0.02-0.05	5.1-6.0	Very low	Low-----------	Moderate-------	---	
Pellejas:									
PeF---------------	0-16	0.6-2.0	0.16-0.21	4.5-5.5	Moderate	Low-----------	High-----------	0.24	3
	16-60	6.0-20	0.06-0.13	4.5-5.5	Low-------	Low-----------	High-----------	0.32	
Reilly:									
Re----------------	0-18	2.0-6.0	0.05-0.10	5.6-6.5	Very low	Low-----------	Moderate-------	---	---
	18-55	>20	<0.05	5.6-6.5	Very low	Low-----------	Moderate-------	---	
Rio Arriba:									
RoB, RoC2---------	0-8	0.2-0.6	0.15-0.20	5.6-7.8	High------	High----------	Low------------	0.17	4
	8-60	0.2-0.6	0.15-0.20	5.6-7.8	High------	High----------	Low------------	---	
Rio Piedras:									
RpD2, RpE2, RpF2--	0-8	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	0.17	4
	8-28	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	0.17	
	28-48	0.2-0.6	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	0.17	
	48	---	---	---	----------	-------------	---------------	---	
Sabana:									
SaF---------------	0-3	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate------	High-----------	0.24	3
	3-15	0.6-2.0	0.20-0.24	4.5-5.5	High------	High----------	High-----------	---	
	15	---	---	---	----------	-------------	---------------	---	
Sabana Seca:									
ScB---------------	0-70	<0.06	0.15-0.20	3.6-5.0	Moderate	High----------	High-----------	0.24	4
Saladar:									
Sm----------------	0-51	0.06-0.2	0.15-0.20	6.6-7.8	Low-------	Moderate------	Low------------	---	---
Soller:									
SoE, SoF----------	0-5	0.6-2.0	0.10-0.15	6.6-8.4	Moderate	High----------	Low------------	0.17	3
	5-12	0.6-2.0	0.18-0.20	6.6-8.4	High------	High----------	Low------------	0.17	
	12-24	---	---	---	----------	-------------	---------------	---	
	24	---	---	---	----------	-------------	---------------	---	
Tanama:									
[1]TaF:									
Tanama part------	0-14	0.6-2.0	0.15-0.20	6.1-7.8	Moderate	High----------	Low------------	0.24	1
	14	---	---	---	----------	-------------	---------------	---	
Rock outcrop part.									
Toa:									
To----------------	0-60	0.6-2.0	0.15-0.20	6.1-7.3	Moderate	Moderate------	Low------------	---	---
Torres:									
TrB---------------	0-28	6.0-20	0.02-0.05	4.5-5.5	Low-------	Low-----------	High-----------	---	---
	28-64	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High----------	High-----------	---	
Tropopsamments:									
Ts----------------	0-60	>20.0	<0.05	7.9-8.4	Low-------	High----------	High-----------	---	---
Urban land:									
[1]Ud:									
Urban land part.									
Durados part-----	0-14	6.0-20	0.05-0.10	6.6-7.3	Low-------	Low-----------	Low------------	---	---
	14-23	6.0-20	0.05-0.10	7.9-8.4	Low-------	Low-----------	Low------------	---	
	23-60	>20	<0.05	7.9-8.4	Low-------	Low-----------	Low------------	---	
[1]Um:									
Urban land part.									

See footnote at end of table.

TABLE 14.--PHYSICAL AND CHEMICAL PROPERTIES OF SOILS--Continued

Soil name and map symbol	Depth	Permeability	Available water capacity	Soil reaction	Shrink-swell potential	Risk of corrosion: Uncoated steel	Risk of corrosion: Concrete	Erosion factors: K	Erosion factors: T
	In	In/hr	In/in	pH					
Urban land:									
Mucara part	0-6	0.6-2.0	0.15-0.17	5.6-7.3	High	High	Low	0.17	3
	6-12	0.6-2.0	0.15-0.17	5.6-7.3	High	High	Low	---	
	12-22	---	---	---	---	---	---	---	
	22	---	---	---	---	---	---	---	
[1]Us:									
Urban land part.									
Sabana Seca part	0-70	<0.06	0.15-0.20	3.6-5.0	Moderate	High	High	0.24	4
[1]Uv:									
Urban land part.									
Vega Alta part	0-8	0.6-2.0	0.15-0.20	4.5-5.5	Low	Moderate	Moderate	0.17	4
	8-84	0.6-2.0	0.15-0.20	4.5-5.5	Low	High	Moderate	---	
Vega Alta:									
VaB, VaC2	0-8	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate	Moderate	0.17	4
	8-84	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	High	Moderate	---	
Vega Baja:									
Vg	0-7	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	4
	7-50	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	
	50-60	0.06-0.2	0.15-0.20	4.5-6.0	High	High	High	0.24	
Via:									
VkC2	0-9	0.6-2.0	0.17-0.20	3.6-4.4	Moderate	Moderate	Moderate	0.17	5
	9-36	0.6-2.0	0.12-0.20	6.1-6.5	Moderate	Moderate	Low	0.17	
	36-52	2.0-6.0	0.03-0.07	5.6-6.0	Low	Low	Low	0.20	
Vivi:									
Vv	0-9	2.0-6.0	0.11-0.18	4.5-5.5	Very low	Moderate	High	---	---
	9-47	2.0-6.0	0.15-0.18	4.5-5.5	Very low	Moderate	High	---	
	47-58	6.0-20.0	0.04-0.08	4.5-5.5	Very low	Moderate	High	---	
Yunes:									
YeE, YeF	0-2	0.6-2.0	0.15-0.20	4.5-5.5	Moderate	Moderate	High	0.17	3
	2-16	2.0-6.0	0.10-0.15	4.5-5.5	Low	Moderate	High	0.17	
	16	---	---	---	---	---	---	---	

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 15.--SOIL AND WATER FEATURES

[Absence of an entry indicates the feature is not a concern. See text for descriptions of symbols and such terms as "rare," "brief," and "perched." The symbol < means less than; > means greater than]

Soil name and map symbol	Hydrologic group	Flooding			High water table			Bedrock		Subsidence	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness	Initial	Total
					Ft			In		In	In
Aceitunas: AaB, AaC	B	None	---	---	>6.0	---	---	>60	---	---	---
Aibonito: AbD, AbE	C	None	---	---	>6.0	---	---	>60	---	---	---
Almirante: AmB, AmC	B	None	---	---	>6.0	---	---	>60	---	---	---
Bajura: Ba	D	Frequent	Brief	Jul-Sep	0.5-2.5	Apparent	Jul-Sep	>60	---	---	---
Bayamon: BmB	B	None	---	---	>6.0	---	---	>60	---	---	---
Caguabo: CaE, CaF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
[1]CbF: Caguabo part	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Rock outcrop part.											
Candelero: Ce	C	Rare	---	---	1.0-1.5	Perched	Aug-Sep	>60	---	---	---
Catalina: ClC	B	None	---	---	>6.0	---	---	>60	---	---	---
Catano: Cn	A	None	---	---	>6.0	---	---	>60	---	---	---
Cayagua: Co	C	None	---	---	0.5-1.5	Perched	Aug-Oct	>60	---	---	---
Colinas: CrD2, CrE2, CrF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Coloso: Cs	D	Frequent	Brief	Jul-Sep	2.0-4.0	Apparent	Jul-Sep	>60	---	---	---
Consumo: CuE, CuF	B	None	---	---	>6.0	---	---	>60	---	---	---
Corozal: CzC	C	None	---	---	0-1.0	Perched	Jul-Oct	>60	---	---	---
Daguey: DaC, DaD	C	None	---	---	>6.0	---	---	>60	---	---	---
Descalabrado: DeF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
[1]DgF: Descalabrado part	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Rock outcrop part.											
Dique: Dm	B	Common	Very brief	Jun-Oct	>6.0	---	---	>60	---	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydrologic group	Flooding: Frequency	Flooding: Duration	Flooding: Months	High water table: Depth	High water table: Kind	High water table: Months	Bedrock: Depth	Bedrock: Hardness	Subsidence: Initial	Subsidence: Total
					Ft			In		In	In
Durados: Dr	A	Rare	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Estacion: Es	B	Common	Very brief	Jun-Oct	>6.0	---	---	>60	---	---	---
Guayama: GuF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Humacao: Hm	B	None	---	---	>6.0	---	---	>60	---	---	---
Humatas: HtE, HtF	C	None	---	---	>6.0	---	---	>60	---	---	---
[1]HuF: Humatas part	C	None	---	---	>6.0	---	---	>60	---	---	---
Rock outcrop part.											
Hydraquents: Hy	D	Frequent	Very long	Jul-Jun	0-1.0	Apparent	Jul-Jun	>60	---	---	---
Jagueyes: JaE2	B	None	---	---	>6.0	---	---	>60	---	---	---
Juncal: JnD2	C	None	---	---	>6.0	---	---	>60	---	---	---
Juncos: JuC, JuD	D	None	---	---	>6.0	---	---	>36	Rippable	---	---
Lares: LaB, LaC2	C	None	---	---	>6.0	---	---	>60	---	---	---
Limones: LmE, LmF	B	None	---	---	>6.0	---	---	>60	---	---	---
Lirios: LoF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Los Guineos: LsE, LsF	C	None	---	---	>6.0	---	---	>60	---	---	---
Mabi: MaA, MaB, MaC	D	Rare	Brief	Jun-Oct	1.5-3.0	Perched	Jun-Oct	>60	---	---	---
Made land: Md.											
Malaya: MlF	D	None	---	---	>6.0	---	---	12-20	Hard	---	---
Maricao: MoF	B	None	---	---	>6.0	---	---	>60	---	---	---
Martin Pena: Mp	D	Frequent	Very long	Jun-Oct	0.5-1.0	Apparent	Jun-Oct	>60	---	---	---
Matanzas: MsB	B	None	---	---	>6.0	---	---	30-58	Hard	---	---
Montegrande: MtB, MtC	D	Rare	---	---	>6.0	---	---	>60	---	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Bedrock		Subsidence	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hard-ness	Ini-tial	Total
					Ft			In		In	In
Morado:											
MuF2	C	None	---	---	>6.0	---	---	22-42	Rip-pable	---	---
Mucara:											
MxD, MxE, MxF	D	None	---	---	>6.0	---	---	20-36	Rip-pable	---	---
Naranjito:											
NaD2, NaE2, NaF2	C	None	---	---	>6.0	---	---	29-45	Rip-pable	---	---
Pandura:											
PaD, PaE, PaF	D	None	---	---	>6.0	---	---	12-19	Rip-pable	---	---
Pellejas:											
PeF	B	None	---	---	>6.0	---	---	>60	---	---	---
Reilly:											
Re	A	Occasional	Very brief	Aug-Oct	2.5-5.0	Apparent	Aug-Oct	>60	---	---	---
Rio Arriba:											
RoB, RoC2	D	Rare	Brief	Jun-Oct	>6.0	---	---	>60	---	---	---
Rio Piedras:											
RpD2, RpE2, RpF2	B	None	---	---	>6.0	---	---	>60	---	---	---
Sabana:											
SaF	D	None	---	---	>6.0	---	---	10-20	Hard	---	---
Sabana Seca:											
ScB	D	None	---	---	2.0-3.0	Apparent	Jul-Oct	>60	---	---	---
Saladar:											
Sm	D	Frequent	Very long	Jun-Oct	0-0.5	Apparent	Jun-May	>60	---	---	18
Soller:											
SoE, SoF	D	None	---	---	>6.0	---	---	20-34	Hard	---	---
Tanama:											
[1]TaF:											
Tanama part	D	None	---	---	>6.0	---	---	12-20	Hard	---	---
Rock outcrop part.											
Toa:											
To	B	Occasional	Brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Torres:											
TrB	A	None	---	---	>6.0	---	---	>60	---	---	---
Tropopsamments:											
Ts	A	Frequent	Very brief	Jul-Jun	0-3.0	Apparent	Jul-Jun	>60	---	---	---
Urban land:											
[1]Ud:											
Urban land part.											
Durados part	A	Rare	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
[1]Um:											
Urban land part.											
Mucara part	D	None	---	---	>6.0	---	---	20-36	Rip-pable	---	---

See footnote at end of table.

TABLE 15.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Bedrock		Subsidence	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hard-ness	Ini-tial	Total
					Ft			In		In	In
Urban land:											
[1]Us:											
Urban land part.											
Sabana Seca part	D	None--------	---	---	2.0-3.0	Apparent	Jul-Oct	>60	---	---	---
[1]Uv:											
Urban land part.											
Vega Alta part--	C	None--------	---	---	>6.0	---	---	>60	---	---	---
Vega Alta:											
VaB, VaC2--------	C	None--------	---	---	>6.0	---	---	>60	---	---	---
Vega Baja:											
Vg---------------	C	Occasional	Brief-----	Jul-Sep	1.5-3.0	Apparent	Jul-Sep	>60	---	---	---
Via:											
VkC2-------------	B	None--------	---	---	>6.0	---	---	>60	---	---	---
Vivi:											
Vv---------------	B	Occasional	Very brief	Jul-Oct	>6.0	---	---	>60	---	---	---
Yunes:											
YeE, YeF---------	D	None--------	---	---	>6.0	---	---	10-20	Rip-pable	---	---

[1]This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and behavior of the whole mapping unit.

TABLE 16.--CLASSIFICATION OF THE SOILS

Soil name	Family or higher taxonomic class
Aceitunas	Clayey, oxidic, isohyperthermic Typic Palehumults
Aibonito	Clayey, oxidic, isohyperthermic Orthoxic Tropohumults
Almirante	Clayey, oxidic, isohyperthermic Plinthic Paleudults
Bajura	Fine, mixed, nonacid, isohyperthermic Vertic Tropaquepts
Bayamon	Clayey, oxidic, isohyperthermic Typic Haplorthox
Caguabo	Loamy-skeletal, mixed, isohyperthermic Lithic Eutropepts
Candelero	Fine-loamy, mixed, isohyperthermic Aeric Tropaqualfs
Catalina	Clayey, oxidic, isohyperthermic Tropeptic Haplorthox
Catano	Carbonatic, isohyperthermic Typic Tropopsamments
Cayagua	Fine, mixed, isohyperthermic Aeric Tropaqualfs
Colinas	Fine-loamy, carbonatic, isohyperthermic Eutropeptic Rendolls
Coloso	Fine, mixed, nonacid, isohyperthermic Aeric Tropic Fluvaquents
Consumo	Clayey, mixed, isohyperthermic Dystropeptic Tropudults
Corozal	Clayey, mixed, isohyperthermic Aquic Tropudults
Daguey	Clayey, oxidic, isohyperthermic Orthoxic Tropohumults
Descalabrado	Clayey, mixed, isohyperthermic Lithic Vertic Ustropepts
Dique	Fine-loamy, mixed, isohyperthermic Fluventic Eutropepts
Durados	Sandy, mixed, isohyperthermic Fluventic Hapludolls
Estacion	Fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls
Guayama	Clayey, mixed, isohyperthermic Lithic Haplustalfs
Humacao	Fine-loamy, mixed, isohyperthermic Fluventic Eutropepts
Humatas	Clayey, kaolinitic, isohyperthermic Typic Tropohumults
Hydraquents	Hydraquents
Jagueyes	Fine-loamy, mixed, isohyperthermic Orthoxic Tropudults
Juncal	Fine, mixed, isohyperthermic Typic Tropudalfs
Juncos	Fine, montmorillonitic, isohyperthermic Vertic Eutropepts
Lares	Clayey, mixed, isohyperthermic Aquic Tropohumults
Limones	Clayey, kaolinitic, isohyperthermic Epiaquic Orthoxic Tropohumults
Lirios	Clayey over loamy, mixed, isohyperthermic Typic Tropudults
Los Guineos	Clayey, mixed, isothermic Epiaquic Tropohumults
Mabi	Fine, montmorillonitic, isohyperthermic Vertic Eutropepts
Malaya	Clayey, mixed, isohyperthermic Lithic Eutropepts
Maricao	Clayey, mixed, isothermic Dystropeptic Tropudults
Martin Pena	Fine, mixed, nonacid, isohyperthermic Tropic Fluvaquents
Matanzas	Clayey, oxidic, isohyperthermic Tropeptic Eutrorthox
Montegrande	Fine, mixed, isohyperthermic Vertic Eutropepts
Morado	Fine-loamy, mixed, isohyperthermic Typic Eutropepts
Mucara	Clayey, montmorillonitic, isohyperthermic, shallow Vertic Eutropepts
Naranjito	Clayey, mixed, isohyperthermic Typic Tropohumults
Pandura	Loamy, mixed, isohyperthermic, shallow Typic Eutropepts
Pellejas	Fine-loamy over sandy or sandy-skeletal, mixed, isohyperthermic Typic Dystropepts
Reilly	Sandy-skeletal, mixed, isohyperthermic Fluventic Hapludolls
Rio Arriba	Fine, mixed, isohyperthermic Vertic Paleudalfs
Rio Piedras	Clayey, kaolinitic, isohyperthermic Typic Tropudults
Sabana	Clayey, mixed, isohyperthermic Lithic Dystropepts
Sabana Seca	Clayey, mixed, isohyperthermic Oxic Plinthaquults
Saladar	Euic, isohyperthermic Fluvaquentic Troposaprists
Soller	Clayey, mixed, isohyperthermic, shallow Eutropeptic Rendolls
Tanama	Clayey, mixed, isohyperthermic Lithic Tropudalfs
Toa	Fine, mixed, isohyperthermic Fluventic Hapludolls
Torres	Clayey, oxidic, isohyperthermic Plinthic Palehumults
Tropopsamments	Tropopsamments
Vega Alta	Clayey, mixed, isohyperthermic Plinthic Tropudults
Vega Baja	Fine, mixed, isohyperthermic Aeric Tropaqualfs
Via	Fine-loamy, mixed, isohyperthermic Typic Tropudalfs
Vivi	Coarse-loamy, mixed, isohyperthermic Fluventic Eutropepts
Yunes	Loamy-skeletal, mixed, isohyperthermic, shallow Typic Dystropepts

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Hydrogeology of the Karst of Puerto Rico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1012

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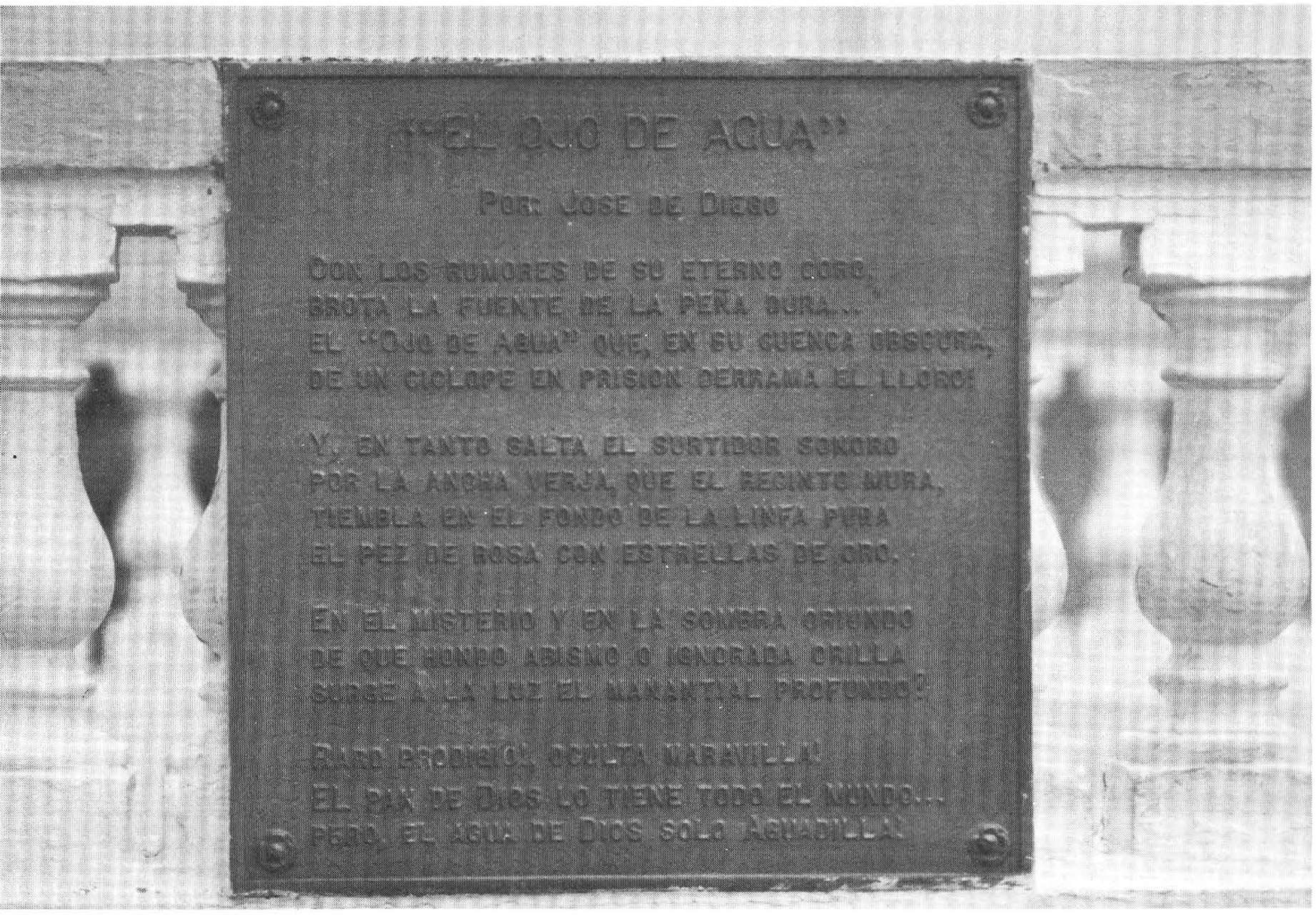
HYDROGEOLOGY OF THE KARST OF PUERTO RICO



Poem by a foremost Puerto Rican concerning the "Karstic Spring" at Aguadilla, Puerto Rico.

Hydrogeology of the Karst of Puerto Rico

By ENNIO V. GIUSTI

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1012

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CONVERSION FACTORS

Metric units	*Conversion factor*	*Foot-pound-second units*	*Remarks*
meter (m)	3.28	foot (ft)	
millimeter (mm)	.039	inch (in.)	
kilometer (km)	.62	mile (mi)	
square kilometer (km^2)	.386	square mile (mi^2)	
degree Celsius (° C)	1.8	degree Farenheit (° F)	add 17.8 to ° C
liter per second (L/s)	15.9	gallon per minute (gal/min)	
kilogram per square centimeter (kg/cm^2)	14.22	pound per square inch (lb/in^2)	
centimeter per second (cm/s)	2,850	foot per day (ft/d)	
cubic meter per second (m^3/s)	35.4	cubic foot per second (ft^3/s)	
milligram per liter (mg/L)	~1	parts per million (ppm)	for dilute solutions
gram per cubic centimeter (g/cm^3)	62.5	pound per cubic foot (lb/ft^3)	
gram (g)	.0022	pound (lb)	
tonne per year (t/yr)	1.1	short ton per year (ton /yr)	

NOTE:—Multiply units in first column by the conversion factor to obtain units of third column. The order of the units shown follows that used in the report.

HYDROGEOLOGY OF THE KARST OF PUERTO RICO

By ENNIO V. GIUSTI

ABSTRACT

About one-fifth of Puerto Rico is covered by a tropical karst formed on a series of six limestone formations ranging in age from middle-Oligocene to middle Miocene. These formations strike east to west and crop out over the north coast of the island. Structurally, the rocks form a simple wedge abutting southward against a mountain chain of volcanic origin and thickening northward to about 1,400 meters by the seashore. All stages of karstification are present: from the incipient, found at the western end of the belt to the residual, found at the eastern end. Maximum development of sinkholes occurs on the Aguada Limestone and upper part of the Aymamón Limestone. These formations have a $CaCO_3$ content range from about 85 to 95 percent. The semi-impermeable Cibao Formation has developed a fluvial drainage. An analysis of stream channel orientations indicates that the present topographic drainage oriented toward the northeast is superimposed on a former drainage system oriented toward the northwest. Transition from the northwestern to the northeastern drainage orientation is ascribed to Pleistocene eastward tilting of the Puerto Rican platform. This tilt is thought to have affected the subterranean drainage pattern as well, so that springs are found mainly on the western wall of northward-oriented valleys. Estimates of the water budget indicate that the karstic stream basins behave on an annual basis much as other stream basins that are not on limestone terrane. Average incoming solar radiation (expressed as evaporated water) and rainfall (2,900 mm and 1,750 mm, respectively) result in an evapotranspiration of about 1,100 mm (millimeters) annually and a discharge of 650 mm. This discharge is accommodated fluvially in areas underlain by the Cibao Formation and by the lower part of the Lares Limestone and subterraneally through the karst elsewhere.

Base flow of streams in limestone in Puerto Rico is less than in streams in volcanic terrane, owing to fast disposal of rainfall through networks of subterranean solution channels. Ground water is found under water-table conditions in the Aymamón and Aguada and under artesian conditions in parts of the Cibao and the Lares. The unconfined groundwater discharges along a strip near the shoreline into swamps and lagoons; the artesian water discharges through a submarine face an unknown distance from the coast and possibly, in part, along a presumed fault near the coast. In the western part of the belt, ground water discharges through the sea bottom, possibly as springs. Permeability is found to decrease exponentially with stratigraphic depth.

Except for lake waters resting on terra rossa, most waters of the limestone belt are saturated or supersaturated with respect to calcite, and as much as 86 percent of the solution is computed to arise mainly from enrichment of rainwater with CO_2 in the soil from the decomposition of organic acids. The denudation rate of the limestone belt through solution is computed as 0.070 mm per year with some evidence that abrasion may increase the denudation rate locally by as much as 40 percent. Calculations based on a projected initial limestone surface and the computed solution rate reveal that the limestone belt emerged from the sea about 4 million years ago and that the eastward tilt of the Puerto Rican platform, reported in the literature, occurred about 1 million years ago. Of the factors pertinent to karst development, aquifer permeability, both vertical and lateral, and primary rock porosity are thought to be the basic control for the existence and morphology of the karst. Assuming sufficiently pure limestone, climate is considered of secondary importance.

INTRODUCTION

Most men of science of ancient times thought that all the water about them originated from large underground caverns, perennially replenished by the sea or by condensation of moist air. This view, along with most scientific theories prevailing at that time, was the legacy of Aristotelian thinking; and it is interesting, within the context of this report, to speculate that only a karst land—the Grecian one, in this instance—could have been responsible for fostering such a theory. Only the karst develops underground rivers, and only carbonate and other soluble rock terranes develop karst. However, not all limestone terranes become karst, and not all karsts contain underground rivers. A great range of conditions occur in many limestone regions; some areas show little effects of solutional erosion, whereas other areas show advanced stages of karst development. A limestone area can occupy any intermediate position within these two limiting conditions; one of the objectives of this report is to place the north coast limestone area of Puerto Rico within such a perspective. The main purpose is to describe the hydrologic and geologic conditions of the karst terrane of the north coast of Puerto Rico.

The writer appreciates the cooperation of the Puerto Rico Aqueduct and Sewer Authority for providing data on well logs and pumpage and for providing a crew to drill holes in well casings to measure water levels.

DATA AVAILABLE AND PREVIOUS INVESTIGATIONS

Areal photographs are available for the area, and topographic quadrangle maps may be obtained at the scale of 1:20,000 with contour intervals of 5–10 m in regions of high relief, and of 1 m in regions of low relief. Geologic maps, also at a scale of 1:20,000, have been published for each quadrangle in the region. Meteorological data include records from about 25 daily rainfall stations scattered throughout the north coast limestone belt and the nearby mountain slopes, and records from 5 evaporation sites at different altitudes in the area. Hydrologic data available prior to this study were limited to monthly water levels from a skeleton network of 5 wells, and miscellaneous low-flow discharge measurements from 20 sites. In addition to these hydrologic data from the limestone area proper, data were available from three long-term (more than 10 year of record), and two short-term (2 years of record) streamflow stations located in the volcanic area near the contact of the limestone belt. Chemical analyses of ground and surface water have been published in basic-data reports.

Reports on the limestone belt include geologic mapping, principally by Monroe (1962, 1968a, 1969a), Briggs (1961, 1966), and Briggs and Akers (1965) and the excellent studies of the karst morphology by Monroe (1964, 1966, 1968b, 1969b). Detailed work on a portion of the area but with conclusions significantly applicable to the limestone belt in general can be found in Williams (1965). Older and more general works, such as those of Lobeck (1922), Meyeroff (1933), and Zapp and others (1948), yield much useful information on the geology and geomorphology of the limestones. The coastal features and shoreline investigation of Kaye (1959), and various geophysical investigations such as the gravity work of Myers (1955) and Shurbet and Ewing (1956), provide information for a better understanding of the three-dimensional boundaries of the limestone belt.

An investigation of the hydrogeology of Puerto Rico, which includes a comprehensive study of the ground-water conditions of the north coast limestone area, was made by McGuinness (1948). Birot and others (1967) present a quantitative evaluation of the water budget of a karst stream basin, and field-analyzed chemical data of karstic water. Bennett and Giusti (1972) evaluated the hydrology of the Laguna Tortuguero area; Diaz (1973 mapped the chemical quality at the Caño Tiburones; and Jordan (1970) reported on ground-water movement in the upper Río Tanamá basin.

THE LIMESTONE AREAS OF PUERTO RICO

The limestones of Puerto Rico are found scattered throughout the island as caps of mountains or as belts draped over the north and south coasts. These limestones (see fig. 1) range in age from early Cretaceous (Briggs and Akers, 1965), the oldest of the patches being found in the interior, to middle Miocene and perhaps as young as middle Pliocene (G. Seiglie, oral commun., 1969), the youngest proposed age for the youngest formation found in the north coast belt. The limestones of the interior represent the remnants of reefs that fringed the Cretaceous volcanoes of Puerto Rico (Meyerhoff, 1933), whereas the north and south belts, were deposited later over the eroded volcanic core, in shallow clear-water environments with open circulation, on a generally stable shelf.

The limestones of the north coast cover an area about 125 km (kilometers) in length from Aguada to Loiza and as much as 22 km in width near Arecibo, encompassing about 1,600 km^2, or one-fifth of the land area of Puerto Rico. The altitude of the north coast belt is about 400 m (meters) at the contact with the volcanic core and decreases northward to sea level.

The discussion in this report is confined to the north coast belt west of the Río de la Plata because it contains important aquifers; moreover, it is the only area that has developed prominent karst topography.

GEOLOGY

VOLCANIC BASEMENT

The limestones of the north coast belt rest unconformably on a faulted and folded volcanic base that is no younger than Eocene in age (Briggs, 1961). The surface of the volcanic rocks beneath the limestone is highly irregular as evidenced by the variability of the angles of the dips and their azimuths reported from seismic reflection work carried out in the search for oil structures (Myers, 1955).

LIMESTONES

The limestones on the north coast were deposited in shallow clear water with open circulation, on a

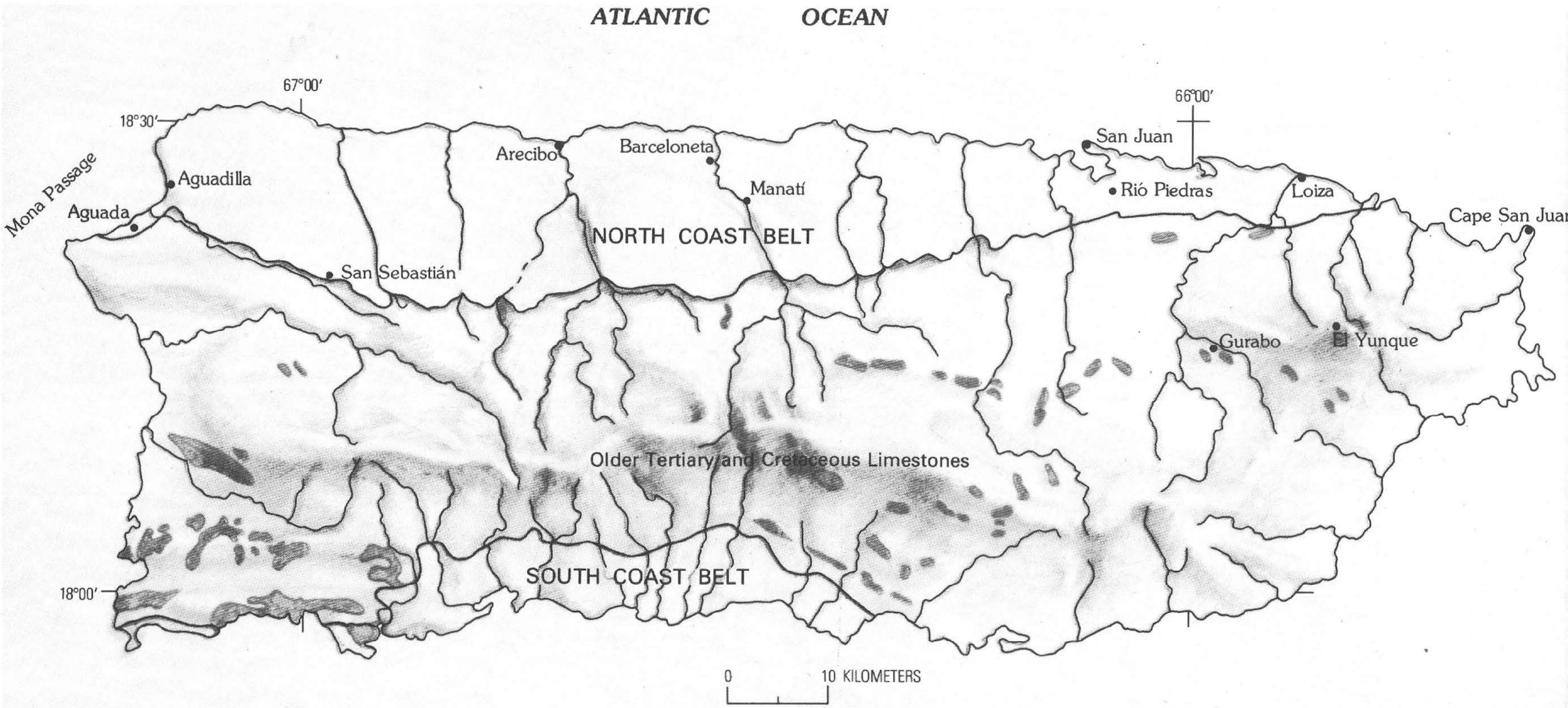

FIGURE 1.—Location of the limestone areas (slightly modified from Briggs and Akers, 1965).

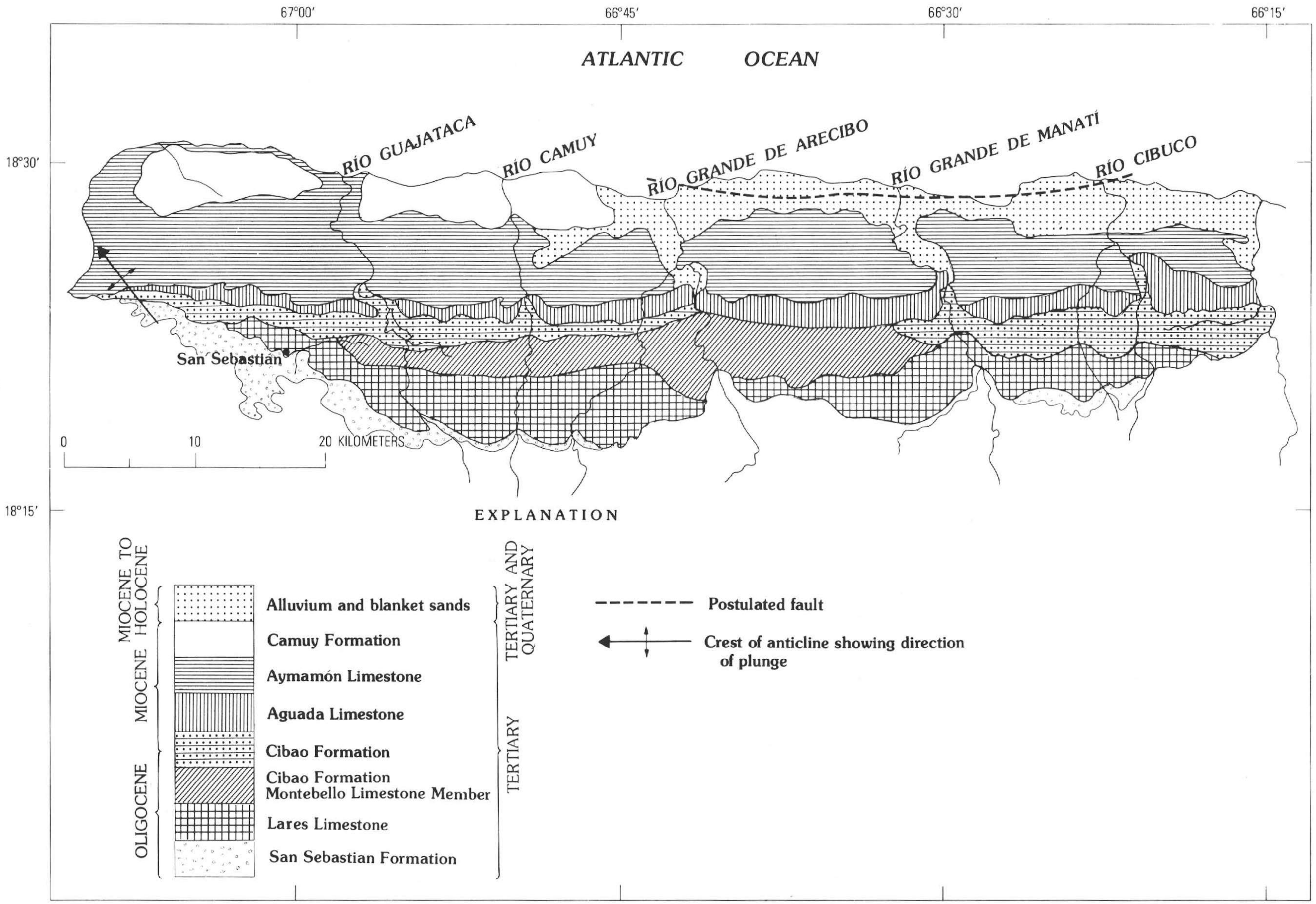

FIGURE 2.—Geologic formations of the north coast limestone area (adapted from Briggs and Akers, 1965).

generally stable shelf, and have undergone little postdepositional structure changes. Most investigators consider the age of the limestones to range from middle Oligocene to middle Miocene.

Above the volcanic base, six formations are recognized (fig. 2); these are described herewith from oldest to youngest (lithology of the rocks units are adapted from the several reports of Briggs and Monroe.).

SAN SEBASTIÁN FORMATION

Essentially the Formation is a poorly cemented shaly bedded claystone, but contains layers of siltstone, sandstone, conglomerate, and locally has lenses of limestone and lignite. The thickness ranges from zero in the middle part of the belt to about 300 m near the town of San Sebastián. The age is controversial. Most investigators consider it to be of middle Oligocene age; Gordon (1959), however, believes that no rock of the north coast Tertiary sequence is older than Miocene. Generally the San Sebastián is too impermeable to serve as a source of ground water and acts as a confining bed in most of the area. In the vicinity of San Juan, however, conglomerate and sandstone zones form part of an important aquifer.

LARES LIMESTONE

The Lares gradationally overlies the San Sebastián. It is a thin-bedded limestone at the base, changing upward to a thick-bedded and massive dense limestone. In the center of the belt it is a very pure limestone about 300 m thick; but it thins both eastward and westward and eventually pinches out at the margins of the belt. The age controversy of the San Sebastián applies to the Lares, but most investigators consider it to be of middle and late Oligocene age. The Lares is a poor aquifer where it crops out because of low permeability; however, in the center of the belt where it is overlain by younger rocks it becomes an important aquifer because of high potentiometric head.

CIBAO FORMATION

The Cibao is the most variable formation of the north coast, to the extent that at least two members are recognized: The Montebello Limestone Member and the Quebrada Arenas Member.

Generally the Cibao is an interbedded sequence of marl, chalk, limestone, sand, and clay as much as 230 m thick. In the eastern and western parts of the belt, clastics are predominant. In the middle part, limestones are predominant.

The Cibao Formation acts either as a confining bed or as an aquifer, depending upon the lithology. In the San Juan area, an artesian aquifer capped by clays that are in turn overlain by water-bearing limestones are all part of the Cibao Formation.

The Quebrada Arenas and the Montebello Members are present in the middle of the belt. These members are thick-bedded to massive finely crystalline to granular limestones. The Montebello Member, which is chalky in some places, is among the purest limestones of the north coast. The Montebello Member at depth is an important artesian aquifer in the middle part of the limestone belt.

The Cibao Formation ranges from Oligocene to Miocene in age, or, according to Gordon (1959), is entirely Miocene.

AGUADA LIMESTONE

The Aguada consists of hard thick-bedded to massive calcarenite, locally rubbly to finely crystalline, alternating with beds of clayey limestone. Maximum thickness is about 90 m. The age is early Miocene. Water-bearing properties of the Aguada are considered to range from poor to fair, reflecting differences in lithology.

AYMAMÓN LIMESTONE

The basal part of the Aymamón is a massive to thick-bedded limestone, finely crystalline, about 70 m in thickness. The middle and upper parts are very pure chalky limestone, riddled with solution channels. Total thickness is about 300 m; the age is early Miocene. The basal part of the Aymamón is similar to the Aguada in its water-bearing properties. The middle and upper parts of the limestone are highly permeable.

CAMUY FORMATION

The youngest limestone formation of the north coast belt is areally extensive only west of Arecibo. The lithology of the rock unit varies from a calcarenite to a limestone conglomerate in a clayey matrix. Some parts of the Camuy are quartz sandstone. Maximum thickness is about 200 m. The age is middle Miocene according to most investigators but may be as young as Pliocene according to micropaleontological work by G. A. Seiglie of the University of Puerto Rico, (oral commun., 1969). In general, the Camuy is not an aquifer because it is above the water table.

UNCONSOLIDATED DEPOSITS

BLANKET SANDS

Overlying the limestone formations are the so-called blanket sands. A sandy-silty-clayey mixture, they fill most depressions of the north coast belt surface to an average depth of about 10 m, though an infill of 30 m is not uncommon nearer the coast. There are some debatable points concerning their formation—some workers attribute them to a reworking of marine sediments (Monroe, 1969b); others (Briggs, 1966) favor a fluvial origin. The latter view appears to be more plausible (Williams, 1965) in view of the fact that no fossils have been found in the blanket sands. Briggs believes the blanket sands to be contemporary with arching of the Puerto Rican platform, being therefore the deposits of the first rivers flowing from the newly risen island. These deposits were later augmented by the insoluble residues of solution of the limestone formations (especially the clastic Camuy). The age of the blanket sands would range, therefore, from late Miocene (or Pliocene) to the present. The blanket sands are important as recharge media, but insignificant as aquifers.

QUATERNARY DEPOSITS

The Quaternary deposits of the north coast belt include the alluvium of the river flood plains, a mixture of unconsolidated sand, gravel, and clay ranging in thickness from 0 to about 100 m. Locally the alluvium is a good aquifer. Other Quaternary deposits include the carbonaceous muck in lagoons and swampy areas, some landslide material at the foot of limestone escarpments, cemented sand dunes along the coast, and recent beach deposits. Some of them, especially the cemented sand dunes, provide important clues to the geologic past of the island (Kaye, 1959). Except for the swamps, which mark areas of ground-water discharge, none of these deposits are involved materially in the hydrogeology of the north coast limestone belt. The geologic map of figure 2 shows the most important unconsolidated deposits.

STRUCTURE

The general attitude of the limestone sequence is that of a homocline gently inclined to the north. Figure 3 shows histograms of the angle and azimuths of the dips. In terms of average values the limestone formations dip 5° in a direction N. 0° 47′ E.

A plot of dip angles with latitude is shown in figure 4. Although there is extensive scatter, a relation line can be drawn through the field of points to show a decrease in dip toward the coast. The decrease of dip angles with latitude (northward) reflects the steeper inclination that the limestone belt must have had near the center of the island, at the contact with the volcanic core, when it arched up in Miocene and Pliocene time. This steeper dip of the Tertiary belt in the interior of the island was noted by Briggs (1961), who stated that the dips ranged from about 3° at the Aymamón-Aguada contact to as much as 6° in the older formations. In the same paper, Briggs discusses the thickening of the formations in a seaward direction as shown in an analysis of the rock material drilled by a deep oil test that penetrated the entire Tertiary sequence.

Shurbet and Ewing (1956), on the strength of gravity data and assumed rock densities, inferred a structure for the north coast limestone belt that showed a thickening of rock seaward. Figure 5, a generalized geologic section through longitude 66° 43′, is derived from the relation line of figure 4 and the structural interpretation made by Shurbet and Ewing.

This sample wedge structure contains a few gentle folds such as the one described by Monroe (1962) in the Manatí area. Most of the folds probably reflect structural features of the basement complex and do not inherently affect the overall struc-

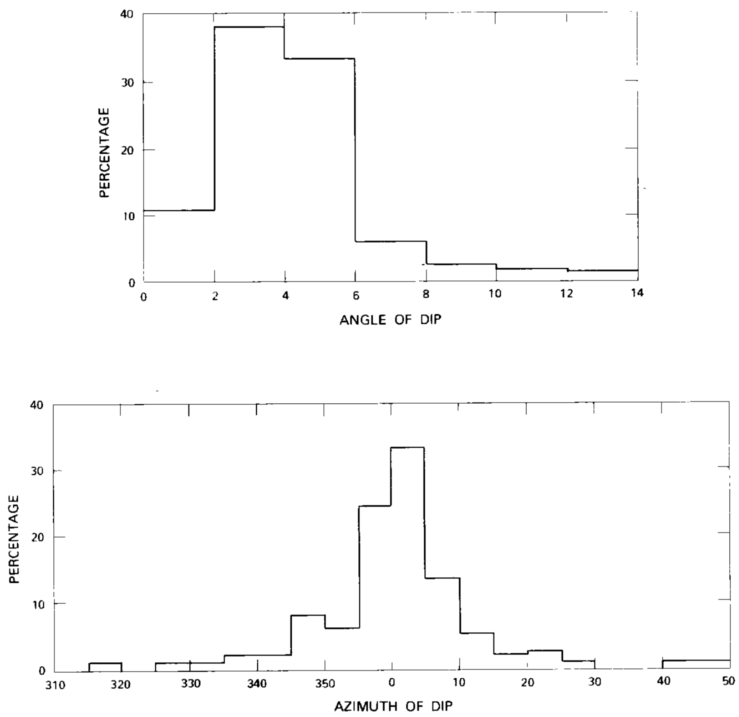

FIGURE 3.—Histograms of north coast limestone dips and orientations.

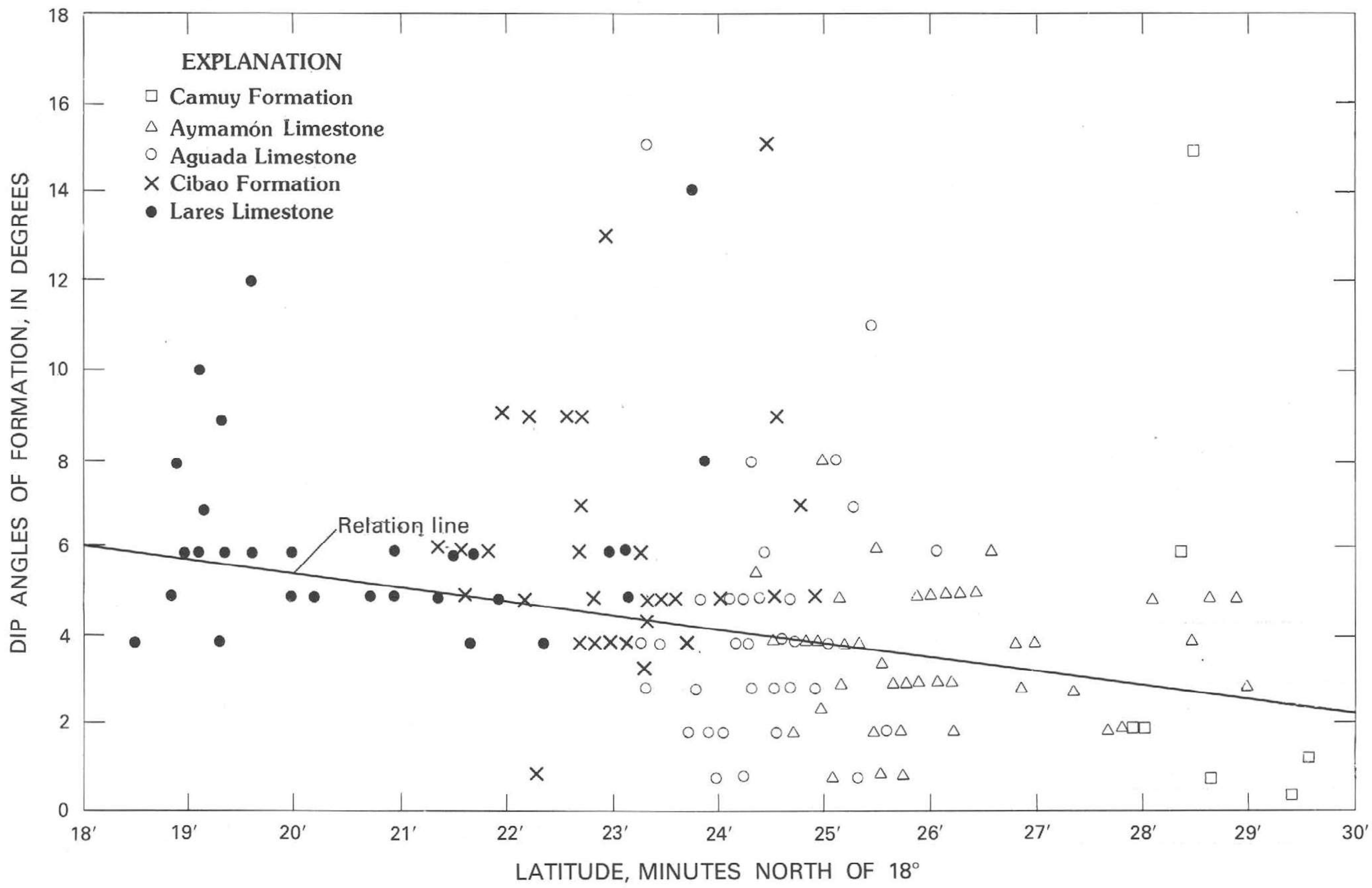

FIGURE 4.—The dip of the limestone decreases in a seaward direction.

tural aspect of the north coast belt. One exception toward the western margin of the belt, southeast of Aguadilla, is a northwest plunging anticline (see fig. 2) accompanied by a few normal faults also alined in a northwest-southeast direction (Monroe, 1969a); possibly there is ongoing tectonic activity related to the Puerto Rican trench and Mona Passage, both known to be seismically active. This anticline and associated faults are probably related to the raised shoreline of the western part of the limestone belt.

Briggs (1961) postulated a major strike fault along the north coast extending from Arecibo east to the Río Cibuco (see fig. 2)—a distance of nearly 40 km.

LANDFORMS—THE KARST

An aerial view of the north coast belt shows the karst as a flat, highly pitted surface lapping against the mountains of the central core (fig. 6). This surface is crossed by two large valleys in the eastern part; westward one can barely discern the sinuous trace of three or four river valleys, not wide enough to provide a clear gap in the flat surface. The terrain, on closer inspection, appears as clusters of hills separated from each other by rounded depressions (fig. 7)—the "lunar landscape" of Monroe (1968b).

A common feature of limestone surfaces is depressions (sinkholes) that drain internally. The areal distribution of sinkholes may be used to draw inferences on the physical-chemical properties of the rocks and on the hydrology of the area. The quantitative map of karst development in figure 8 was prepared from topographic maps by dividing the

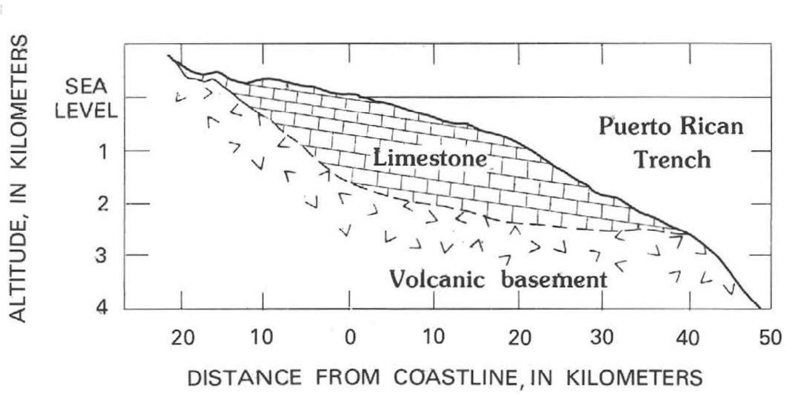

FIGURE 5.—Section of the north coast limestone belt through longitude 66°43′ (adapted from Shurbet and Ewing, 1956).

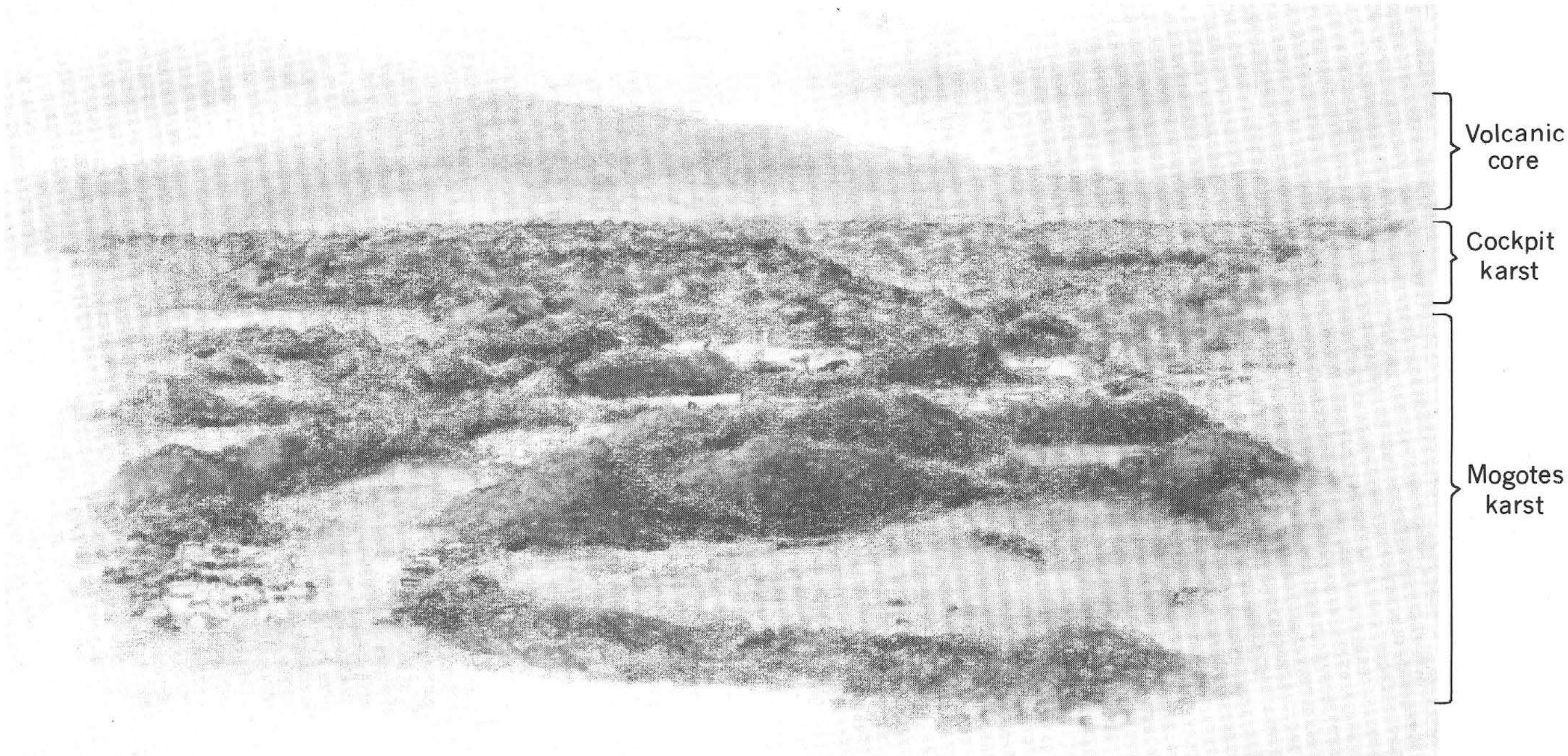

FIGURE 6.—The karst is a highly pitted surface lapping against the central volcanic core of the island.

FIGURE 7.—Rounded depressions mark the bottom of the karst. Here the depressions have coalesced to form a narrow valley.

region into rectangles of 1-minute longitude by 1-minute latitude, and measuring the percentage of the area of each rectangle falling within closed topographic contours. The topographic maps used were at the scale of 1:20,000 with contour intervals of 5 and 10 m. The maximum karst development (100 percent) as defined by this topograhic method occurs where half of the chosen sample area is covered by closed contoured depressions and half by hills separating them. A close correlation between geologic properties of the formations and degree of karst development is indicated. (Compare figs. 2 and 8.)

Some degree of karstification has taken place on all the limestones with the exception of the predominantly clastic San Sebastián Formation. In the far western part of the area the Lares Limestone has a normal fluvial development of streams that drain southward to the Río Culebrinas. Eastward, however, the Lares Limestone has developed slight to moderate karstification. The Cibao Formation shows but slight karst development in the eastern and western parts of the area, where it is predominantly clastic (figs. 9 and 10). In the center of the north coast belt, however, where the Cibao Formation is a pure limestone (Montebello Limestone Member), an extensive karst has developed. Karstification increases northward in the overlying Aguada Limestone and reaches its maximum development in the southern outcrop area of the Aymamón Limestone;

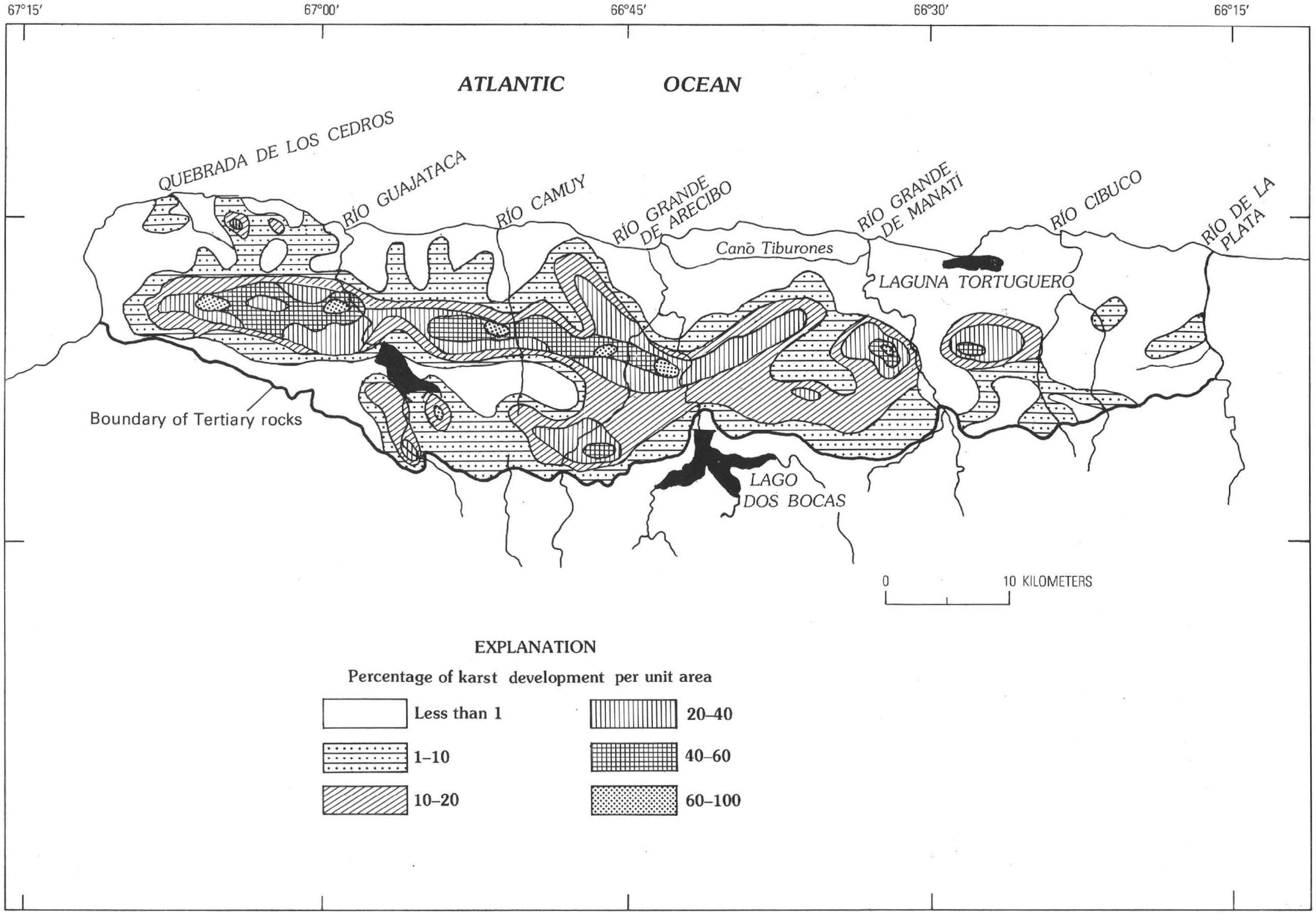

FIGURE 8.—Karst development of the north coast limestone belt.

FIGURE 9.—The Cibao topography is one of rolling hills—no karst. Aguada karst in background.

it then decreases seaward. The small degree of karstification in the northwestern part of the belt reflects a youthful stage of incipient karst development. The equal lack of karstification in the northeastern part of the belt reflects the opposite—a mature to old stage which marks the final dissolution phase.

Monroe (1966, 1968b) believes that the formation of the Puerto Rican karst is the result of limestone solution and reprecipitation, with the karst morphology depending on the lithology and structure of the limestones. He describes the surface of the limestone hills as a pitted hardened shell, a few meters thick at most, covering a soft interior. This feature can be seen in most roadcuts. The hard shell, as well as the asymmetry of the hills (mogotes), which show a flatter gradient on the eastern side, is explained in terms of the preferential soaking of the eastern side by rain, wind, driven from the east, and in terms of reprecipitation of calcium carbonate supersaturated overland flow near the foot of the hills. The flat areas of land between mogotes are, in Monroe's view, where the limestone is actively being dissolved at the contact beneath the cover of the blanket sands. Organic acids, which are associated with the dense vegetation growing on the limestones and washed down into the blanket sand-covered depressions, greatly increase the solubility of the limestones. The influence of the lithology and structure on the different landforms of the karst is related to the purity of the limestones and to their bedding thickness. Thus, areas in warm and humid climates underlain by massive pure limestone can develop into cockpit karst (Kegelkarst) marked by subconical hills separated by steep-walled valleys. Mogotes, typified by subconical hills rising out of a blanket-sand covered plain are found on the pure somewhat chalky Aymamón Limestone. Zanjones, or trenchlike elongated depressions somewhat parallel to each other, have developed where limestone is thin bedded and brittle. Caves and natural bridges have formed in areas of alternating beds of hard and soft limestone.

FIGURE 10.—Rolling topography of the Quebrada Arenas Limestone Member of the Cibao Formation.

In this report, the mogote karst is regarded as a phase of the karst development, being somewhat the equivalent of the monadnocks of the Piedmont region of the eastern continental United States, representing the last geomorphic expression prior to complete obliteration of land relief. From the classical geomorphic approach of stage development, the northwestern area of the north coast limestone represents the youthful stage: it is marked by a plateaulike surface slightly pitted with shallow closed depressions. The next or mature stage is represented by the rugged cockpit karst found throughout the Aguada Limestone and lower part of the Aymamón Limestone in the middle of the belt, and in patches on the Lares Limestone. The next phase, or old stage, would be the mogote karst. It, in turn, would further degrade to a fluvial drainage developed on blanket sands, evidence of which appears in the eastern part of the north coast belt. These stages, of course, allow for local features caused by lithologic and structural differences; however, in general, attributing morphology to the purity and thickness of limestone is not sufficient to explain the landform development other than in a restricted area.

The mogote karst may once have been a cockpit karst; the cockpit may develop into mogote karst in due time—just as the plateaulike northwestern part of the belt will mature into a cockpit area eventually. Figure 11 illustrates the relation between karst development and topographic altitude; this figure was constructed from the results of the analysis of percent karst development that were utilized in constructing figure 8. The horizontal axes in figure 11 represent karst development in percent, as previously defined, and topographic relief in meters. Frequency of occurrence, shown on the vertical axis, represents the number of 1-minute map rectangles at a given average altitude which exhibit a given percent of karst development. The maximum development of the karst—the cockpit karst—is in areas where the relief ranges from about 80 to 120 m. Beyond this range of relief the author interprets figure 11 to imply that the karst

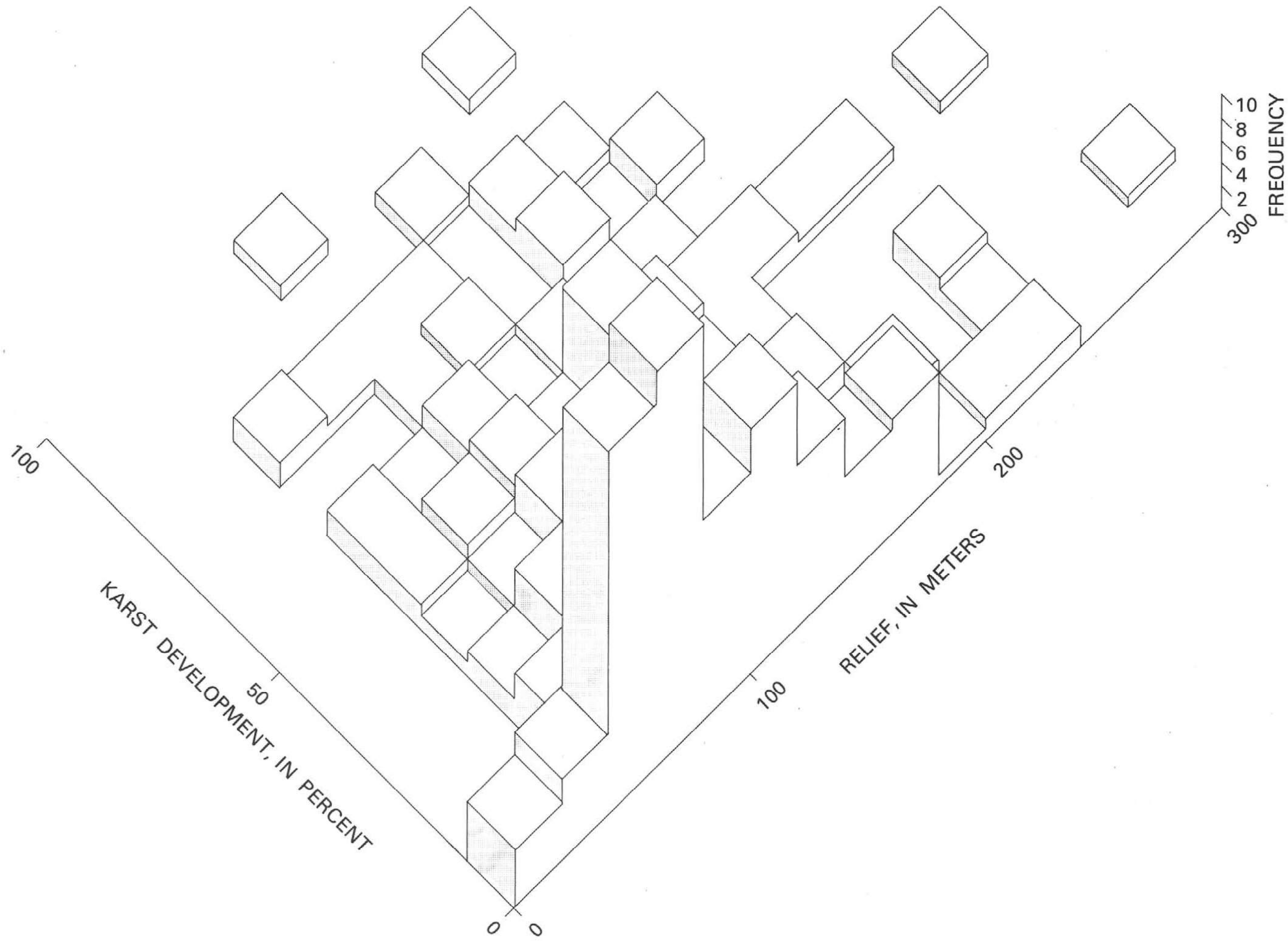

FIGURE 11.—Distribution surface of karst areas.

decreases by collapse of underground caves or surfaces erosion and that the stream courses begin to develop.

STREAM NETWORK

The limestone belt is traversed by six rivers whose headwaters are found in the volcanic terrane to the south. Figure 12 shows the stream network developed on the north coast limestone, the major springs, and the altitude contours of land surface. (The stream network is shown in more detail in pl. 1.) The contours represent the mean altitude above sea level of each 1-minute square of the limestone belt. The mean altitudes were computed by dividing each 1-minute square into 25 grid points, and averaging the altitude of these points as taken from a topographic map. The average direction (azimuth) of the topographic slope is about N. 5° E. compared with a geologic dip direction essentially due north. The major rivers generally cross the belt in a direction west of north (Williams, 1965, p. 160–182).

In the general area southeast of Lago de Guajataca (fig. 13) the alinement of the sinkholes area is peculiarly in a northwesterly direction. The portion of Río Guajataca shown in the southwestern corner of the map of figure 13 was probably formed by the collapse of a series of these northwesterly oriented sinkholes. There is an indication that this preferential alinement is related to the drainage patterns of the original fluvial system that formed at the time of emergence of the Puerto Rican platform from the sea.

Whatever major tributaries there are enter the rivers from the west within the limestone belt. The short segments of streams shown about the middle of figure 12 reflect the fluvial development formed on top of the Cibao Formation; and it should be noted that even these short segments tend to orient themselves so that they would, if

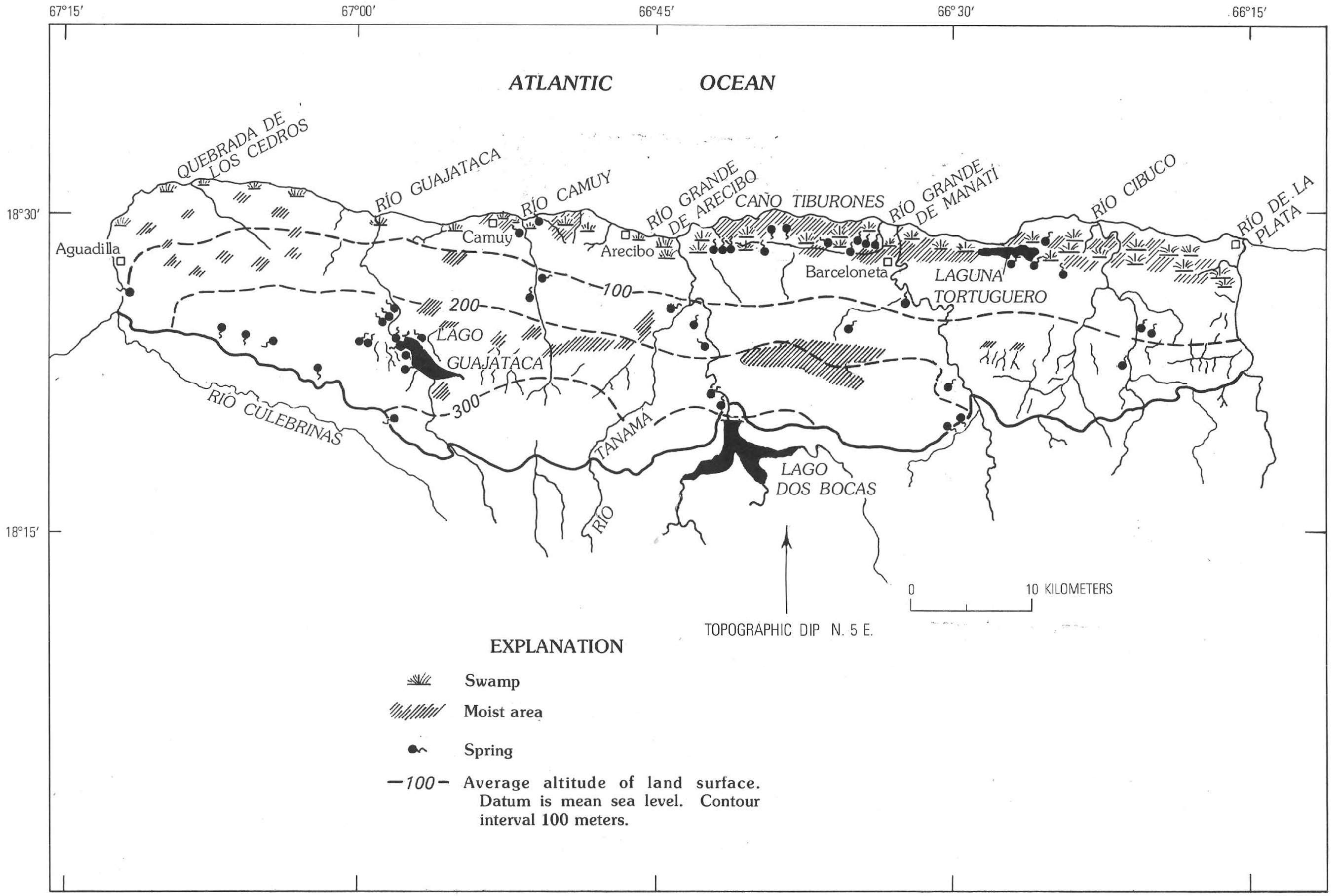

FIGURE 12.—Average altitude of land surface, stream network, and major springs of the limestone belt.

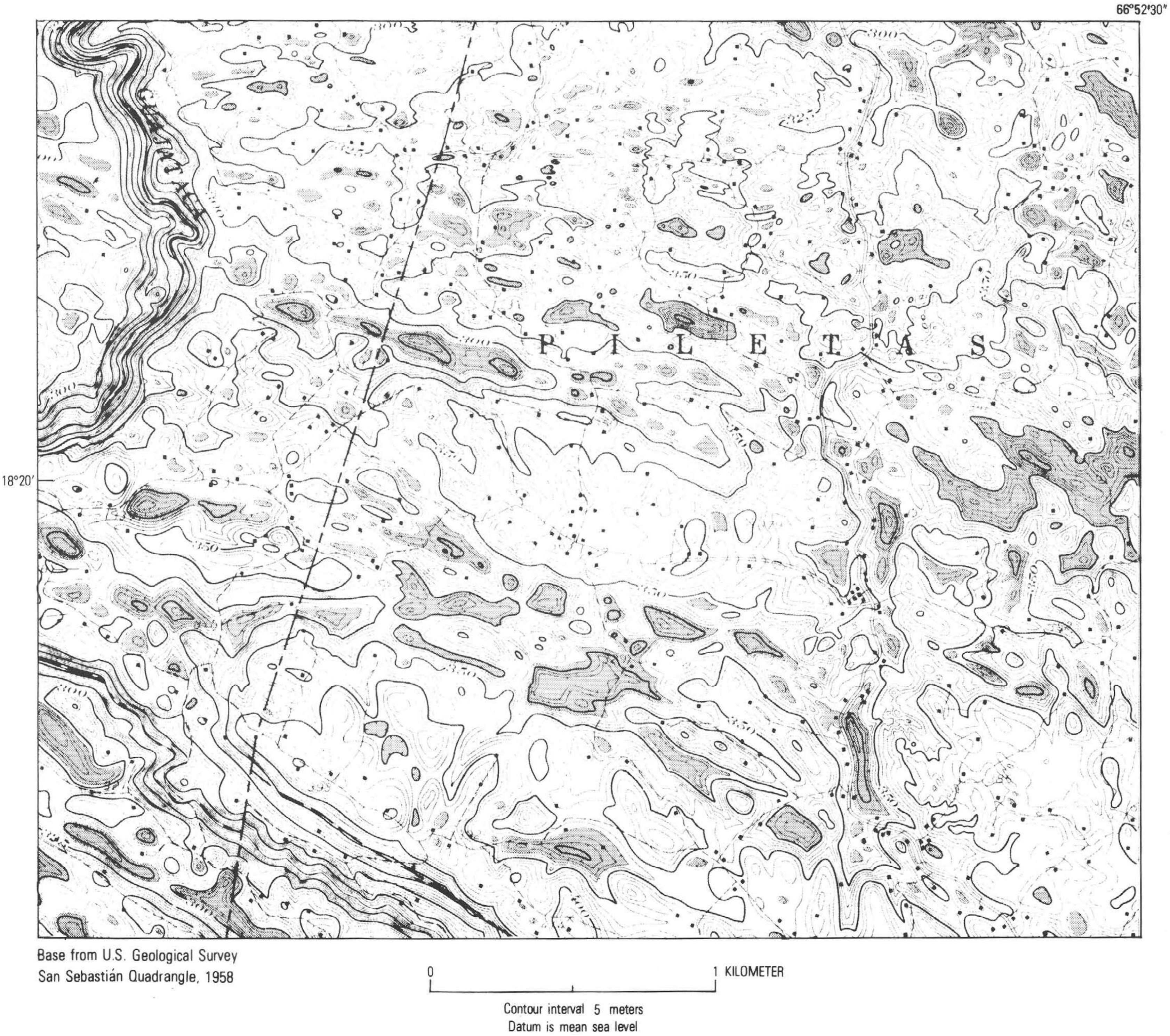

FIGURE 13.—Northwest-southeast alinement of the sinkholes in the Lares Limestone southeast of Lago de Guajataca.

linearly extended, enter the main rivers from the west. This preferential alinement could not develop on a lithologically uniform surface dipping gently northward. The main reason for the anomaly is to be found in the eastward tilt of the entire Puerto Rican platform. This tilt, which was argued for by Lobeck (1933) and Meyerhoff (1933) on the basis of the raised coastline found along the western margin of the north coast, is thought to have occurred sometime during the Pleistocene. Monroe

(1968a) found terraces at altitudes of 40 to 70 m on top of the raised limestone platform in the west, which he dates from the Pleistocene, though he favors eustatic rather than tectonic movements to explain the existence of the raised beach deposits.

Most of the rivers flow in normal valleys open to the sky, but both the Río Camuy and the Río Tanamá flow underground for some stretches. The Río Camuy disappears underground soon after entering the limestone and emerges at a straight-line distance of about 6 km downstream. The surface where the Río Camuy flows underground is marked by "lines of steep-walled collapsed sinks" (Monroe, 1968b). The Río Camuy flows through the lower part of a series of caves lying at different levels; they have been only partly explored (Gurnee, R. H., and others, 1966). The Río Tanamá flows underground at different points, for distances of less than a kilometer. Its course can readily be interpolated between its points of disappearances and reappearances. Clearly, at least parts of these river courses have formed through the collapse of caves or sinkholes.

Another river, the Río Guajataca, shows evidence of collapsed caves, the floor of its canyon being strewn in places with a chaotic rubble of collapsed blocks of limestone. In fact, at places the arch of former caves can be easily reconstructed (fig. 14). The Río Guajataca is probably an example of the next stage of development that follows that of the Río Tanamá; a canyon has been opened to the sky, but except for some isolated inland reaches and a short interval near the coast, there has been no development of a proper channel with river banks and a flood plain. The development of a proper channel, which is usually concurrent with the development of meandering, marks the approach to the equilibrium stage described by Mackin (1948). In the north coast belt, the equilibrium stage is achieved by the Río Grande de Manatí (fig. 15), Río Grande de Arecibo (fig. 16), and the Río Cibuco.

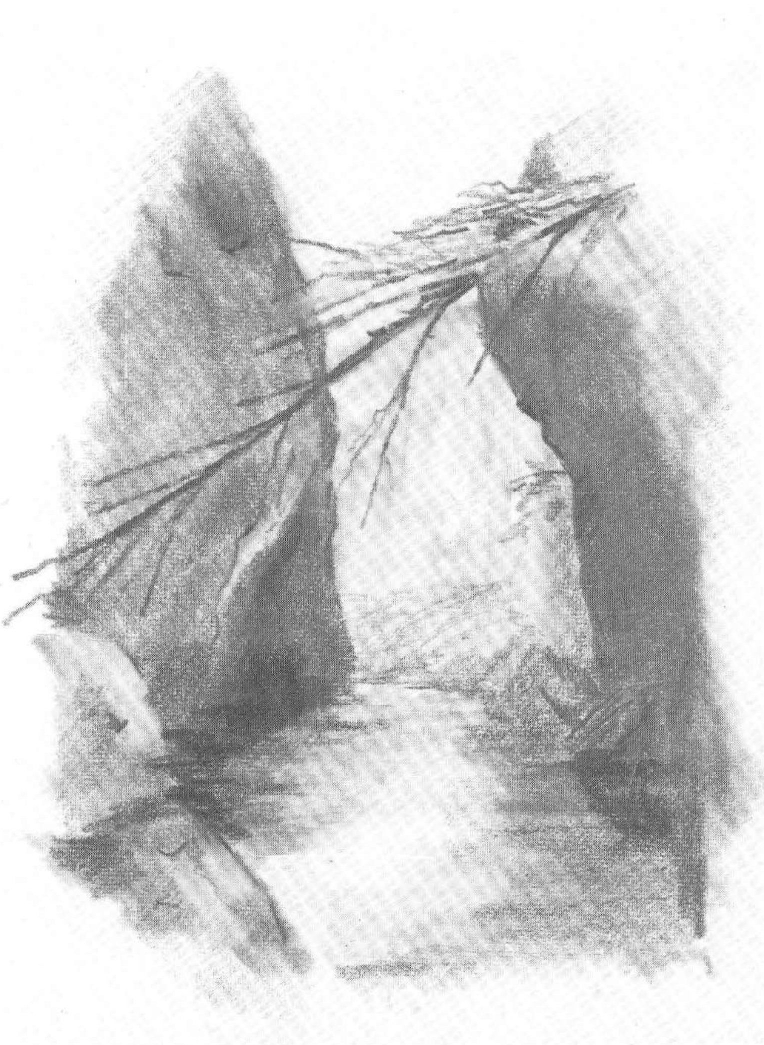

FIGURE 14.—Former cave of the Río Guajataca.

DRAINAGE AREAS

The computation of water balances of river basins required the quantitative assessment of rainfall, evaporation, and streamflow as well as the determination of storage changes; thus the area of the drainage basins were needed.

It became apparent early in the study that drainage divides in the karst areas could not be unequivocally determined from the available maps. Because the divides about many sinkholes occurred at the same altitude, it was not known whether a given sinkhole area was to be assigned to one river basin or to another. Two criteria were used to obtain at least a first estimate of interbasin boundaries and thus of drainage areas:

1. Any sinkhole was assumed to drain to the neighboring sinkhole of lowest altitude.
2. Where neighboring sinkholes lay at the same altitude the preferential path was chosen according to the general orientation of stream courses. An example of the application of these criteria is shown on a portion of a topographic map in figure 17.

A number of indeterminate drainage areas that did not seem to belong to any stream basin were found; their probable drainage pattern is discussed later with the streamflow data. The results of the water-balance computation were themselves used to evaluate the reliability of the computed drainage areas. An error made in the drainage area evaluation, therefore, would have affected the results of the water-balance computations.

FIGURE 15.—The Río Grande de Manatí exhibits a well developed flood plain.

OTHER LANDFORMS

The limestone terminates abruptly near the coast west of Arecibo (figs. 18 and 19) in sea cliffs, or is separated from the sea by a narrow strip of beach (Kaye, 1959). East of Arecibo large swampy areas have formed, the Caño Tiburones between the Río Grande de Manatí and the Río Grande de Arecibo, and Laguna Tortuguero between the Río Grande de Manatí and the Río Cibuco are prominent features of this swampy terrain, and are notable for the large amounts of nearly freshwater they discharge. The alinement of these areas of freshwater outflow was taken by Briggs (1961) as suggesting, though he qualified the evidence as circumstantial, the presence of a large strike fault (discussed in the chapter on structure). Stringfield (written commun., 1971) interpreted these swamps as drowned karst features that formed during a low stand of the Pleistocene sea. Other landforms found in a narrow belt north of the swampy areas, along the coast, and even drowned offshore, are sea cliffs and cemented sand dunes; these are described by Kaye (1959).

CLIMATE

The climate of northern Puerto Rico is humid tropical (Picó, 1950). As an aid to numerical comparison, climate can be conveniently represented as a function of rainfall and evaporation only; the latter integrating the effects of solar radiation, wind, and temperature. In terms of the climatic index of Thornthwaite (1931), northern Puerto Rico has an index of about 90 (Giusti and Lopez, 1967), which correlates with the meteorologically based description of humid, or, on the basis of vegetation pattern, with the forest province. Thus, the north coast belt is climatically consonant with the popular image of Puerto Rico.

RAINFALL, TEMPERATURE, AND WIND

The average annual rainfall on the north coast limestones is 1,800 mm (millimeters), and rainfall

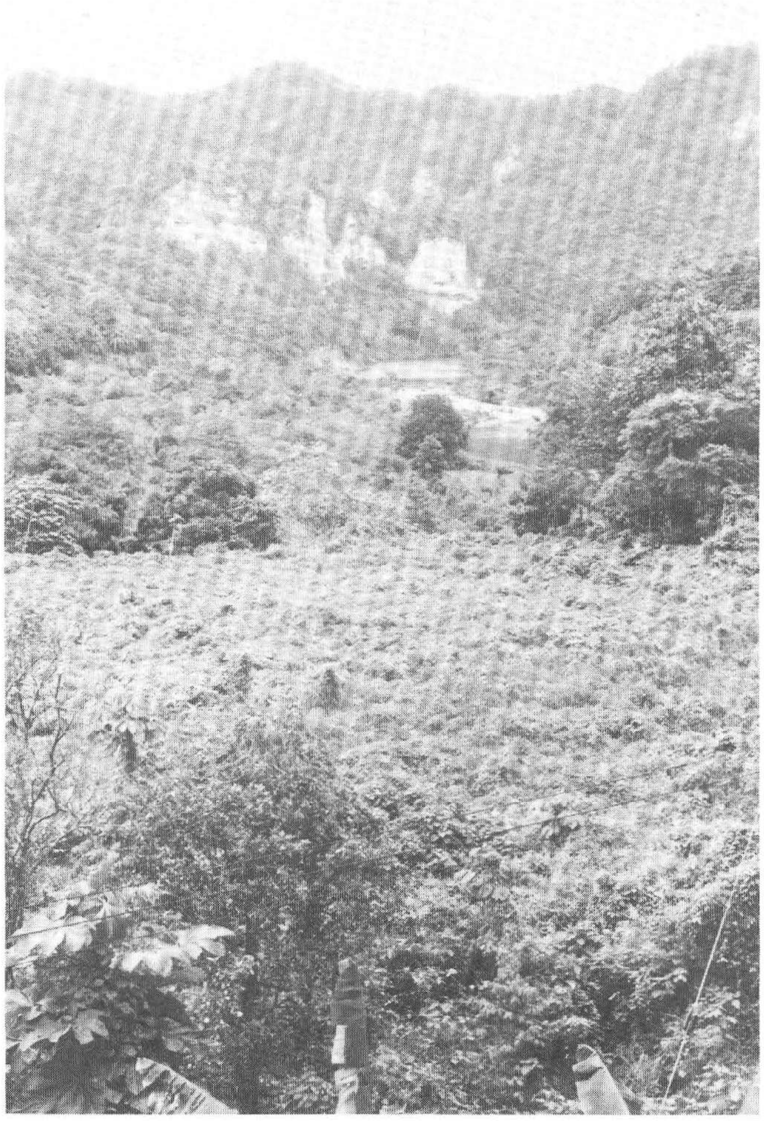

FIGURE 16.—The flood plain (foreground) of the Río Grande de Arecibo begins where the river emerges from the canyon.

ranges from 1,550 mm on the coast to 2,300 mm inland in the areas where the limestones are in contact with the mountains of the central core. To the extent that rainfall in Puerto Rico increases rapidly with altitude, the small range of rainfall found on the north coast belt reflects the slight differences of relief. The variability within the year follows an islandwide trend: a generally dry period that begins in December and usually ends in March or April, a spring rainfall period in April and May, an erratic, semidry period in June-July, and a wet season from August through November. Greatest monthly rainfall is in September. The hurricane season is from June through October and in any 1 year can produce a very wet June or July.

The average annual air temperature is 24° C on the north coast belt and varies but a few degrees from winter to summer.

Puerto Rico lies in the path of the easterly trade winds which are almost constantly blowing across the island. Data published by Briscoe (1966) indicate that the winds vary from month to month and that there is a yearly average ranging from 16 km/h (kilometers per hour) at Cabezas de San Juan on the east coast to 5 km/h at Gurabo in the interior. In general, there are more constant and stronger winds in the coastal areas than in the interior areas. Differential heating between the sea and land also produces an onshore breeze during the day and an offshore breeze at night.

EVAPOTRANSPIRATION

Evapotranspiration is a major factor in the water balance of the north coast limestone region. Unfortunately, field data on evapotranspiration are sparse; for this reason it is desirable to establish a relation between evapotranspiration and a more readily available hydrologic parameter. Because reasonably good rainfall records are available for the karst region, an analysis was made to relate evapotranspiration to precipitation. Before presenting the results of this analysis, certain theoretical concepts will be reviewed, with the aim of showing that a relationship between evapotranspiration and precipitation can be accepted with reasonaable confidence.

Potential evapotranspiration represents the maximum possible rate of evapotranspiration from an area—that is, the rate which is observed under a full plant cover, when an unlimited supply of water is available for evapotranspiration. Actual evapotranspiration depends upon the available water supply, and is generally much less than potential evapotranspiration. Potential evapotranspiration is a function of such factors as solar radiation and the moisture content of the atmosphere. Actual evapotranspiration also depends upon these factors, but depends as well upon the available water and the plant cover. In the limiting case of a desert area, potential evapotranspiration is very high, whereas actual evapotranspiration is low because of the lack of available water. In more humid areas potential evapotranspiration is lower because of reduced solar radiation and increased humidity, while actual evapotranspiration is higher. In permanently wet areas, such as a rain forest, the theory of Bouchet (1963), verified by the work of Morton (1965) and Solomon (1967), predicts that potential evapotranspiration and actual evapotranspiration should approach the same value, equal to one-half the absorbed solar radiation as expressed in millimeters

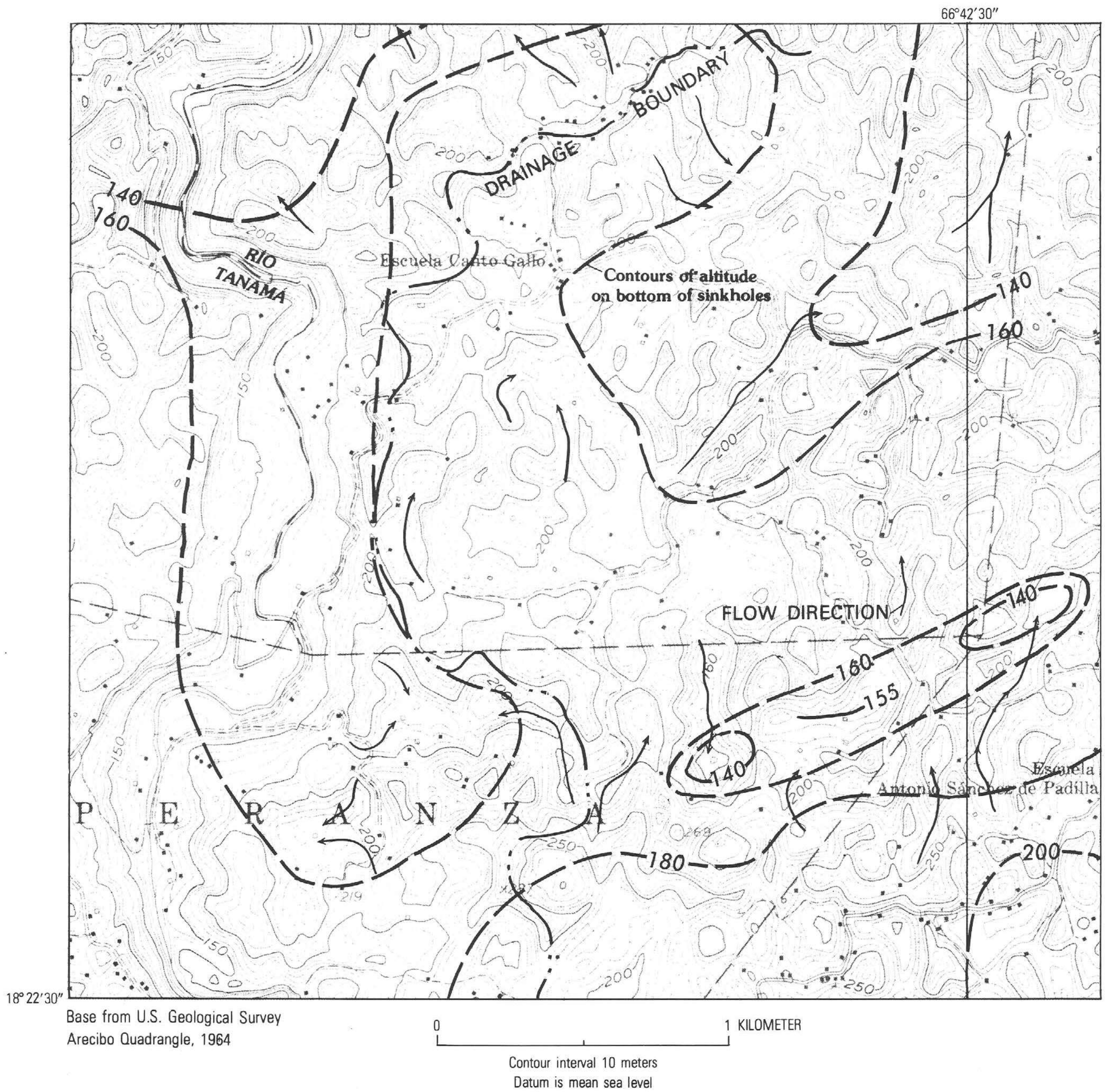

FIGURE 17.—Example of criteria used to delineate drainage boundaries in karst terrane. The dashed lines are contours of the altitude on the bottom of the sinkholes.

of evaporated water. Thus potential values should decrease with increasing precipitation, while actual values should increase with increasing precipitation, until the two become approximately equal for the limiting case of a very humid region.

As a first step in developing a relation between evapotranspiration and precipitation, an analysis was made of the relation between solar radiation and precipitation in the north coast area. The basic assumption was that a relation between evapotranspiration and precipitation would follow from an underlying relation between solar radiation and precipitation. This approach also provided a means of estimating solar radiation in areas (or over periods) for which direct data were lacking.

The theoretical annual extraterrestrial solar

FIGURE 18.—Coastline west of Arecibo. Raised shoreline in the distance.

FIGURE 19.—Sea caves on Aymamón Limestone cliffs, west of Arecibo.

radiation—that is the radiation at the upper limit of the atmosphere—is equivalent to 5,000 mm of evaporated water per year, at the latitude of Puerto Rico (Smithsonian Meteorological Tables, 1966). This very high total is distributed monthly as shown in figure 20. Figure 21 shows a plot of the ratio Rg/Ra versus precipitation, where Rg is the observed annual incoming radiation, and Ra is the theoretical annual extraterrestrial radiation, 5,000 mm of water per year. The observed radiation values are based upon a few years of record (M. Capiel, oral commun., 1970) and averages (Briscoe, 1966) of total incoming solar radiation. For values of rainfall between 500 and 2,500 mm, the line whose equation is

$$\frac{Rg}{Ra} = (0.73 - 0.00009P) \qquad (1)$$

where

P = rainfall, in millimeters

provides a fair fit to the data. For an average Ra of 5,000 mm for the island

$$Rg = 3{,}650 - 0.45P. \qquad (2)$$

The equation of Glover and MacCullock, as given by Roche (1963), may be used to show the relation indicated in figure 21, and equation 2 gives results which fall within reasonable limits. Their equation is

$$\frac{Rg}{Ra} = 0.29 \cos\lambda + 0.52\frac{n}{N} \qquad (3)$$

where

Rg and Ra are as previously defined, and
λ = latitude in degrees,
n = number of observed hours of insolation, and
N = number of maximum possible hour of insolation.

To obtain an upper limit for Rg/Ra, the fraction n/N may be set equal to 1.0, approximating a condition of zero rainfall—that is, maximum insolation; to obtain a lower limit, n/N may be set equal to zero, corresponding to a condition of no days of sunshine. For the latitude of Puerto Rico, taking n/N as 1.0 gives a maximum value for Rg/Ra of

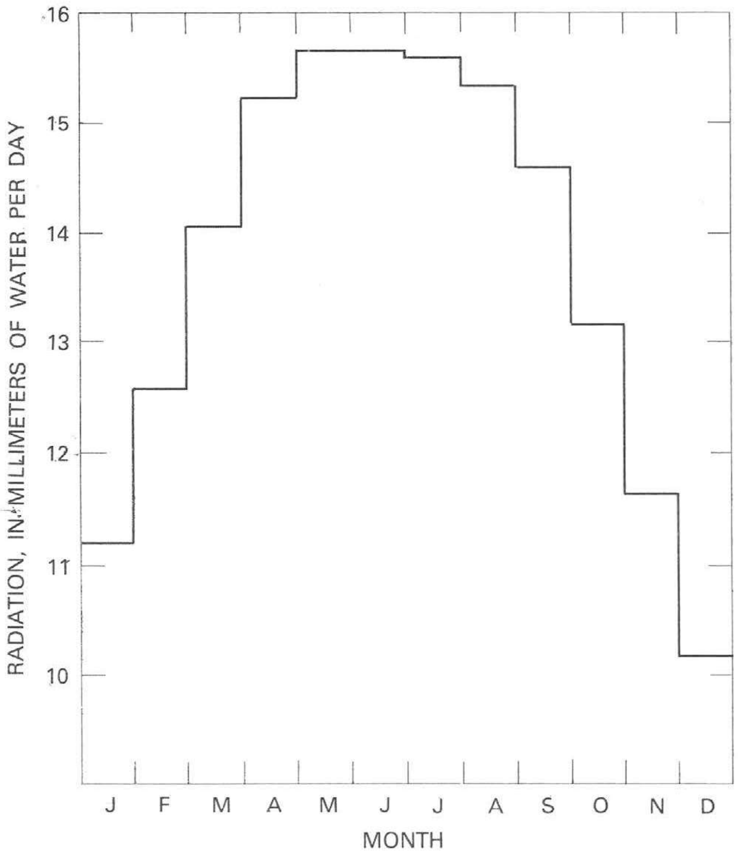

FIGURE 20.—Mid-monthly theoretical solar radiation in equivalent evaporated water for Puerto Rico.

about 0.8. This would presumably correspond to a condition of zero rainfall. The equation of Glover and MacCullock gives 0.28 as a minimum value of Rg/Ra; however, because of the very low probability of occurrence of a year with no days of sunshine, a value of 0.35 is probably a more realistic lower limit for Rg/Ra, corresponding to a year of very high precipitation. Examination of figure 21 shows that these limiting values bracket the field data very reasonably.

Bouchet (1963) gives the equation

$$Ep+ET=(1-a)Rg \qquad (4)$$

Where Ep represents potential evapotranspiration; ET is actual evapotranspiration; Rg, as before, is solar radiation (expressed as equivalent evaporated water); and a is the albedo of the region. The term $(1-a)Rg$ represents the absorbed solar radiation. Equation 4 is applicable provided the underlying assumption of the theory, that there is no net exchange of energy between the region and its surrounding areas, is satisfied. Where such border exchanges (termed "oasis effects" in the theory) do occur, deviations can be expected.

In terms of equation 4, the limiting conditions referred to previously may be expressed as follows:

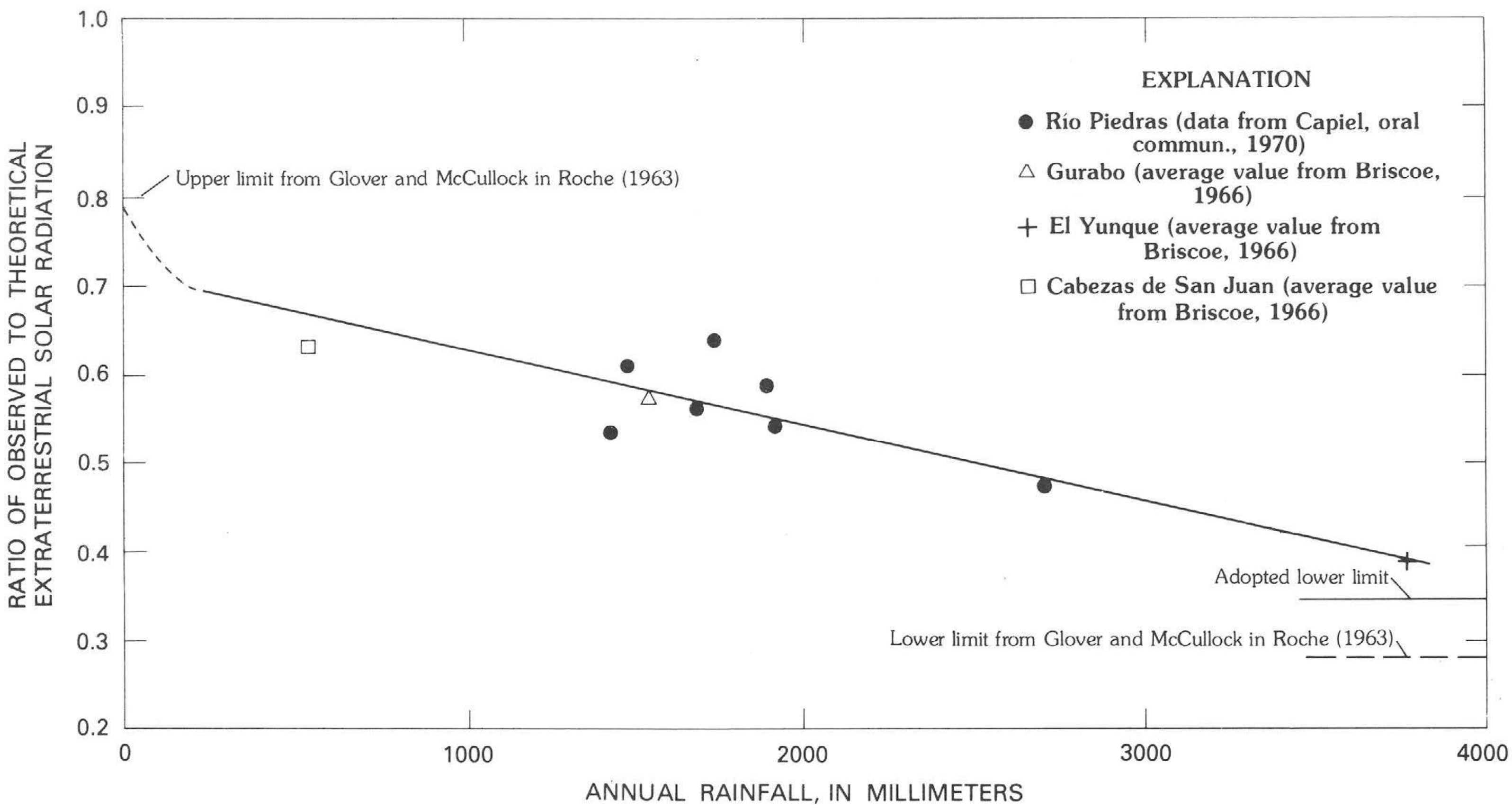

FIGURE 21.—Variation of fractional radiation (ratio of observed to theoretical solar radiation) with rainfall, annual values.

for rainless regions,

$$ET=0 \text{ and } Ep=(1-a)\ Rg \quad (5)$$

for permanently wet regions,

$$ET=Ep=0.5(1-a)Rg \quad (6)$$

Thus the ratio $Ep/((1-a)Rg)$ decreases from a maximum of 1.0 at no precipitation to a minimum of 0.5 at very high values of precipitation; while the ratio $ET/((1-a)Rg)$ increases from a minimum of zero at no precipitation to a maximum of 0.5 at very high values of precipitation.

Figure 22 shows a plot of the ratios $E/((1-a)Rg)$ and $ET/((1-a)Rg)$ versus precipitation, where E represents pan evaporation and ET represents regional evapotranspiration as determined by local water budget calculations. The values of Rg used in forming these ratios were taken from figure 21. Pan evaporation, E, may be taken here as an approximate measure of potential evapotranspiration, Ep. The estimates of actual evapotranspiration were made by considering closed basins in various parts of Puerto Rico for which net inflow and outflow of ground water could reasonably be considered zero, over periods for which the storage change was zero, and computing the difference between precipitation and stream discharge.

The relations shown in figure 22 conform closely to the behavior predicted by Bouchet's theory. Although there is scatter due to data errors and due to border ("oasis") effects near the coast, the limiting conditions established by the theory are clearly satisfied.

In figure 23, values of annual pan evaporation

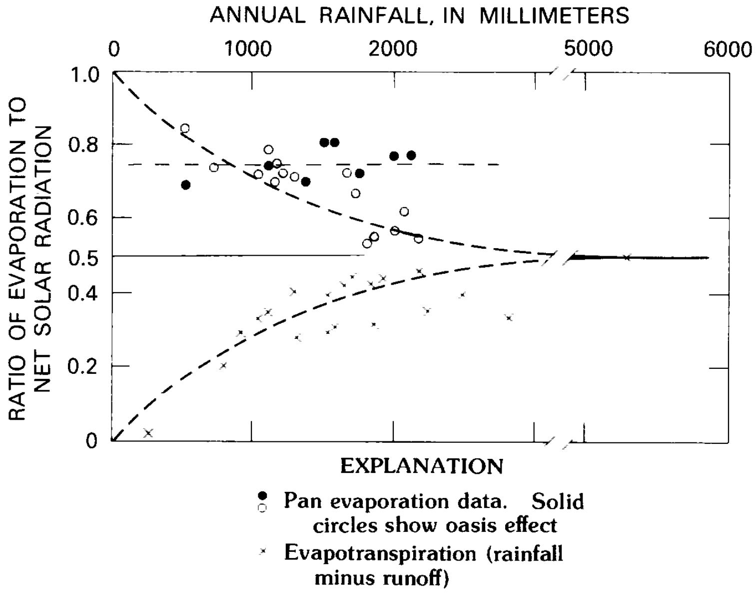

FIGURE 22.—Evaporation to net solar radiation ratio as a function of rainfall in Puerto Rico.

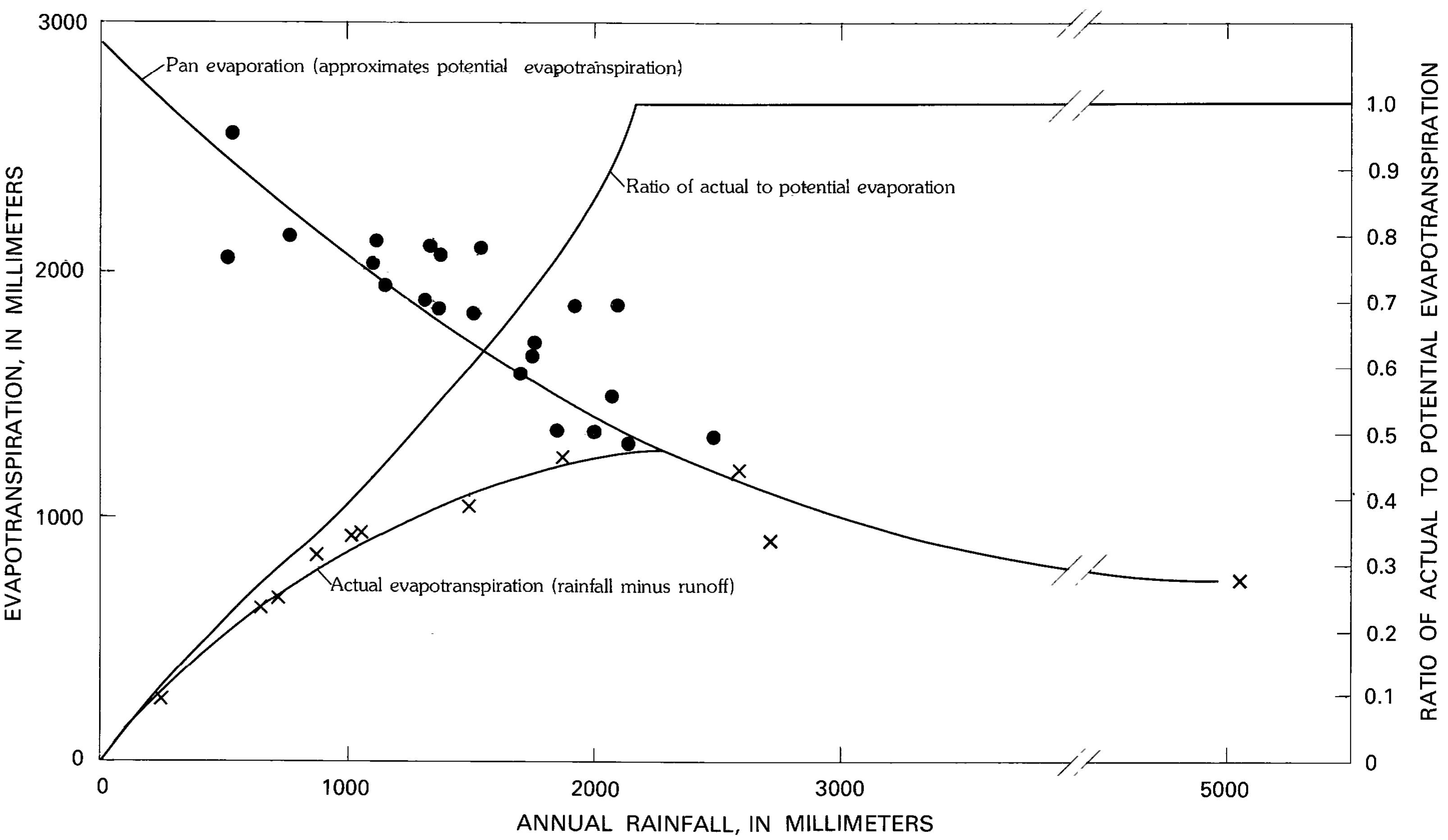

FIGURE 23.—Potential and actual evaporation and their ratio as a function of rainfall.

and evapotranspiration, and values of the ratio of evapotranspiration to pan evaporation, are plotted as functions of annual precipitation. From this graph, the average evapotranspiration from the north coast limestone area, corresponding to the average annual rainfall of 1,800 mm, appears to be about 1,150 mm. Taking pan evaporation as roughly equivalent to potential evapotranspiration, the corresponding average value of ET/Ep is about 0.76. However, it should be noted that this is an average value; the actual value of the ratio depends upon precipitation. The relationship shown in figure 23 was utilized in a water-budget analysis for the limestone area to compute actual evapotranspiration from pan evaporation and precipitation data; this is described in a later section of the report.

HYDROLOGY

The decision at the beginning of this investigation was that the most practical approach to the study of the area would be to obtain a water balance of the entire limestone belt. This goal required assessment of all inflows and outflows; therefore, 10 stream inflows from the volcanic terrane were gaged continuously where they entered the limestone belt, and 12 stream outflow points from the limestone were gaged as far downstream as possible. The difference between the discharge of the upstream and downstream sites constitutes the contribution to streamflow from the limestone area. Rainfall and pan evaporation (potential evaporation) were obtained from the available data published by the National Weather Service, supplemented by data from a few temporary sites to fill some gaps in the areal distribution of the existing meteorological network. Rainfall and pan evaporation data were collected at 25 and 5 sites respectively. About 40 wells were used to gather information on the water-table configuration.

GROUND WATER

WATER-TABLE LEVELS

A contour map of the water-table surface is shown on plate 1. River-bed altitudes were used as control points in constructing this map. In the pattern of ground-water flow suggested by these contours, recharge in the topographically high areas moves radially outward toward the streams and the coast. The streams, the swampy features along the coast, and to some extent the sea floor itself thus all function as drains for the ground-water system. Within the most seaward part of the Aymamón Limestone, the altitude of the water table is just above mean sea level, with an average slope of about 0.0007, reflecting the high permeability of the Aymamón in this area. Southward the gradient steepens to about 0.045 within a transition zone which varies locally, but that in general includes the less permeable lower part of the Aymamón and Aguada Limestone. The gradient flattens again to about 0.003 within the Cibao Formation and the Lares Limestone, possibly indicating higher permeability or a smaller component of lateral ground-water movement.

ARTESIAN ZONES

Until July 1968, the known aquifers in the area were under water-table conditions, although conditions of local confinement had apparently been encountered occasionally by well drillers. No large-yield flowing well had ever been drilled in the north coast limestone belt; however, no well deeper than about 250 m had ever been drilled in the area. In July 1968, a disposal well was drilled in the Cruce Dávila area of Barceloneta. To obtain permission to use the well for disposal of certain industrial effluents, the law required that the well reach salty water. Therefore, the well was drilled deeper than any other water well in Puerto Rico. At a depth of about 350 m below the surface the well penetrated a "crumbly limestone layer" from which water flowed at a rate of 160 L/s (liters per second) with about 7 kg/cm^2 (kilograms per square centimeter)/ of shut in pressure at the land surface. The water was fresh.

The artesian zone occurs within the Montebello Limestone Member of the Cibao Formation which, in the outcrop area, is a very pure chalky limestone. The driller's report indicates that a massive limestone layer was penetrated above the crumbly limestone of the artesian aquifer, while W. H. Monroe (written commun., 1970) reports several meters of clay above the artesian zone. Both types of material undoubtedly contribute to the confinement of the Montebello artesian zone.

A second artesian zone was found at a depth of about 500 m, in the Lares Limestone. Since 1968 several more deep wells have been drilled in the same vicinity; all have penetrated the upper artesian zone and some the lower zone. A first approximation to an average potentiometric surface for the artesian zones is shown in cross section $C-C'$ of plate 2. This surface was constructed by linear interpolation between an average water-table altitude in the

Cibao-Lares outcrop area, and an average static head in the artesian wells at Cruce Dávila.

Drilling in the Tortuguero area in 1972 confirmed the existence of a very limited artesian zone in the Cibao in that area, together with a thick and well-defined artesian zone in the Lares. However, only in the east-central part of the limestone belt, between Río Grande de Arecibo and Río Cibuco, has it been proved that ground water flows under water-table conditions within the Aymamón and possibly the Aguada Limestones, and under artesian head within the Montebello Member of the Cibao Formation and the Lares Limestone. Elsewhere there is only indirect evidence to indicate probable paths of flow.

PERMEABILITY DISTRIBUTION AND GROUND-WATER FLOW

To compute the ground-water flow requires a knowledge of the permeability of the aquifer, as well as information on the head gradient and the cross-sectional area of the flow. These factors are utilized in Darcy's Law to compute the rate of ground-water flow, under the assumption that the flow approximates uniform movement through a porous medium when considered on a regional scale. Because of the possibility that in limestone the flow may be concentrated locally in "pipes" or along bedding planes or through fractures, Darcy's Law may not be applicable in a local sense. However, at the scale of regional flow it is assumed that the networks of solution pipes, fractures, and bedding planes are interconnected and spaced so as to approximate flow through a porous medium. The degree to which results from the application of Darcy's Law agree with the water-budget evaluation will give an indication of the reasonableness of these assumptions.

Estimates of permeability for the water-producing intervals of the rocks were obtained using specific capacity data from all wells in the north-coast limestone area for which information on lithology and well construction was available. The method of estimation was based on Thiem's equation for steady-state radial flow to a pumping well, and thus again involved the assumption that Darcy's Law was applicable in a general sense over the area of influence of the well. The equation used was

$$K = 37\frac{Q}{SM}\log\frac{re}{rw} \qquad (7)$$

where

K = permeability, in centimeters per second;
Q = well discharge, in cubic meters per second;
S = drawdown, in meters;
M = screened or open intervals of the well, in meters;
re = the radius of a plan view of the cone of depression, in meters, taken arbitrarily as 150 meters in all cases; and
rw = radius of casing, in meters.

The error involved in using an assumed radius of influence is probably small. Because the term re/rw appears in the logarithm, an error in K of only 100 percent is introduced when re is in error by 1,000 percent.

The permeability values computed in this way ranged from less than 10^{-4} cm/s (centimeter per second) to about 1 cm/s. The estimated average permeability south of Caño Tiburones is shown in figure 24. An estimate of the ground-water flow through the area south of Caño Tiburones can be made substituting the values for permeabilities from figure 24 and the gradients from plate 2 in the equation for Darcy's Law. For 1-kilometer width of aquifer:

$$Q = 10\,K\,I\,t \qquad (8)$$

where

Q = discharge, in cubic meters per second;
K = permeability, in centimeters per second;
I = head gradient, dimensionless; and
t = thickness of aquifer, in meters.

For the Aymamón and Aguada Limestones, the head gradient was taken as the water-table gradient; for the Cibao and Lares formations, the gradient was taken as the difference between the average water-table altitude in the Cibao-Lares outcrop area and the average artesian level in the wells at Cruce Dávila, divided by the distance of flow. The discharges for the various aquifers are as follows:

Aymamón
$$Q = 10 \times 0.2 \times 0.00095 \times 60 = 0.11 \text{ m}^3/\text{s}$$
Aguada
$$Q = 10 \times 0.02 \times 0.00095 \times 100 = 0.02 \text{ m}^3/\text{s}$$
Cibao (Montebello Limestone Member)
$$Q = 10 \times 0.005 \times 0.0021 \times 180 = 0.02 \text{ m}^3/\text{s}$$
Lares
$$Q = 10 \times 0.0002 \times 0.0021 \times 75 = 0.0003 \text{ m}^3/\text{s}$$

The flow through the entire limestone section south of Caño Tiburones, calculated using a width of 15 km (derived from the flow pattern shown on plate 1), amounts to about 2.3 m³/s or 0.15 m³/s per kilometer width.

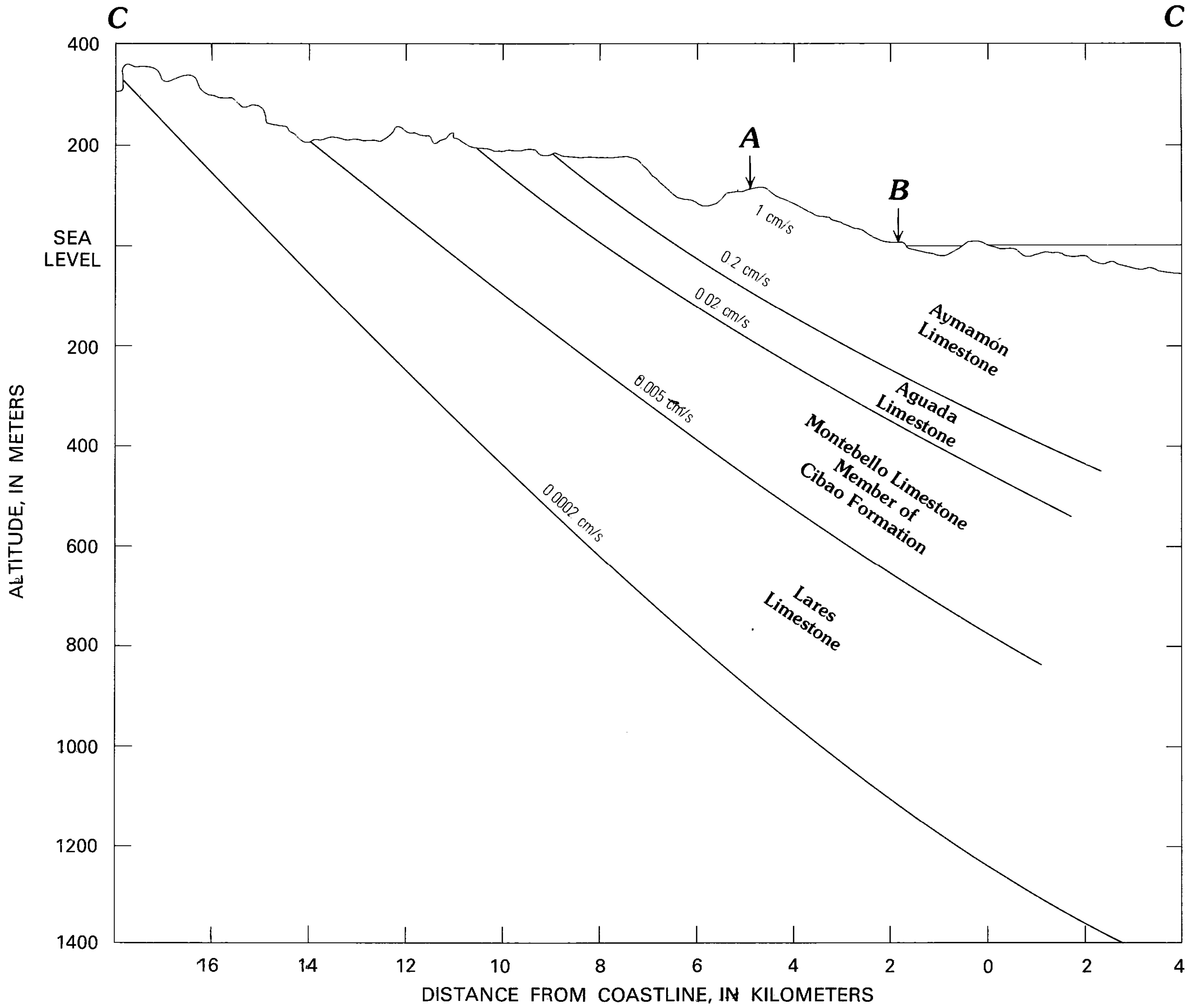

FIGURE 24.—Average permeability distribution within cross section *C–C′* through the Caño Tiburones area between points A and B. See plate 1 for location of cross section.

Similar calculations carried out for various sections shown on plate 2 are summarized in table 1. The results for the sections through the Río Cibuco basin, Laguna Tortuguero, Caño Tiburones, and the Río Camuy basin are more reliable than the results for the sections through the Río Guajataca basin and through the westernmost part of the belt, which were based on data projected from sections to the east. These results will be compared later in this report with the budget results computed from streamflow and meteorological data.

The data in figure 24 clearly show a permeability decrease from a high in the Aymamón to a low in the Lares. A plot showing all the computed permeabilities as a function of stratigraphic depth, measured from the projected top of the Aymamón Limestone, is shown in figure 25. The plot is semilogarithmic, and the average straight line indicates an exponential decrease in permeability with stratigraphic depth. However, this relationship refers only to the permeability of the aquifer intervals and should not be inferred to mean a continuous change of permeability with depth. Low permeability layers —that is, aquitards (for which no permeability calculations were made)—are found intermixed with the more permeable zones. The permeability of the massive limestone found on top of the artesian aquifers south of Caño Tiburones is orders of magnitude lower than that of either the overlying or the underlying layers.

TABLE 1.—*Ground-water flow of the north coast limestones*
[Sections are shown on plate 2]

Formation	Thickness (meters)	Slope	Permeability (cm./s)	Discharge (m³/s per km width)
		Vega Alta-La Plata		
Aymamón Limestone	60	0.00076	0.1	0.046
Aguada Limestone	75	.00076 ?	.02	.011
Cibao Limestone	150	.0028 ?	.002	.008
Lares Limestone	130	.0028 ?	.0005	.002
Total	---	------	-----	.067 = .80 for 12 km
		Manatí-Tortuguero		
Aymamón Limestone	90	0.00057	0.1	0.0510
Aguada Limestone	60	.00057 ?	.005	.0020
Cibao Limestone	170	.0028	.0005	.0024
Lares Limestone	110	.0028 ?	.0002	.0006
Total	---	------	-----	.0560= .67 per 12 km
		Arecibo-Barceloneta		
Aymamón Limestone	60	0.00095	0.2	0.1140
Aguada Limestone	100	.00095 ?	.02	.0190
Cibao Formation	180	.0021	.005	.0190
Lares Limestone	75	.0021	.0002	.0003
Total	---	------	-----	.1523=2.28 for 15 km
		Camuy-Arecibo		
Aymamón Limestone	60	0.001	0.05	0.0300
Aguada Limestone	90	.001	.002	.0018
Cibao Limestone	170	.003 ?	.001	.0051
Lares Limestone	300	.003 ?	.0002	.0018
Total	---	------	-----	.0387= .43 for 11 km
		Guajataca-Camuy		
Aymamón Limestone	60	0.001 ?	0.02	0.0120
Aguada Limestone	90	.001 ?	.002	.0018
Cibao Limestone	200	.003 ?	.0005 ?	.0030
Lares Limestone	300	.003 ?	.0002 ?	.0018
Total	---	------	-----	.0186= .20 for 11 km
		Aguadilla-Guajataca		
Aymamón Limestone	60	0.001 ?	.02 ?	.0120
Aguada Limestone	90	.001 ?	.002 ?	.0018
Cibao Limestone	200	.001 ?	.0005 ?	.0010
Total	---	------	-----	.0148= .25 for 17 km

NOTE: Total for entire belt = 4.6 m³/s.

GROUND-WATER FLOW PATTERNS

The caves found in the karst of the north coast belt are almost invariably tunnellike and develop from limestone solution along bedding planes. As a result, the regional ground-water flow lines tend to follow the bedding of the limestone layers down dip, presumably along preferential paths of higher permeability.

ARTESIAN FLOW PATTERNS

In the section through the Caño Tiburones area in figure 26, three possible patterns of ground-water outflow from the artesian zones are illustrated. The simplest pattern is direct discharge to sea in a submarine outflow area; it is illustrated by the arrows in the lower right corner of figure 26. In such submarine outflow, the ground water must discharge against the static head exerted by the column of seawater above the outflow area. This head can be measured in terms of an equivalent freshwater potentiometric head, defined as the height above sea level to which freshwater would rise in a piezometer inserted to the seabed. This equivalent freshwater head increases seaward as the depth of saltwater increases. The solid line above the sea surface in figure 26 shows the trend of the equivalent freshwater head.

The potentiometric head of the artesian zones beneath the sea can presumably be found by extending the artesian-head gradients measured on land. Extensions of the potentiometric head of the artesian aquifers seaward in this manner involves the assumptions that there are no changes in permeability within the artesian zones and that there is no gradual loss of flow from these zones by upward leakage. If these assumptions are satisfied, the

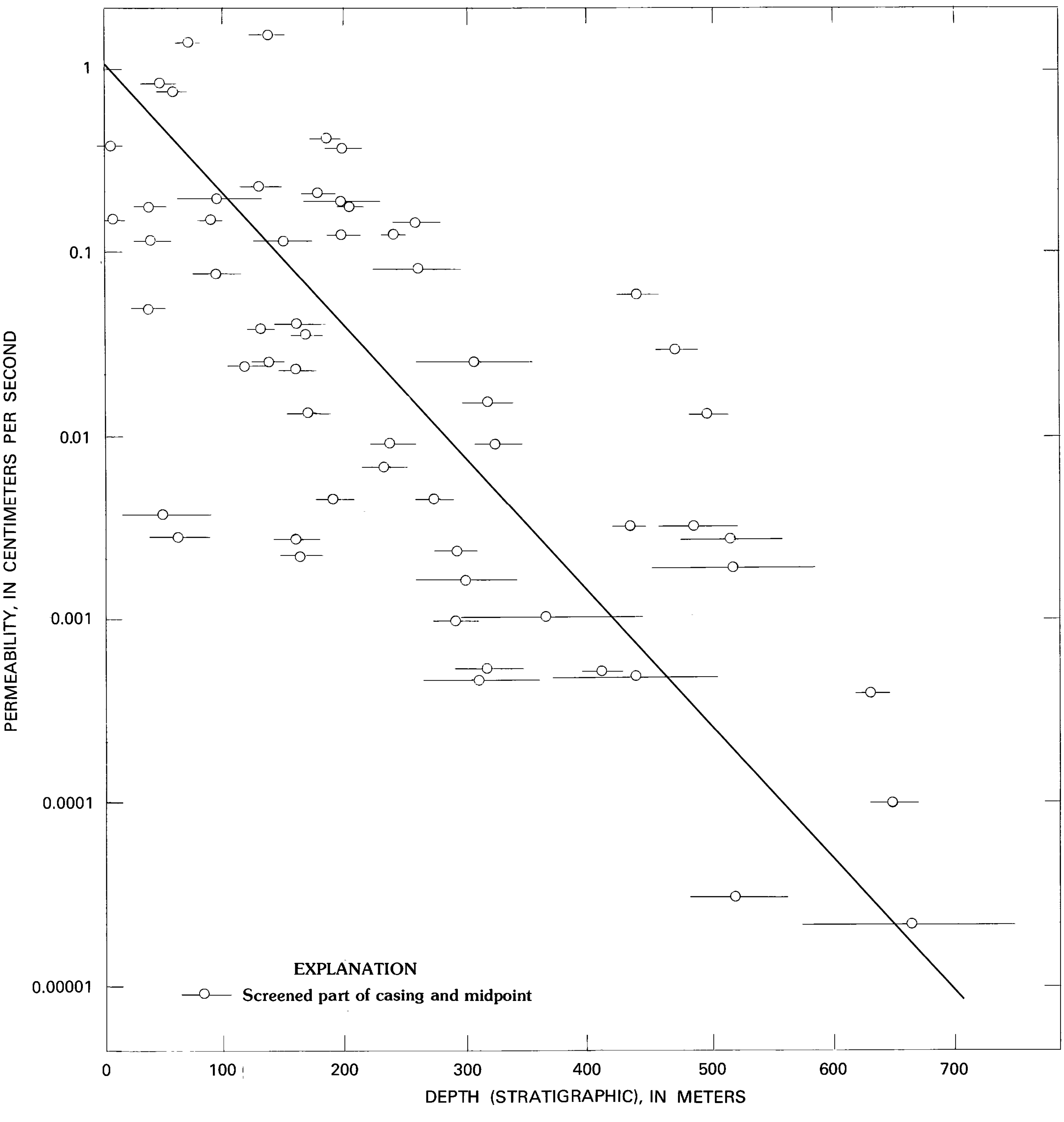

FIGURE 25.—Variability of permeability with stratigraphic depth from projected top of Aymamón Limestone.

upper dashed line in figure 26 is obtained as an average potentiometric surface for the Cibao and Lares systems. Discharge at a submarine area requires that the artesian head in the aquifer balance the equivalent freshwater head of the column of sea water above the discharge area. In figure 26, this condition is indicated by the intersection of the dashed line representing artesian head with the solid line representing equivalent freshwater head at the sea floor. This intersection occurs approximately 30 kilometers offshore; this is in reasonable agreement with locations of the submarine outcrops of the artesian zones, as obtained by extrapolation of the dip seaward. However, the extrap-

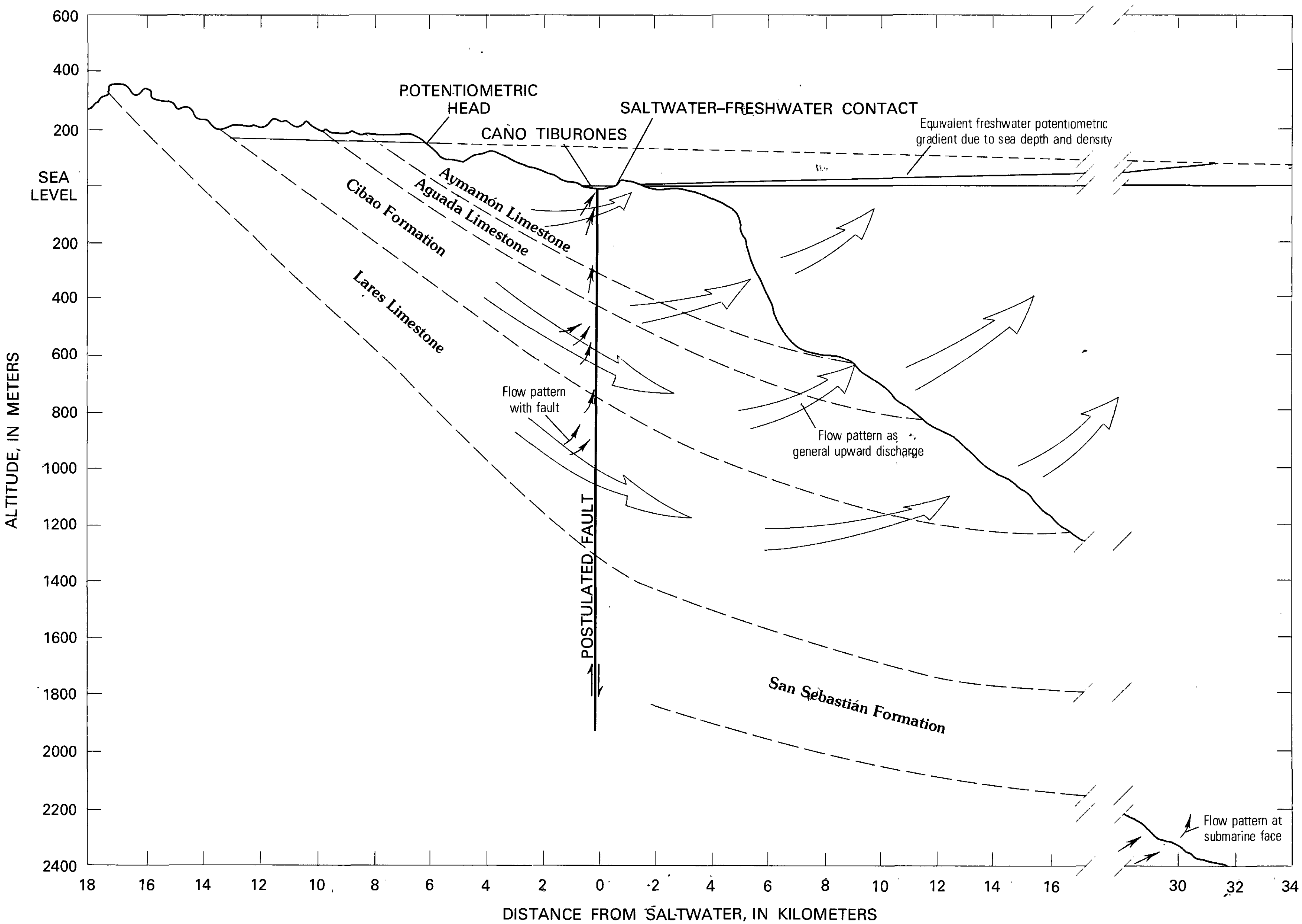

FIGURE 26.—Possible patterns of ground-water flow in Caño Tiburones area.

olation of head gradients and geologic dips for tens of kilometers is questionable, and this agreement may be no more than fortuitous.

A second possible pattern of ground-water discharge is shown by the large arrows in figure 26. If the permeability of the artesian zones decreases seaward, the head gradient in the aquifer cannot be linear, and the above extrapolation of heads would not be valid. Rather, the loss in head per kilometer would increase seaward, and the artesian head would be dissipated much closer to shore than 30 km. If a permeability decrease were gradual with distance and with the stratigraphic depth, the result would probably be a widespread upward discharge of ground water through the confining beds (large arrows of figure 26). Some of this upward seepage would probably escape through the sea floor and some through discharge areas on land.

A third possible pattern of discharge is related to the faulting postulated by Briggs (1961) in the Caño Tiburones area. Such faulting would presumably have thrown rock of low permeability against the artesian zones, and the barrier so created would block or impede flow seaward and force discharge upward. It is possible that fracturing associated with the postulated faulting could have produced a zone of high vertical permeability along the fault trace, creating conditions favorable to vertical outflow. The pattern of ground-water flow that might result from these conditions is shown by the small solid arrows in figure 26.

WATER-TABLE FLOW PATTERNS

Throughout the limestone area, but particularly east of Arecibo, ground water under water-table conditions discharges through springs and by areal seepage, either directly to sea or to the swampy areas along the coast. These swampy areas discharge, in turn, by evapotranspiration or by surface drainage to the sea.

A two-dimensional steady-state electric analog analysis of conditions south of Laguna Tortuguero was made by G. D. Bennett (Bennett and Giusti, 1972). The results of this analysis are shown in figure 27. The model, made of conducting paper of fixed resistance, was designed to simulate the water-table aquifer with a vertical to horizontal ratio of permeability of 1 to 10. The results of measuring the electric current at the boundaries, equivalent to measuring the ground-water flow, indicated that 75 percent of the outflow takes place inland from the coast and is disposed of through Laguna Tortuguero's direct outflow to sea, and by evapotranspiration from swampy areas, while 25 percent of the outflow takes place along the sea bottom in a zone a few hundred meters wide. Conditions in the Río Cibuco basin can be expected to be very similar to those in the Tortuguero area. Original conditions in the Caño Tiburones area were probably also similar. At the present time, however, agricultural drainage within the Caño Tiburones has lowered the water table several feet, so that all ground-water flow toward the coast enters the Caño Tiburones itself and discharges either by evapotranspiration or into drains, from which it is pumped to the sea. The water table in the northern part of the Caño Tiburones has in fact been lowered below sea level, inducing a substantial inflow of sea water, which makes up roughly one-third of the total pumpage from the drain system of the Caño.

West of Arecibo the conditions of ground-water outflow in the water-table zone are more speculative. From water-budget data to be presented later, it appears that the Río Tanamá, Camuy, and Guajataca act as highly efficient ground-water drains, and therefore only a small part of the regional flow from the areas between these rivers can be expected to discharge to coastal swampy areas or through the sea bottom.

The coastline west of Arecibo is formed by cliffs that rise several meters above the sea. No springs were noticed issuing from these cliffs. A few ponds and swampy areas occur at the foot of the sea cliffs, but these are the only evidence of ground-water outflow inland from the coast. No large freshwater springs are known to occur at sea with the exception of one unverified report about such an offshore spring near the town of Camuy. The evidence points to ground-water outflow mainly as the base flow of streams.

The pattern of ground-water outflow in the westernmost part of the limestone belt, between Río Guajataca and the west coast, remains unknown. In the southernmost part of this region, the outcrop area of the Lares is drained southward by streams tributary to Río Culebrinas (fig. 12). The Cibao Formation in this area is a nearly impermeable clayey marl.

In the northern part of this area west of the Guajataca, the karst is well developed in the Augada and lower part of the Aymamón. The younger Camuy Formation crops out on a flat surface of youthful stage karst. The estimate of ground-water outflow to the north, given in table 1, is much larger than the estimated maximum evapotranspiration outflow from swampy areas at the foot of the sea

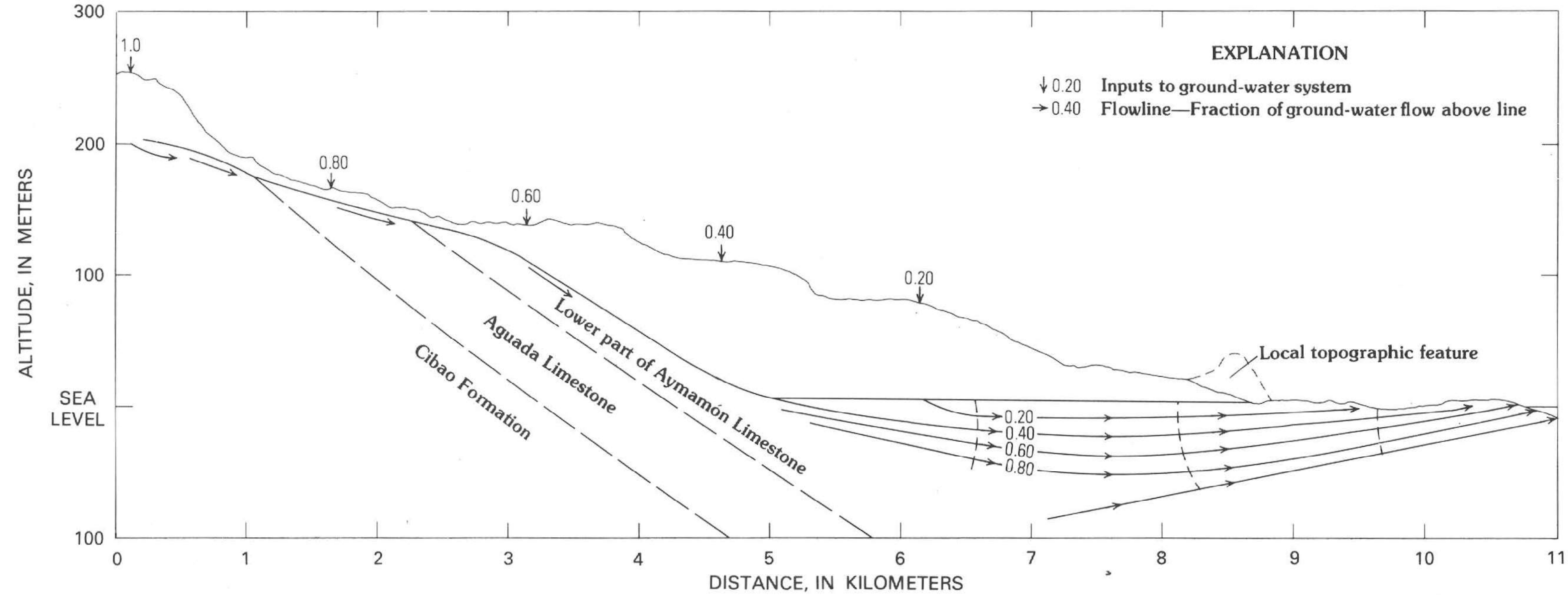

FIGURE 27.—Ground-water flow pattern in the Tortuguero area (Bennett and Giusti, 1972).

cliffs. Quebrada de los Cedros, the only stream in the area, is normally dry. Thus the most reasonable explanation at this time is that the ground-water outflow from the northwestern corner of the limestone belt is mainly through the sea bottom.

SPRINGS

There are thousands of springs within the limestone area. Those springs of large yield which were found in the field are located on the map of figure 12. The springs discharging near the coast rise through the blanket sands or swamp deposits, and give rise to Caño Tiburones (figs. 28 and 29) and to Laguna Tortuguero. Springs contributing water to rivers issue from cliffs (figs. 30 and 31) or emerge through the alluvium. A few springs (fig. 32) flow only after heavy rains; during droughts they stand as nearly circular pools of water marking the surface of the water table.

In regions where horizontal strata are cut by a river, one would normally expect to find an equal

FIGURE 29.—Large spring at the south end of Caño Tiburones.

FIGURE 28.—Small spring (cancora) in the Caño Tiburones area. Hundreds of such springs flow upward through the muck of this former lagoon.

FIGURE 30.—Salto Collazo Spring, from the Lares Limestone, discharges southward to the Río Culebrinas drainage system.

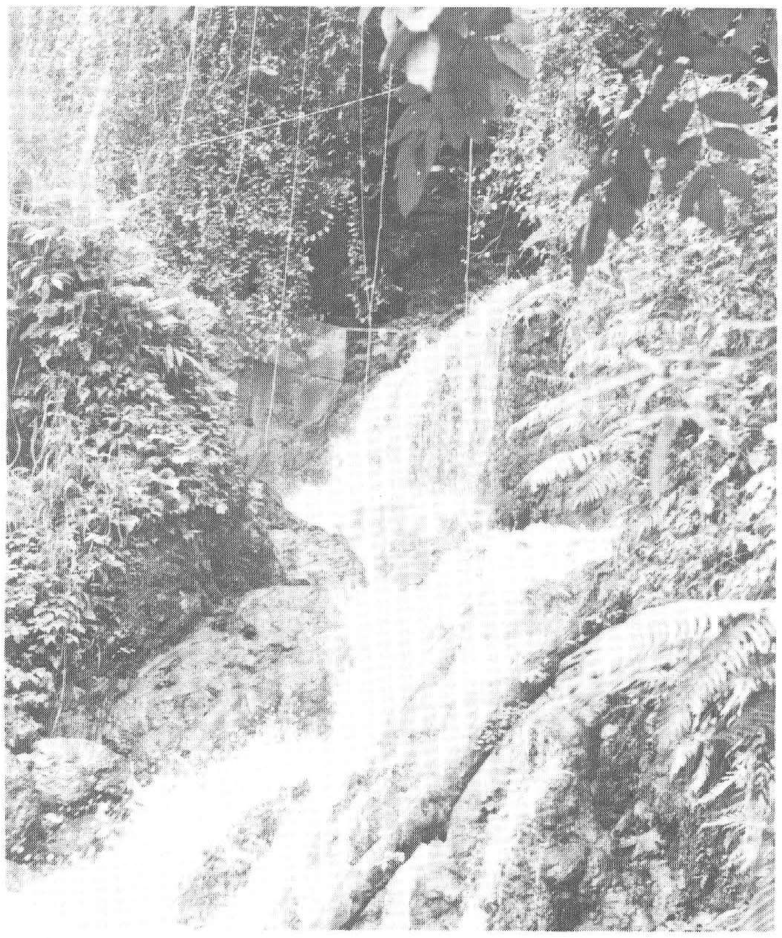

FIGURE 31.—Spring El Chorro to Río Grande de Arecibo—note travertine deposits in lower right.

FIGURE 32.—Spring in flood plain of Río Grande de Arecibo. This spring flows only after heavy rains.

number of springs on both sides of the river valley. Instead, springs along the rivers in the north coast limestone occur mainly on the west sides of the river valleys. Their position suggests that the eastward tilt of the Puerto Rican platform has affected the pattern of drainage of ground water.

STREAMFLOW AND WATER BUDGET

To test whether the results of water-budget calculations would yield important clues to the ground-water movement in the north coast limestones, data were collected for a period of approximately a year and a half on streamflow, rainfall, and pan evaporation in the limestone drainage basins. For those streams draining both volcanic and limestone terranes, the streamflow was recorded both where the streams entered the limestone belt and at their mouths; by difference, therefore, the contribution from the limestone part of the basin could be assessed. The data shown in table 2 cover selected drainage basins for 1 year of record—the period between November 1969 and October 1970. This choice of period reflects the most reliable data; the streamflow at the beginning and at the end of this period was nearly equal.

In table 2, the drainage basins are grouped geologically into those draining volcanic terrane and those draining limestone terrane. Measurement sites are indicated by number and by the name of the gaged stream, and are located on the map of plate 1. The numbers in column 1 are the rainfall in millimeters over the basin, as obtained from Thiessen averaging. Column 2 lists the evapotranspiration, computed by multiplying a Thiessen averaged pan evaporation (shown in column 6) by the ratio of evapotranspiration to pan evaporation; this ratio was taken from figure 23, as a function of precipitation. More properly, the ratio between evapotranspiration and pan evaporation should have been treated as a constant for the permanently moist parts of the basins, such as flood plain, swamp, or lake areas, and as a function of precipitation, according to Bouchet's theory, elsewhere in the basin. However, the quantity and quality of the available data did not appear to warrant this refinement, particularly as the period of record was about 20 percent wetter than normal (2,200 versus 1,800 mm).

The stream discharge per unit drainage area is listed in column 3. For those streams that drain volcanic terrane there is no reason to assume that the topographically derived drainage areas (column 5) may be in error; therefore, anomalies in the figures for streamflow per unit area cannot be ascribed to errors in drainage area. Not so, however, for the streamflow per unit area from limestone basins; for those streams there is an inherent difficulty in

TABLE 2.—*Water-budget results of the north coast limestone belt for the period November 1969–October 1970*

	Streamflow site	(1) Rainfall P, mm	(2) ET, mm	(3) Discharge Q, mm	(4) $\pm\Delta S$, mm	(5) Drainage area, km²	(6) Pan evaporation, mm
	Basins in volcanic terrane						
1	Upper Camuy	2,210	1,240	960	0	19.7	1,370
2	Criminales	2,210	1,240	1,120	−140	11.7	1,370
3	Arecibo below Lago	2,360	1,200	1,090	+70	438	1,320
4	Upper Tanamá	2,230	1,240	920	+70	47.8	1,370
5	Upper Manatí	2,540	1,140	1,270	+130	330	1,320
6	Upper Cibuco	2,360	1,200	1,040	+120	39.0	1,370
7	Mavilla	2,440	1,170	1,730	−460	24.6	1,370
8	Unibón	2,230	1,240	1,200	−210	13.7	1,370
9	Cialitos	2,310	1,220	960	+130	44.0	1,370
10	Upper Guajataca	2,210	1,240	860	+110	8.3	1,400
	Basins in limestone terrane [1]						
11	Guajataca to Lago	2,230	1,240	760	+230	79.0	1,800
12	Guajataca to mouth	2,030	1,220	560	+250	76.6	1,650
13	Lower Camuy	2,110	1,240	840	+30	170	1,520
14	Lower Tanamá	2,080	1,240	560	+280	103	1,500
15	Lower Arecibo	1,860	1,200	15	+650	76	1,570
16	Lower Manatí	1,860	1,200	860	−200	174	1,320
17	Lower Cibuco	2,030	1,220	890	−80	170	1,500
18	Lajas	2,080	1,220	1,090	−230	21.8	1,370
19	Quebrada de los Cedros	1,730	1,170	25	+530	37.8	1,800
20	South Canals	1,320	1,040	51	+220	53.4	1,800
21	Caño Tiburones	1,320	1,040	2,110	−1,830	46.3	1,800
22	Laguna Tortuguero	1,730	1,170	510	+50	43.5	1,570

[1] For basins that begin in volcanic terrane, discharge is the difference between total downstream flow minus upstream flow. Other data refer to limestone portion of basin only. Location of sites, including those in volcanic terrane, is shown on plate 1.

computing drainage areas for the basins. The drainage areas shown in column 5 for the limestone basins represent a first estimate, to be tested for hydrologic reasonableness as shown later.

The term $\pm\Delta S$ of column 4 is simply the residual from the budget equation:

$$\pm\Delta S = P - ET - Q \qquad (9)$$

where P represents precipitation, ET is evapotranspiration, and Q is stream discharge per unit area. Assuming that ground-water inflow and outflow from the basin are negligible. ΔS represents the change in water storage per unit area in the basin; a plus sign indicates that water was taken into storage, while a minus sign indicates that water was released from storage.

A plot of the streamflow per unit area versus the difference between the rainfall and the estimated evapotranspiration is shown in figure 33. The deviations of the points from the 45-degree line indicate change in storage, ground-water inflow or outflow across the borders of the basin, or data error. Most of the points fall within a band ±20 percent of the 45-degree line. One basin in volcanic terrane plots slightly over +30 percent. There are, however, four basins in the limestone terrane that deviate excessively from the 45-degree line, and their deviation must be explained. The basin numbered 21 is Caño Tiburones. Its discharge per unit area was computed from a drainage area of 47 km²; from plate 1, this represents the immediate surface drainage area as interpreted from the topographic divides. It should be remarked that the actual outflow from Caño Tiburones is a mixture of freshwater and seawater. The discharge shown in table 2 represents only the freshwater portion, calculated on the basis of a chemical rating table. Clearly this freshwater discharge of Caño Tiburones cannot be accounted for by a drainage area of 47 km²; thus the discharge must include a large proportion of ground-water flow from the area to the south (pl. 1), which has no apparent drainage to the sea. This area includes extensive outcrop areas of the Aymamón and Aguada Limestones, and smaller outcrop areas of the Cibao Formation and Lares Limestone. (The flow into Caño Tiburones may also include a small amount of leakage from the artesian zones of the Cibao and Lares; this would represent ground-water inflow even in terms of the extended drainage area.) A new calculation of streamflow per unit area was therefore made for the Caño Tiburones, in which the previously unassigned drainage area to the south was included (refer to pl. 1 for drainage area boundaries). Rainfall and evapotranspiration were taken equal to those of the lower Arecibo basin. It can be seen from figure 33 that, with the new drainage area, Caño Tiburones plots within the main scatter field, thus indicating that the newly assumed drainage boundaries are generally correct.

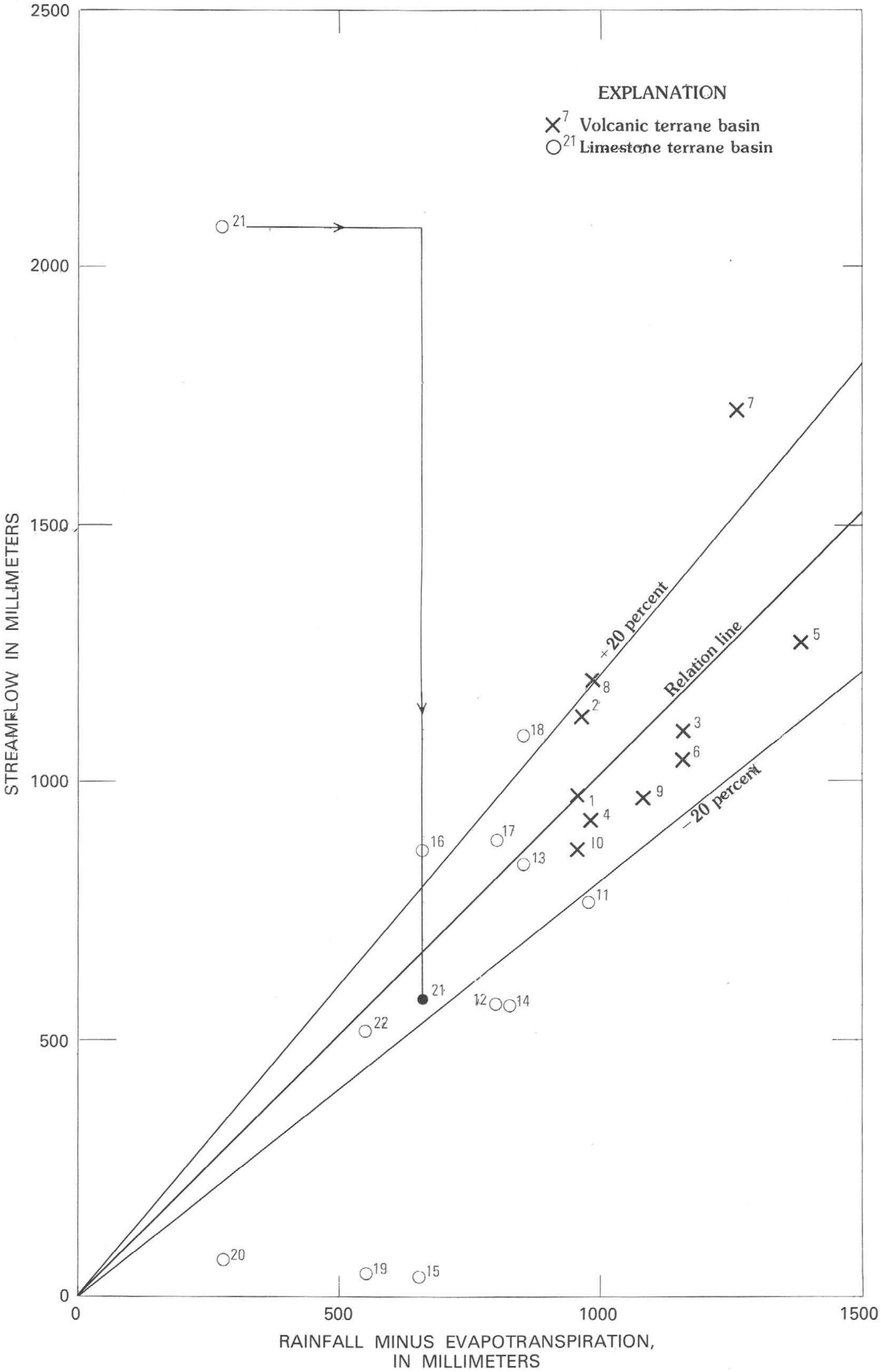

FIGURE 33.—Streamflow versus differences between precipitation and evapotranspiration. Data from table 2.

The basin numbered 15 is the lower Arecibo. It consists largely of valley plain downstream from Lago Dos Bocas. A yearly discharge of 56 mm is obtained by including the discharge of one spring whose flow is diverted from the basin for public supply (a direct subtraction of upstream from downstream flow would have resulted in a negative flow, indicating a loss). To a certain extent, the valley of the Río Grande de Arecibo acts like a sponge, absorbing water from the river during high flow and releasing it to the stream channel during the dry season, with an apparent near-zero net yearly contribution to the streamflow. Actually, from figure 23, for a rainfall of 1,800 mm, the drainage area between the upstream and the downstream site should yield a discharge of 600 mm for the year, about 550 mm greater than calculated. The excess probably flows into Caño Tiburones through the very permeable upper part of the Aymamón Limestone. The cluster of springs at the west end of Caño Tiburones is interpreted to mark the outflow area for this interflow from the Río Grande de Arecibo basin.

The remaining two basins showing excessive deviation from the 45-degree line of figure 33 are numbers 19 and 20. They are, respectively, Quebrada de los Cedros, and an area to the south of Caño Tiburones, which is drained by canals. Quebrada de los Cedros is usually dry, as its bed lies above the water table; it flows only after prolonged rainfall. Its drainage area is, therefore, only that part of the basin which has direct communication with the main channel, or fraction of the 38 km^2 assigned to it on the basis of sinkhole alinement. In addition, during storm runoff, this stream loses water through its bed all along its course. The canal-drained area south of Caño Tiburones (area 20) was assigned a drainage area of 54 km^2. Evidently the canals flow only in response to direct rainfall, and most of the rainfall outside their immediate area emerges as springflow in Caño Tiburones.

BASE FLOW

The separation of streamflow into components of floodflow and base flow involves definitions that are somewhat arbitrary. As used in this report, the term "floodflow" refers to that part of streamflow that produces discrete and clearly defined peaks on the hydrograph. (See fig. 34.) The remainder of the streamflow is considered base flow. It should be noted these definitions are based upon the shape of the surface-water hydrograph, rather than upon the origin of the water making up the various flow components.

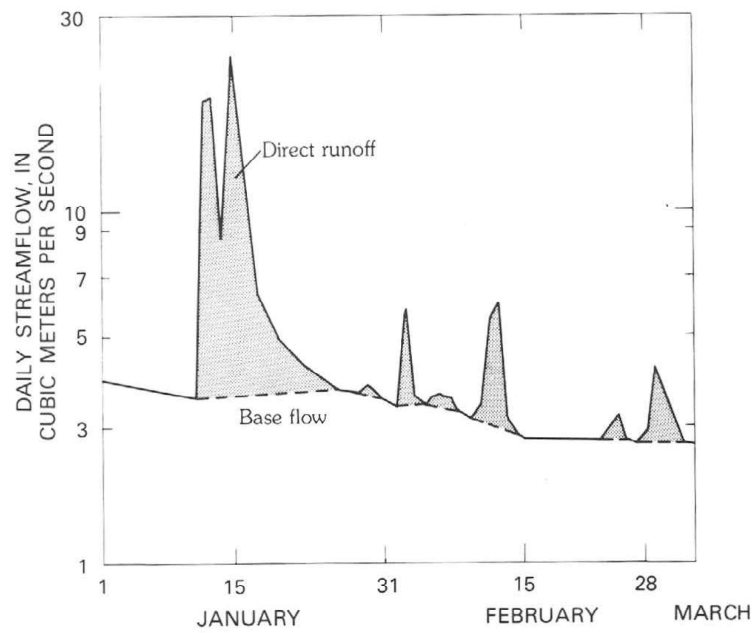

FIGURE 34.—An example of base-flow separation by computer.

A computer program to separate base flow from the total streamflow was adapted for the purposes of this study by T. D. Steele of the U.S. Geological Survey. This program is based on the recognition of points of minima in the hydrograph of daily flows; an empirical function allows for the separate computation of base flow and direct runoff, with the sum of the two being the total discharge. An example of this base-flow separation is shown in figure 34. In general, the program served its purpose well except for a few sites where the base-flow component was somewhat underestimated. The results are shown in table 3.

Two results of the hydrograph separation analysis deserve comment. The first is that the ratio of base flow to total flow, which is plotted against total flow in figure 35, is generally lower, for the major rivers, in the limestone than in the volcanics. The second is that the total base-flow from the limestone region is considerably higher than the total computed ground-water flow in table 1.

Both of these results can be explained by assuming that a certain fraction of the water which infiltrates the land surface in limestone terrane is routed rapidly to the streams through shallow circulation. In some cases this may represent circulation above the normal water table, through conduits which are dry except following a recharge event; in other cases it may represent rapid infiltration to the water table, followed by a correspondingly rapid discharge

TABLE 3.—*Base flow of limestone basins during period November 1969–October 1970*

	Streamflow site	Average base flow (m^3/s)	Lowest flow recorded (m^3/s)	Total flow (m^3/s)	Ratio of base flow to total flow
		Basins in volcanic terrane			
1	Upper Camuy	0.32	0.10	0.60	0.53
2	Criminales	.25	.062	.44	.57
3	Arecibo below Lago	----	----	----	----
4	Upper Tanamá	.89	.25	1.37	.65
5	Upper Manatí	3.50	.84	13.40	.26
6	Upper Cibuco	.48	?	1.30	.37
7	Mavilla	.55	?	1.31	.42
8	Unibón	.23	?	.52	.44
9	Cialitos	.52	.07	1.33	.39
10	Upper Guajataca	.094	.008	.21	.44
		Basins in limestone terrane [1]			
11	Guajataca to Lago	----	----	----	----
12	Guajataca to mouth	0.50	0.13	1.35	0.37
13	Lower Camuy	1.25	.54	4.46	.28
14	Lower Tanamá	1.05	.27	1.81	.58
15	Lower Arecibo	2.15	----	.07	30.00
16	Lower Manatí	2.00	.77	4.65	.43
17	Lower Cibuco	.94	.28	4.48	.21
18	Lajas	.18	.023	.75	.24
19	Quebrada de los Cedros	0	0	----	0
20	South Canals	.002	----	.07	.03
21	Caño Tiburones	2.45	2.0?	3.06	.80
22	Laguna Tortuguero	.55	.30	.74	.75

[1] For basins that begin in volcanic terrane, discharge is the difference between total downstream flow minus upstream flow. Other data refer to limestone portion of basin only. Location of sites is shown on plate 1.

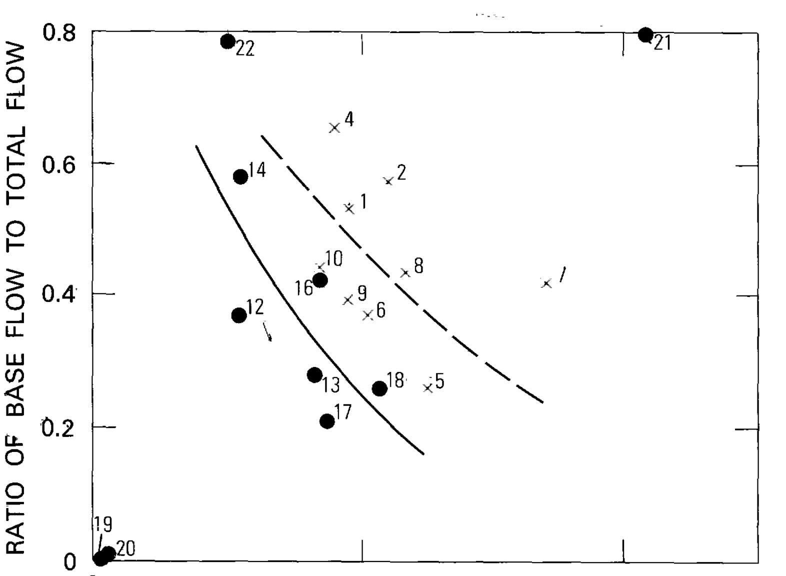

FIGURE 35.—Ratio of base flow to total flow versus discharge per unit area. Data from tables 2 and 3.

to the streams through the shallowest part of the saturated zone. The dye tracing results of Jordan (1970), in which a velocity of about 1.2 cm/s was calculated for water infiltrating to the Río Tanamá through shallow solution channels, confirm that such rapid circulation does occur.

One effect of this type of rapid circulation is that some of the water which infiltrates limestone terrane during a recharge event appears in the stream before "flood peak" has passed. Thus even though this water has infiltrated below land surface, it contributes to the flood peak rather than to base flow and causes the ratio of base flow to total flow to be lower than might be expected. The shallow circulation also persists, however, after passage of the flood peak, and thus also contributes to the base flow of the stream. As a result the total base flow is higher than the total ground-water flow as computed from head gradients in table 1; the computed flow, which is based on average long-term water levels, would not include shallow transient components. The situation forms a marked contrast to that in the volcanic basins, where infiltrating water tends to be held in storage in the weathered zone, and released slowly to the streams, generating a typical base flow recession curve, in which ground-water flow and base flow are presumably equivalent. The results are generally similar to those noted by Olmsted and Hely (1962) for the Brandywine Creek basin in Philadelphia, which flows through a gneiss-schist terrane.

It should be noted that the data for the Caño Tiburones and the Laguna Tortuguero do not fit the pattern outlined above. Base flow forms a high percentage of the total flow for these features and coincides reasonably well with the computed ground-water flow as given in table 1. The hydrologic role of these coastal discharge features differs from that of the major rivers, and neither direct runoff nor transient shallow circulation can form a major component of their discharges.

In table 3 are listed also the lowest streamflow measurements during the period 1959–70. This period includes the severe droughts of 1964 and 1965, which are rated to have frequencies of occurrence of several decades. Therefore these discharges indicate the order of the minimum flows.

DIRECT RUNOFF

The difference between total flow and base flow is generally termed the direct runoff. This terminology is retained in this report even though, as explained in the preceding paragraphs, this component of the streamflow in the limestone terrane would include a contribution from transient shallow ground-water circulation, in addition to direct overland flow. Figure 36 was obtained by plotting total direct runoff during each month for each major stream entering the limestone from the south, versus the corresponding monthly direct runoff of the same stream at its downstream gaging site, after crossing the limestone. Data points which fall below the 45° line, or equality line, on figure 36, represent instances in which the direct runoff component was smaller at the downstream site than at the upstream site. It is possible that in a few instances this effect could be caused by differences in hydrograph characteristics, through which flow classified as direct runoff at the upstream site is classified as base flow at the downstream sites. In the majority of cases, however, points falling below the equality line on figure 36 must indicate a loss in the flow across the limestone, during periods of high flow. The basins that have well-developed flood plains, the Río Cibuco and the Río Grande de Manatí, show a loss for small inflows. The Río Grande de Arecibo consistently shows a loss. For the Río Grande de Manatí and the Río Cibuco the loss may represent water taken into temporary storage by the flood plain, to be released later as base flow. For the Río Grande Arecibo valley, as already noted in the yearly water budget, a probable transbasin flow to Caño Tiburones is indicated. The large scatter of the data suggests that the network of solution channels in the limestone basins is complex and responds to rainfall in different ways under different conditions, and that the traditional methods used in hydrology of interstation correlation are unreliable for estimating the contribution from the karst. In total flow, however, a fairly reliable correlation exists between the monthly flows of the upstream and downstream sites. It must be noted, however, that the correlation is biased, statistically, because the total flow downstream includes the upstream flow.

GEOCHEMISTRY

The development of the karst arises from an interaction between a slightly acidic rainfall and the soluble limestone. It is, therefore, instructive to analyze some of the chemical and physical properties of the limestones in relation to those of rainfall and to analyze further the properties of the water after this interaction between rainfall and limestones has taken place. The background for the following discussion was obtained by a selective sampling of rocks and of water. The water was field analyzed for pH, bicarbonate, and temperature. The locations of the sample sites are shown on plate 1 and figures 37 and 38 and the data are presented in tables 4, 5, 6, and 7.

THE LIMESTONES

Some physical and chemical properties of the limestones are shown in table 4. The analyses, listed by site, are by the author and by W. H. Monroe (written commun., 1970). Whereas Monroe's data provided detailed information on the geochemistry of the rocks, the samples collected by the author were chemically analyzed only for the more important constituents. Some effort, however, was spent to obtain a measure of rock density and porosity which was unavailable from the literature. The color of the dry rock powder or the "streak" was also obtained and is expressed in units of the Munsell scale as measured from a Rock Color Chart issued by the Geological Society of America. Porosity was measured by leaving oven-dried (at 110°C) rock chips (approx 50 g) in distilled water for 72 hours and recording the amount of water absorbed by the rock. The density was calculated as the ratio of the weight of the oven-dried chips divided by their volume which was in turn measured by the water volume displaced by the water-saturated chips.

The data of table 4 show that the limestones are pure. The Lares Limestone and the Montebello Limestone Member of the Cibao Formation in the central part of the limestone belt range from 94 to 96 per-

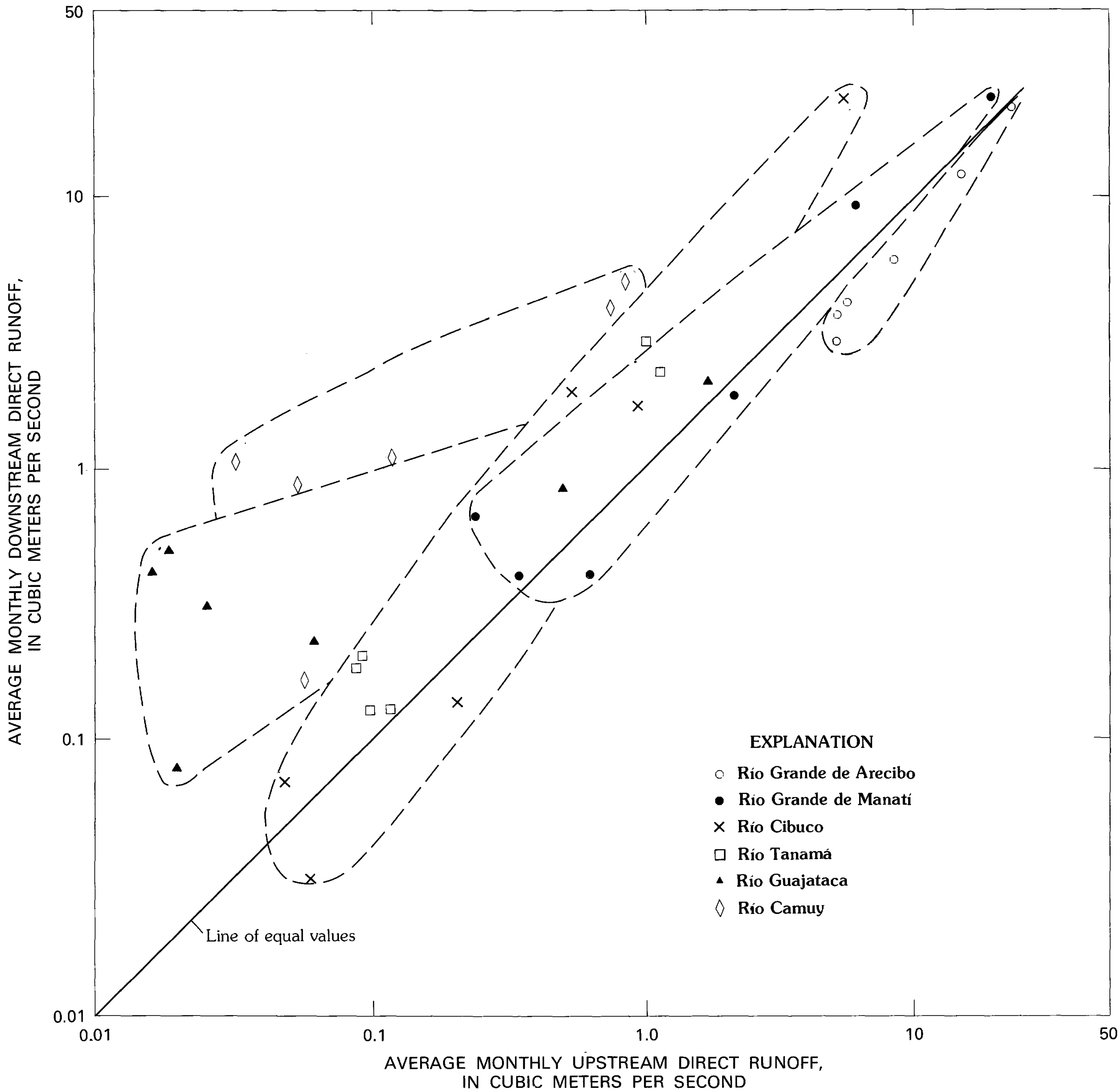

FIGURE 36.—Downstream direct runoff versus upstream direct runoff for those streams that begin in volcanic terrane and cross the limestone belt.

cent $CaCO_3$; the Aymamón Limestone ranges even higher—to 99 percent, but there is an indication from a few samples that these formations are less pure to the east and west. The Cibao Formation ranges from 59 to 91 percent $CaCO_3$, reflecting its variability as previously noted in the description of the geologic formations. The Aguada Limestone is somewhat less pure than the Aymamón and Lares, ranging from 82 to 94 percent; whereas, the Camuy Formation proves to be the most variable of all, ranging from 50 to 95 percent. The magnesium content of the limestones is generally low, less than 2 percent of $MgCO_3$, except for a few samples from the upper part of the Aymamón and the Camuy which show up to 39 percent $MgCO_3$, making these samples calcitic dolomites.

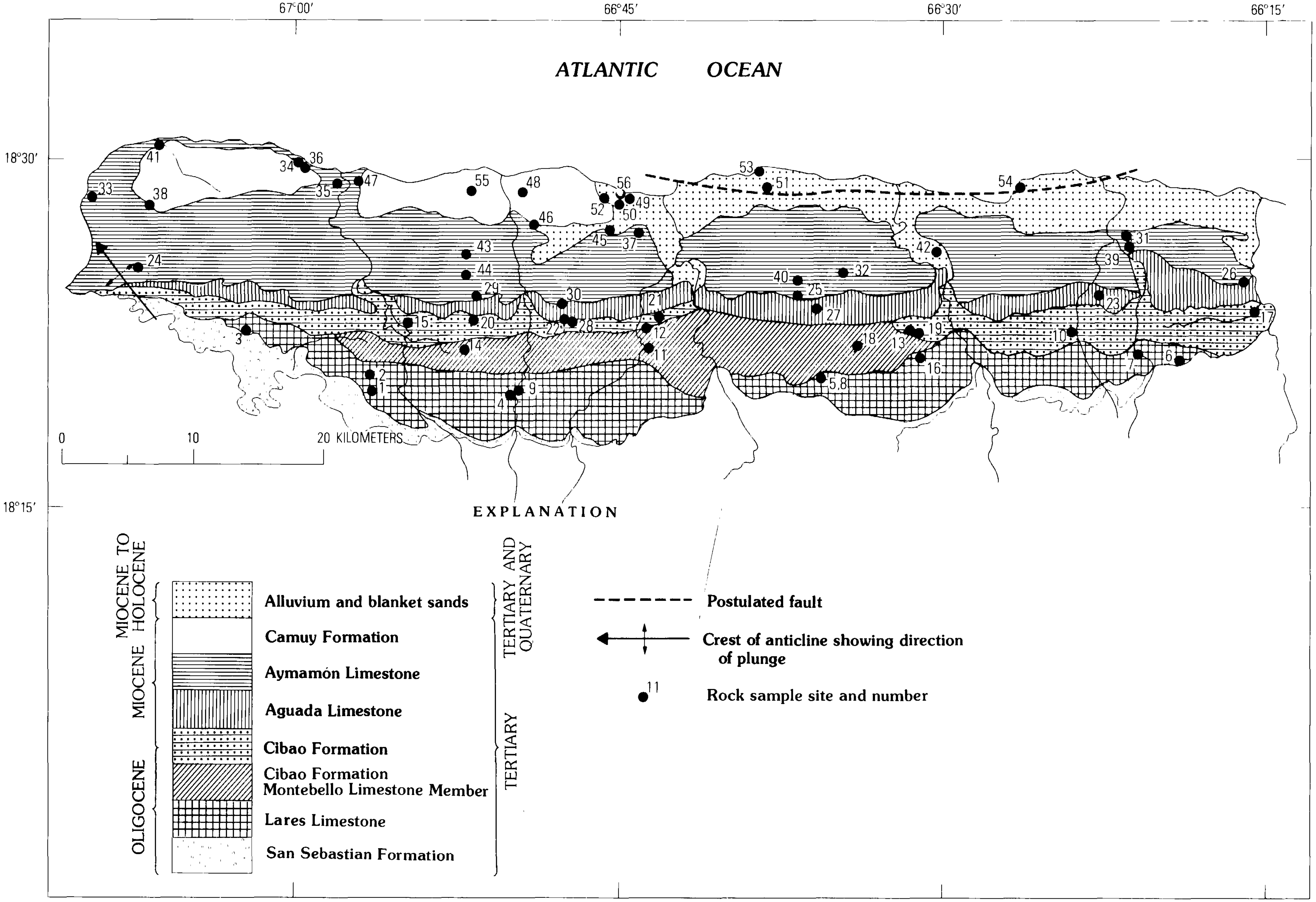

FIGURE 37.—Rock sample sites (data in table 4).

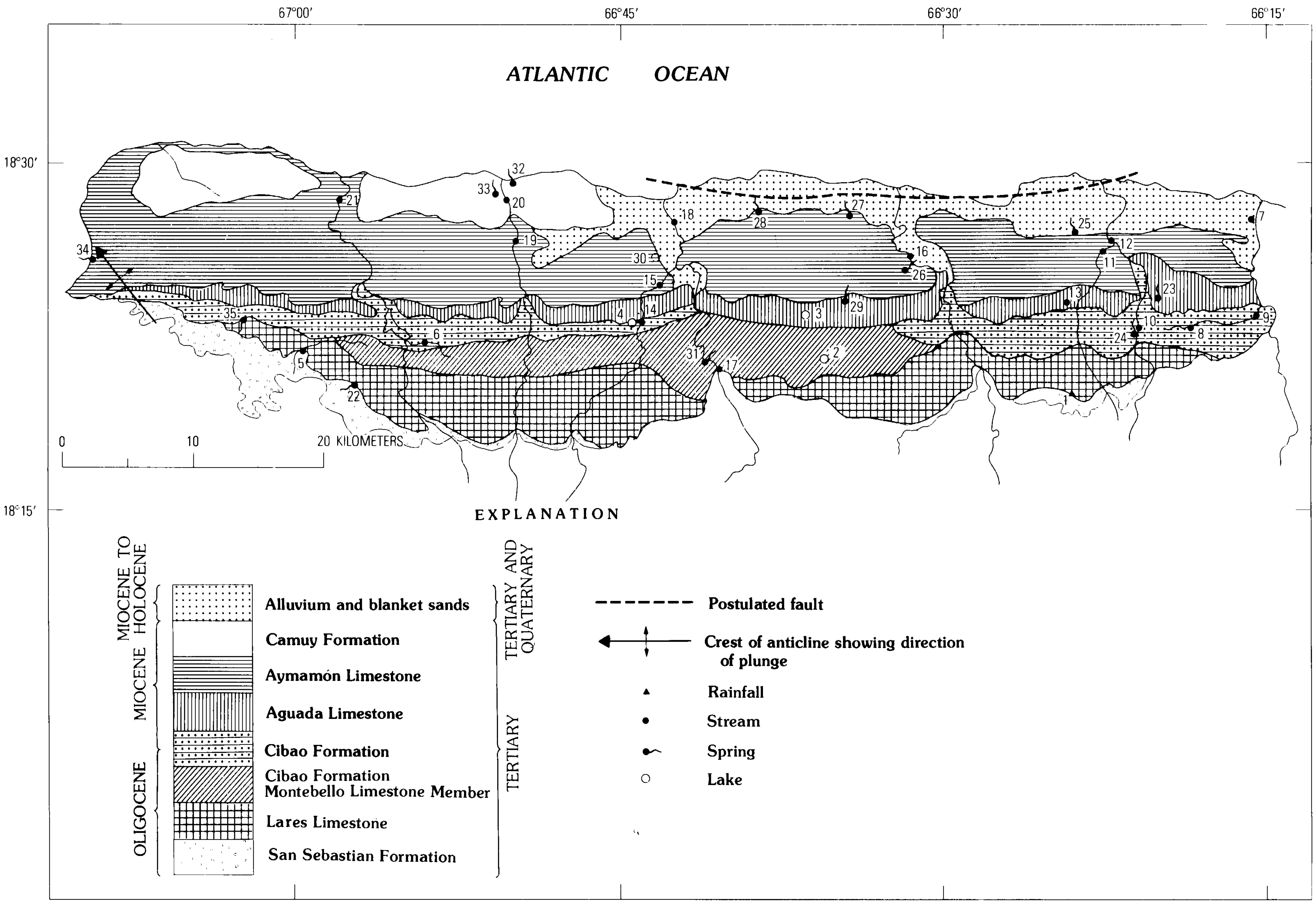

FIGURE 38.—Water sampling sites (data in table 5).

TABLE 4.—*Chemical and physical data of north coast limestone*

[Location is shown in fig. 37. Items in parentheses are from W. H. Monroe (written commun., 1970). Values of silica which are set in italics are from the relation of fig. 39]

No.	Geologic unit	Data, in percent: SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	Insoluble residue	Porosity	Bulk density (g/cm^3)	Powder color (dry), Munsell scale [1]
(1)	Lares Limestone	6.4	2.7	2.3	83.8	2.5	---	--	---	---------
(2)	do	1.2	.5	0	94.3	1.9	---	--	---	---------
(3)	do	16.9	5.1	2.2	68.7	3.3	---	--	---	---------
(4)	do	.3	.1	0	97.0	.8	---	--	---	---------
(5)	do	.6	.2	.1	95.4	.6	---	--	---	---------
6	do	*24*	--	2.8	60	2.5	34.7	.32	1.39	10 *YR* 6/4
7	do	*1.5*	--	.1	95	1.1	1.9	.16	1.48	10 *YR* 8/2
8	do	*.9*	--	0	97	.8	1.1	.19	1.37	5 *Y* 9/1
9	do	*2.0*	--	.2	94	1.2	2.5	.15	1.98	10 *YR* 8/2
(10)	Cibao Formation	4.0	1.2	1.0	88.7	1.7	---	--	---	---------
(11)	Montebello Limestone Member.	.1	.1	0	97.0	.8	.5	--	---	---------
(12)	do	.2	.1	.1	97.8	.8	.7	--	---	---------
(13)	Quebrada Arenas Limestone Member.	.4	.3	.2	96.5	.6	.8	--	---	---------
(14)	Cibao Formation	3.4	1.0	.4	91.4	1.9	---	--	---	---------
(15)	do	12.3	4.5	1.6	74.8	2.1	---	--	---	---------
(16)	do	8.6	2.8	1.1	83.8	.8	10.0	--	---	---------
17	do	*5.1*	--	.8	90	1.9	6.3	.17	1.73	10 *YR* 8/2
18	Montebello Limestone Member.	*.5*	--	.1	96	.6	.6	.30	1.54	5 *Y* 9/1
19	Cibao Formation	*17*	--	.8	76	.7	20.6	.12	1.98	10 *YR* 7.5/4
20	do	*29*	--	1.4	59	1.3	35.9	--	1.10	5 *Y* 7/4
21	Aguada Limestone.	6.6	1.2	.6	89.2	.6	7.5	--	---	---------
(22)	do	4.0	2.7	.9	88.8	1.0	---	--	---	---------
(23)	do	1.2	.7	.2	93.6	.4	1.3	--	---	---------
(24)	do	4.4	2.8	1.1	86.5	.8	---	--	---	---------
(25)	do	7.2	2.0	.3	88.4	.6	9.0	--	---	---------
26	do	*9.8*	--	.3	84	.8	11.9	.16	1.81	10 *YR* 7/5
27	do	*12*	--	.6	82	1.0	14.3	.11	2.13	10 *YR* 8/2
28	do	*2.6*	--	1.9	93	.7	3.2	.03	2.53	10 *YR* 5.5/3
29	do	*6.7*	--	1.0	87	.9	8.2	.04	2.16	10 *YR* 8/4
30	do	*1.7*	--	.6	95	.6	2.1	.09	2.22	10 *YR* 6.5/2
(31)	Aymamón Limestone.	.0	0	0	98.8	.2	---	--	---	---------
(32)	do	.5	.3	.1	97.5	.6	.8	--	---	---------
(33)	do	.5	.2	0	61.6	34.5	---	--	---	---------
(34)	do	.7	.6	0	61.2	35.5	---	--	---	---------
(35)	do	.5	.4	0	57.7	38.9	---	--	---	---------
(36)	do	.7	.3	0	62.7	34.3	---	--	---	---------
(37)	do	.1	.1	0	97.8	1.0	.3	--	---	---------
(38)	do	.8	.4	0	95.5	.6	---	--	---	---------
39	do	*.4*	--	.1	97	.6	.5	.18	1.95	*N* 9
40	do	*2.5*	--	.4	94	.8	3.1	.06	1.38	5 *YR* 8/4
41	do	*9.5*	--	1.3	84	1.9	11.7	.17	1.59	10 *YR* 7/6
42	do	*0*	--	.2	99	.7	0	.13	1.88	5 *Y* 9/1
43	do	*.9*	--	.2	96	.6	1.1	.28	1.63	10 *YR* 8/4
44	do	*0*	--	.1	99	.7	0	.18	1.86	10 *R* 8/2
45	do	*.2*	--	.2	98	.9	.3	.21	1.59	10 *YR* 8/4
(46)	Camuy Formation	8.3	3.0	3.7	79.6	1.5	---	--	---	---------
(47)	do	3.4	.8	.3	55.5	36.0	---	--	---	---------
(48)	do	2.2	.6	.3	93.6	.8	---	--	---	---------
(49)	do	10.6	1.7	1.3	82.2	.8	12.7	--	---	---------
(50)	do	31.7	4.2	1.9	57.0	1.0	39.5	--	---	---------
(51)	do	9.2	2.0	.9	84.8	1.0	11.3	--	---	---------
(52)	do	7.0	1.2	.6	88.8	1.0	7.7	--	---	---------
(53)	do	2.4	.6	.5	94.8	1.5	2.9	--	---	---------
(54)	do	*1.9*	--	.4	---	40.0	2.3	.26	1.23	5 *Y* 8/1
(55)	do	*21*	--	.2	70	.9	26.4	.24	1.67	5 *YR* 9/1
(56)	do	*38*	--	.5	50	.8	46.2	.18	1.93	10 *YR* 7/3

[1] See Goddard and others (1948).

TABLE 5.—*Miscellaneous chemical and physical data on water from north coast limestone*

[Data in milligrams per liter except temperature in degrees Celsius, and specific conductance in micromhos per centimeter at 25°C. Location of sites is shown in fig. 38. Number in parentheses are acidified samples]

	Temperature, °C	SiO_2	Ca		Mg		Na	K	HCO_3		SO_4	Cl	NO_3	Dissolved solids	Specific conductance	pH	
									Laboratory	Field						Laboratory	Field
1. Rainfall, average at Morovis.	---	--	1.2	-----	.6	-----	--	--	4.7	---	1.8	4.5	.5	18	----	6.1	--
2. Lago near Montaña.	25	2.1	4.2	(4.9)	1.0	(.9)	2.6	3.5	17	17	0.8	5.5	.7	29	53	6.1	6.3
3. Lago near Alianza.	26	3.8	22	(22.8)	1.1	(.9)	4.3	4.0	66	67	2.6	9.8	.8	81	155	6.7	6.7
4. Lago at Esperanza.	26.7	2.8	58	-----	1.7	-----	6.9	1.9	168	---	12.0	12.0	5.0	183	332	7.3	--
5. Río Guatemala at San Sebastián.	27	8.0	59	(59)	5.8	-----	8.1	1.2	182	181	24	13	2.4	212	364	8.0	7.4
6. Río Chiquito	23.5	5.9	88	(90)	5.2	(5.2)	5.1	.9	274	276	17	8.5	2.7	268	469	8.0	7.4
7. Ciénega Higuillar	24.5	8.7	33	(33)	10	(10.4)	32	3.8	130	181	10	57	1.3	220	419	7.4	7.2
8. Río Lajas at Hwy 823.	24	8.9	85	(93)	6.5	(7.3)	7.9	.7	268	320	14	15	4.7	275	493	7.7	7.8
9. Río Lajas at Toa Alta.	23.4	11.0	78	(81)	4.9	(5.7)	9.8	1.2	240	288	15	19	4.5	262	469	7.7	8.0
10. Río Cibuco at Hwy 647.	23.6	26	38	(41)	7.9	(8.3)	11.0	1.9	142	141	13	16	5.9	190	308	7.6	7.9
11. Río Indio at Hwy 160.	22.8	16	73	(75)	5.8	(6.9)	12	1.8	228	234	13	19	5.6	258	451	7.7	8.0
12. Río Cibuco at Hwy 2.	23.2	21	56	(58)	7.4	(7.8)	12	2.1	190	194	14	17	5.9	230	391	7.6	7.8
13. Quebrada Hicatea	---	11	119	-----	6.3	-----	14	2.8	356	---	---	----	.3	----	659	7.3	--
14. Río Tanamá near La Esperanza.	24.5	12	47	(52)	3.9	(4.3)	6.3	.7	154	158	8.0	7.0	2.3	163	279	7.6	7.3
15. Río Tanamá at Hwy 10.	22.0	18	47	(46)	3.7	(4.2)	5.9	.6	156	156	4.0	7.3	2.1	166	290	8.0	7.2
16. Río Grande de Manatí at Hwy 2.	26	23	36	(42)	7.7	(4.9)	9.8	1.3	136	146	7.0	11	2.1	166	281	7.2	7.0
17. Río Grande de Arecibo below dam.	24.5	24	21	(21)	6.0	(6.0)	10	1.4	85	78	13	10	3.3	131	197	7.2	7.0
18. Río Grande de Arecibo at Cambalache.	26	17	40	(42)	5.2	(3.9)	8.4	1.2	140	---	4.4	11	4.3	160	290	7.2	7.8
19. Río Camuy at Salto Máquina.	24	7.4	58	(64)	3.8	(3.7)	6.4	.7	184	200	10	9.0	4.1	191	333	8.0	7.6
20. Río Camuy at gaging station.	25	7.4	63	(57)	3.7	(4.1)	6.4	.9	198	191	9.4	9.8	3.4	202	361	7.8	7.6
21. Río Guajataca at gaging station.	25	4.7	56	-----	4.1	-----	7.0	1.1	184	---	11.0	9.8	1.6	186	335	7.9	--
22. Spring, Salto Collazo.	23	4.4	72	(74)	3.2	(3.2)	4.5	.8	220	---	12	8.4	1.6	215	385	7.8	7.5
23. Spring, Hwy 647 near Vega Alta.	25.3	9.4	85	(86)	3.9	(4.7)	9.3	.7	264	266	3.4	21	4.5	267	496	7.8	7.4
24. Spring, El Convento, Hwy 647.	24.5	6.6	86	(89)	6.1	(7.0)	6.4	.4	276	283	4.6	14	10	270	498	7.7	7.3
25. Spring, Comunidad El Ojo del Agua.	25.5	7.3	96	(98)	10	(9.9)	44	1.6	268	267	16	92	11	410	791	7.6	7.2
26. Spring near Manatí.	24.8	6.6	90	(92)	3.2	(3.9)	8.3	.6	278	278	2.8	15	5.1	269	498	7.8	7.3
27. Cáncora Garrochales.	28	8.9	168	(170)	34	(33.6)	241	.8	276	284	53	562	11	1,210	2,300	7.7	7.1
28. Spring north of Garrochales.	25.5	5.6	97	(100)	16	(15.6)	118	.5	266	270	29	218	13	628	1,160	7.3	7.3
29. Spring Riachuelo	24	15	89	(91)	3.8	(4.2)	6.6	.5	276	274	2.8	10	6.4	270	483	7.7	6.9
30. Spring, Central Los Caños.	25	15	83	(85)	3.9	(3.9)	10	1.1	258	257	4.0	18	12	274	483	7.5	6.7
31. Spring, Los Chorros.	23	7.4	56	(61)	2.5	(2.9)	5.6	.4	174	182	4.2	8.8	3.3	174	305	7.8	7.6
32. Spring near Hatillo.	23.5	11	77	-----	19	-----	108	11	268	---	27	190	3.7	581	1,040	7.7	--
33. Spring, Camuy at Hwy 2.	24.5	8.9	102	(109)	30	(30)	225	8.7	288	---	60	402	7.7	986	1,800	7.6	--
34. Spring in Aguadilla.	25	7.7	83	(88)	4.5	(4.6)	7.6	.9	266	264	3.2	12	12	262	469	7.7	6.8
35. Spring near San Sebastián.	26	25	119	(144)	7.3	(7.3)	11	.5	376	460	19	12	1.6	381	628	7.5	6.9

Most of the insoluble residue from the limestone samples is silica (81 percent) as is shown in figure 39. Minor amounts of aluminum and iron are present in the quantities shown in table 4. Measurable quantities of strontium and titanium and traces of other metals not listed in table 4 were also found.

The primary porosity ranges from a minimum of 0.03 for a sample from the Aguada to a high of 0.32 for a sample from the Lares. In general, the Aguada seems to be the least porous, and the Camuy the most. The densities measured are inversely related to the porosity, with the Aguada clearly denser than all other formations.

The streak of the dry powders of most samples showed very pale colors in the orange section of the color spectrum. The chalky limestones were generally white or very pale gray.

TABLE 6.—*Chemical and physical data from ground water of the north coast limestone*

[Data in milligrams per liter except temperature in degrees Celsius, specific conductance in micromhos per centimeter at 25°C, and pH]

	Well Nos.[1]	Geologic unit	Temperature °C	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	Dissolved solids	Specific conductance	pH
1.	26–24	Aymamón Limestone.	---	9.0	81	3.2	----24----		256	2.0	28	0	19	335	534	7.9
2.	27–20	Aymamón Limestone.	29	6.8	50	4.4	19	0.8	154	8.8	38	0.1	1.4	205	384	8.0
3.	26–33	Lower part of Aymamón Limestone.	---	7.0	110	3.4	12	.0	144	9.0	34	0	26	345	581	7.6
4.	24–25	Aguada Limestone	---	6.2	88	9.8	----------		302	2.1	18	.1	2.2	283	485	7.4
5.	26–55	Aguada Limestone	---	21	100	4.1	----35----		385	3.8	19	--	---	523	---	7.2
6.	24–19	Cibao Formation	---	8.5	112	12	----22----		370	4.4	39	.1	18	404	680	7.7
7.	22–31	Cibao Formation	29	4.8	103	1.7	6.2	.5	300	5.2	10	0	12	291	514	7.4
8.	22–47	Cibao Formation	24.4	7.4	88	9.8	-----3.2---		300	28	11	.2	2.3	273	667	7.8
9.	26–33	Montebello Limestone Member, artesian.	---	7.3	37	9.1	8.8	1.5	136	19	14	.1	.4	---	---	--
10.	25–33	Montebello, Limestone Member, artesian.	---	3.6	78	10	6.2	.3	272	7.2	10	--	4.5	254	458	7.9
11.	26–33	Lares, Limestone artesian.	---	16	50	52	69	5.1	310	181	30	4.2	---	560	906	7.8
12.	25–33	Lares Limestone artesian.	---	5.8	69	18	7.8	.6	284	10	12	.2	3.2	266	485	7.5

[1] Well numbers are minutes north of lat 18° for first 2 digits, and minutes west of long 66° for next 2 digits; and can be used to locate the well roughly.

TABLE 7.—*Average values of dissolved constituents and of physical properties of surface water in the north coast limestone belt*

[Data in milligrams per liter except specific conductance in micromhos per centimeter at 25°C, and pH. Note that averages shown are means of samples and are not adjusted for discharge]

	Name and location of stream[1]	Rock type	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Dissolved solids	Specific conductance	pH
1.	Guajataca at Lares (10)	Volcanic	29.8	26.5	5.8	11	1.7	114	6.0	9.0	3.6	150	230	7.5
2.	Camuy near Lares (1)	do	21.8	13.9	5.3	7.5	1.0	57.5	17.3	6.7	1.6	103	154	7.5
3.	Criminales near Lares (2)	do	21.9	10.2	4.5	6.5	1.0	47.5	7.8	6.7	2.7	85	121	7.2
4.	Arecibo below Dos Bocas (3)	do	21.6	19.3	5.9	10.1	1.7	78.3	15.0	10.1	1.6	124	189	7.2
5.	Manatí at Ciales (5)	do	27.4	21.1	8.7	11.0	1.4	102	8.4	12.2	1.9	147	230	7.5
6.	Cialitos at Ciales (9)	do	29.9	23.7	6.5	10.2	1.4	109	3.4	10.5	2.8	142	222	7.5
7.	Cibuco below Corozal (6)	do	33.4	25.9	10.6	14.0	2.2	124	12.4	17.2	3.8	181	290	7.6
8.	Mavilla near Morovis (7)	do	28.9	19.5	8.7	12.2	2.6	85.7	10.9	15.3	4.8	150	234	7.7
9.	Unibón near Morovis (8)	do	23.3	24.8	9.6	11.6	2.1	118	10.6	14.9	2.7	163	261	7.7
10.	Guajataca, below Lago (11).	Limestone and volcanics.	8.6	57.5	4.9	7.5	1.0	185	9.1	12.4	3.1	195	355	7.8
11.	Guajataca at mouth (12)	do	7.7	58.9	5.4	6.7	1.0	190	8.9	14.0	3.9	203	368	7.9
12.	Camuy near Camuy (13)	do	9.9	54.5	4.2	6.5	.8	175	7.6	9.4	3.4	184	327	7.9
13.	Tanamá at Charco Hondo (14).	do	13.0	42.7	4.0	6.1	1.2	144	6.4	7.2	1.7	154	266	7.9
14.	Arecibo at Cambalache (15).	do	21.5	30.4	5.3	8.3	1.3	114	12.2	9.6	2.8	148	233	7.5
15.	Manatí at Highway 2 (16)	do	20.0	28.9	6.5	8.8	1.5	96.4	7.6	10.6	3.2	144	244	7.5
16.	Cibuco at San Vicente (17).	do	21.5	49.6	8.4	12.6	2.1	170	12.4	18.2	3.1	217	373	7.8
17.	Caño Suroeste[2] (20)	Limestone	10.4	15.5	3.2	6.7	5.7	47	14	9.0	1.2	86.5	136	6.8
18.	Caño Noreste[2] (20)	do	9.7	22.0	6.3	27.0	3.8	66	----	50	2.3	177	312	6.7
19.	Caño Tiburones[2] (21)	do	10.3	126	69.0	498	20	80	248	910	2.6	1,880	5,320	7.3
20.	Laguna Tortuguero (22)	do	6.9	88.2	52.1	328	11.4	140	113	721	1.0	1,440	2,680	7.8
21.	Lajas at Toa Alta (18)	do	10.9	86.2	6.3	10.4	1.7	242	13.9	20.3	2.8	287	505	8.0

[1] Numbers in parentheses identify stations listed in tables 2 and 3.
[2] High flows.

THE WATER

RAINFALL

Chemical and physical data on the water of the study area are given in tables 5, 6 and 7. However, whereas the data of tables 5 and 6 refer mainly to once only sampling for each given site, those of table 7 on rivers are averages from about 12 samples collected at each site.

The first row of table 5 shows the averaged mineral composition of rainfall at Morovis. These data were provided by Raúl Díaz (written commun., 1970). As expected for an island, chloride salts are the main constituents in the rainfall. The average pH of the rainwater is 6.1 (slightly acidic). A sample of rainfall analyzed in the field immediately after collection showed a pH of 6.2; thus the average of 6.1 of Díaz' samples, which were kept in storage for prolonged periods prior to analysis, can be considered valid.

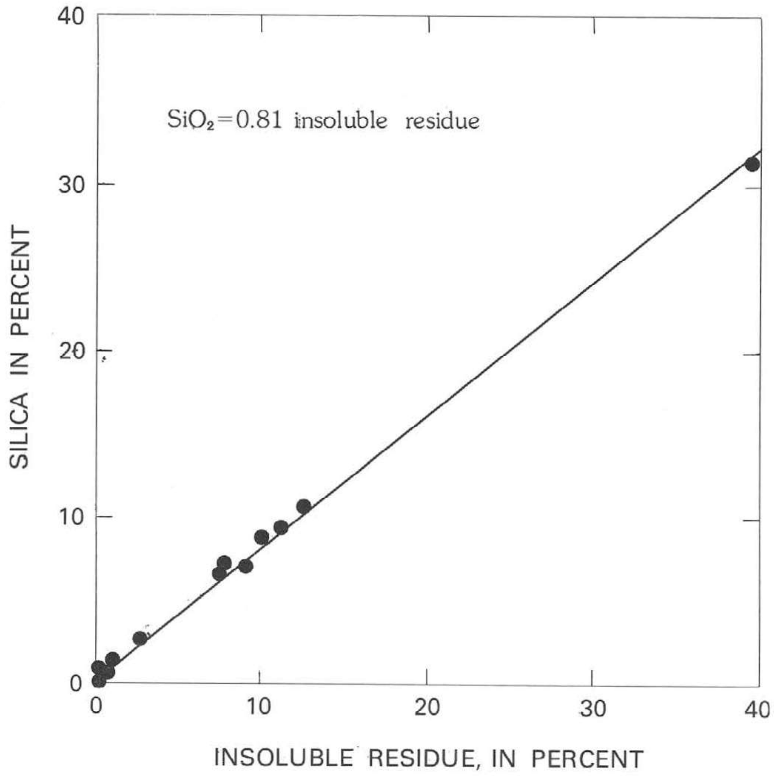

FIGURE 39.—Relation between silica and insoluble residue.

LAKES

The lake water analyses, shown in table 5, were taken from three lakes at progressively lower altitudes, and the results clearly indicate a general increase of mineral concentration. The first analysis—2, a pond resting on terra rossa receiving only direct runoff—shows a concentration similar to that of rainwater, the slight increase of some constituents, particularly calcium, being no more than a leaching of terra rossa or slight concentration from evaporation. The pH is the same; thus the capacity of this water to take limestone into solution remains unaltered. The terra rossa, as mentioned by Birot and others (1967), provides an inert medium for surface water flowing or resting on it. The samples were collected in 1970–71; the fact that these years are considered wet years lessens the possibility of general increase of mineral concentration from evaporation. Analyses 3 and 4, which are lakes that are partly spring-fed, especially 4, show a rapid increase of mineral concentration—especially, calcium.

SPRINGS

Analyses 22 to 35, table 5, are from waters which have been in contact with the limestones. Spring analyses that show sodium and chloride concentrations much larger than the rest, such as 27 and 28, are from springs which lie in the zone of diffusion between ground water and sea water. (See fig. 38.) The generally high chlorides and nitrates of all the springs and, in fact, of all waters of the north coast limestones, are not acquired from dissolution of limestone, but rather arise from the minerals introduced by the rainfall (especially the chlorides) or by residues of biological activities

There are no great differences among the waters from the various formations. The Aguada and the Cibao seem to have a larger SiO_2 content (about 10 mg/L) than the Lares and the Aymamón (about 6.7 mg/L), but the sampling can hardly be considered exhaustive. Spring 35, which flows about 100 L/h (liter per hour) has the highest SiO_2 content of all the springs sampled. This spring issues from the Cibao Formation, which has a large SiO_2 content. The source of the spring, therefore, may explain, in part, the high silica content; however, the increase in concentration could also result from direct evaporation or evapotranspiration.

The calcium content of the springs which are not in the saline zone near the coast ranges from 56 to 119 mg/L. The lowest value is for the spring shown in figure 31 which is associated with travertine deposition, whereas the high value is for spring 35 for which evaporation may be responsible for the higher-than-average calcium concentration. The average concentration of calcium in spring water seems to be about 85 mg/L.

GROUND WATER

Data on the major chemical constituents of ground water are given in table 6. The chemical analyses show that the water from the various formations is similar. The general similarity of the ground water to the spring water is also noted, and most comments about spring water apply to ground water, except that ground water has a high mineral concentration without the effect of evaporation. Of special interest are the data for the deep artesian wells, analyses 9 to 12. The fact that artesian aquifers show smaller concentrations of calcium than water-table aquifers indicates possibly precipitation of $CaCO_3$ through crystallization within the aquifer, for which there is much field evidence (figs. 40 and 41), or simply loss of $CaCO_3$ from the samples after collection (the analyses were not made with acidified samples).

RIVERS

The average composition of water from streams is shown in table 7. The data in table 7 are mainly from low flows, which are normally more concentrated than high flow, and thus the averages are

FIGURE 40.—Evidence of recrystallized limestone.

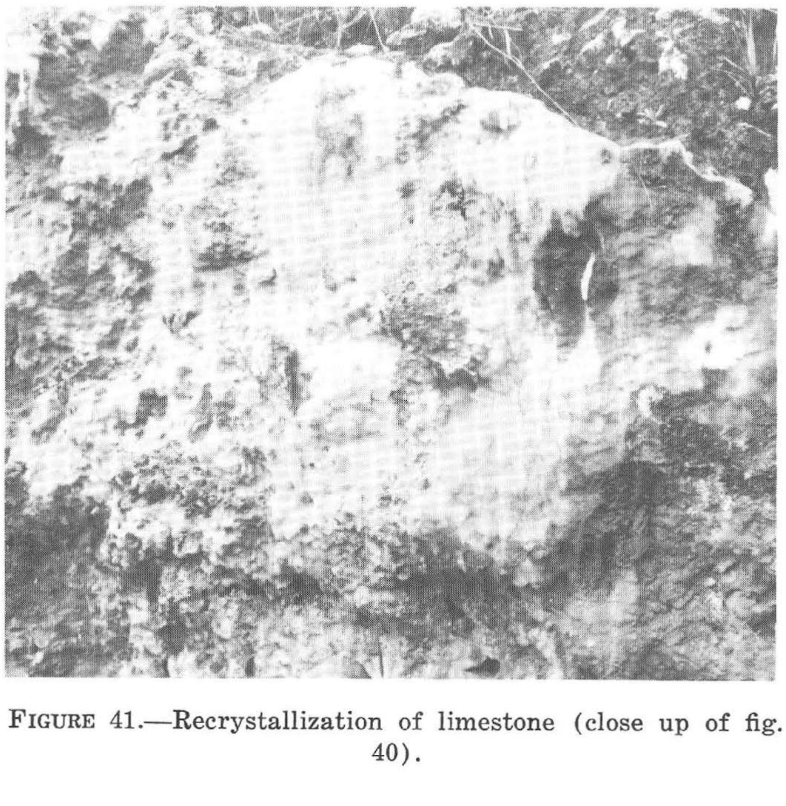

FIGURE 41.—Recrystallization of limestone (close up of fig. 40).

somewhat higher than a true average such as would be obtained from a continuous sampling that would incorporate data from more diluted high flows. Concentration of mineral constituents, as shown by the relation of $CaCO_3$ to discharge in figure 42, in the water is an inverse function of streamflow. This inverse relationship is most applicable to the streams flowing out of volcanic terrane; the limestone streams have a more nearly constant concentration. To the extent that table 7 serves as a comparison between streamflow from the volcanic terrane and that from limestone, the remark about the averages of table 7 is of little importance. It should be taken into account, however, if a comparison is made with data that are averaged relative to the flow. An example of a proper averaging of chemical constituents is shown in the rating table of figure 43 used to compute the equivalent freshwater outflow of Cãno Tiburones.

As expected, the main difference between the streamflow from the volcanic terrane and that from the limestone is the increase in concentration of calcium and, inherently, of bicarbonate, and a slight decrease of all other measured constituents. For those streams that originate in the volcanic terrane and cross the limestone belt, the decrease may be a dilution process, especially in the case of silica. The only sample valid for comparison from purely limestone terrane is from the Río Lajas (station 21 in table 7) that mainly drains the Cibao Formation which, in the Lajas basin, is an impure limestone. Assuming that no precipitation of silica takes place along the stream channel, the contribution of silica from the limestone is of the order of 10 mg/L for the Cibao Formation and perhaps for the Aguada Limestone, and of 6–7 mg/L for the Lares Limestone and Aymamón Limestone.

At the upstream volcanic terrane sites, the streams have a silica content in excess of 20 mg/L and less than half this value at the downstream sites after the streams have crossed the limestone belt. Assuming no streamflow losses through the limestone belt (as borne out by the water-budget results) and ignoring losses by evapotranspiration, one can write:

$$C_u \cdot Q_u + C_L \cdot Q_L = C_D \cdot Q_D \qquad (10)$$

where

C = concentration of silica
Q = streamflow
u, L, D = upstream, limestone, and downstream, respectively, and
$Q_L = Q_D - Q_u$

For the Río Camuy (including the Río Criminales), for example, using the water-budget data from table

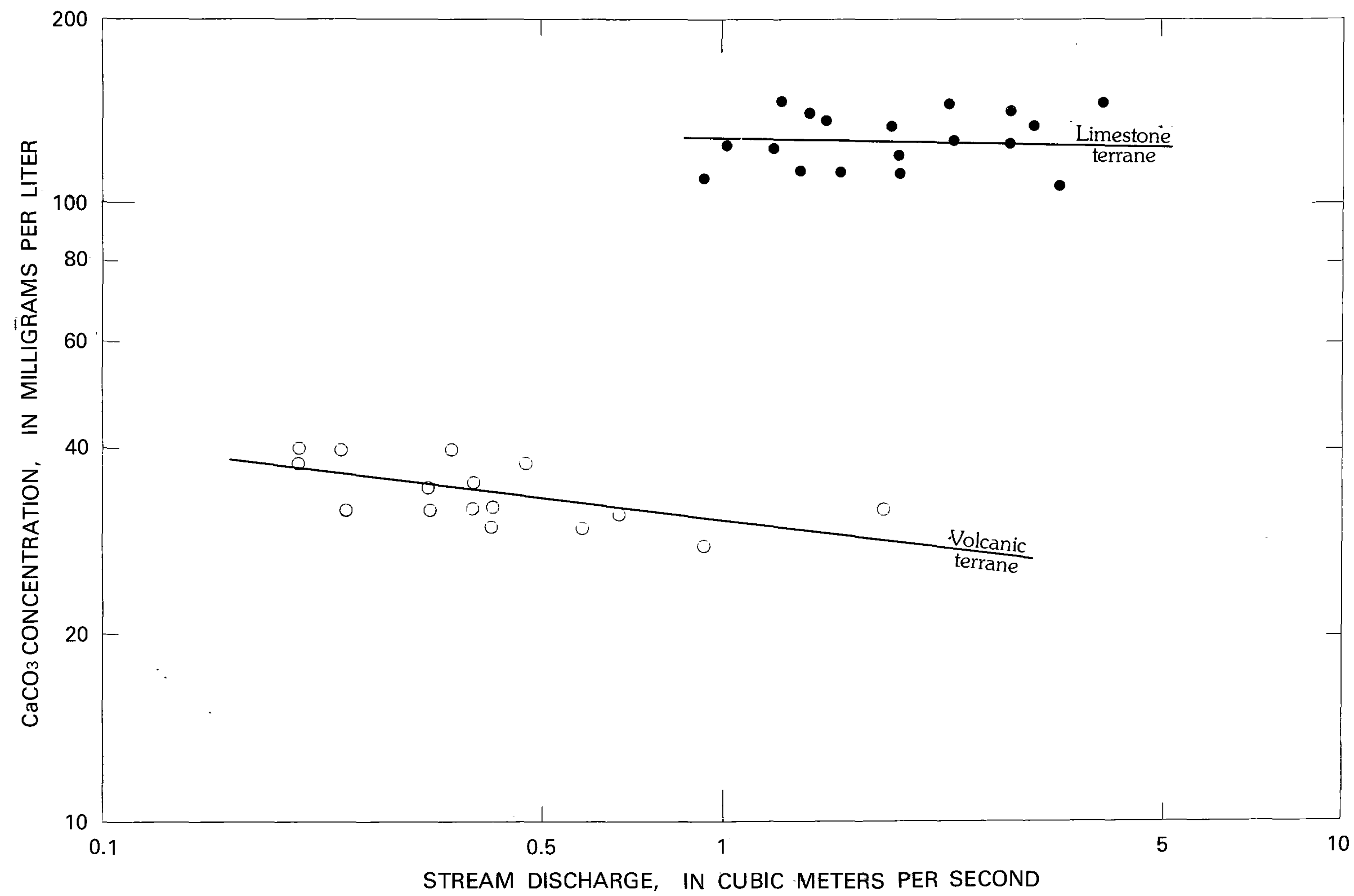

FIGURE 42.—Relation between $CaCO_3$ concentration and discharge (instantaneous values).

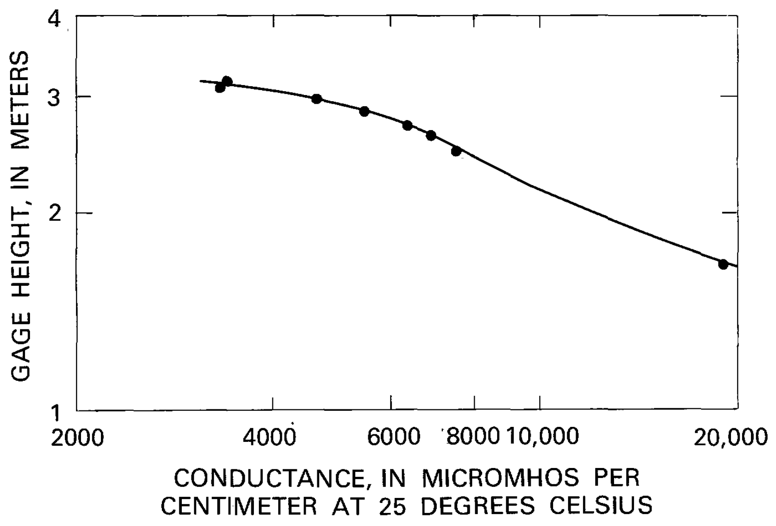

FIGURE 43.—Rating curve used to compute the equivalent freshwater discharge of Caño Tiburones.

2 converted to cubic meters per second, and the concentrations in milligrams per liter of table 7,

$$(21.8)\cdot(0.59)+(21.9)\cdot(0.33)+(X)\cdot(3.4)=(9.9)\cdot(4.3).$$

Solving for X, the silica concentration for the limestone part of the basin, gives a value of 6.6, which is about the concentration of silica found in Lares and Aymamón waters. Although more work is needed, it would seem that silica may provide a good natural tracer to compute the streamflow at the downstream end of those rivers that originate in volcanic terrane.

Samples 14, 15, and 16 are from sites on streams with substantial flood plains. Silica concentrations approach those from upstream sites in volcanic terrane, suggesting that the flood plain itself contributes silica to the water; possibly from contact with clay minerals.

THE SOLUTION PROCESS[1]

The ability of rainfall to interact with carbonate rocks is a function of the pH of the water. The potential for solution of calcium carbonate can be demonstrated by determining the chemical equilibria for rainfall which is given by

$$\frac{[H^+]\,[HCO_3^{-2}]}{[H_2CO_3]}=K\,H\,CO_3^{-2}10^{-6.4}. \qquad (11)$$

[1] The following chemical considerations are based on Garrels and Christ (1965), Back (1963), and F. Quiñones (oral commun., 1970).

where K is the equilibrium constant.

It is accepted that in the equilibria of carbonic acid in water, both CO_2 and H_2CO_3 molecules are present, but it has been customary to represent CO_2 as H_2CO_3.

The carbonate system in equilibria is represented by the relation

$$\frac{[Ca^{+2}]\ [CO_3^{-2}]}{[CaCO_3]} = KCaCO_3 = 10^{-8.3}. \qquad (12)$$

In both equations above, activities are expressed in moles per liter. For $CaCO_3$ the activity is unity. Further developing the equilibria for the constant of bicarbonate ions,

$$\frac{[H^+]\ [CO_3^{-2}]}{[HCO_3^-]} = KHCO_3 = 10^{-10.3} \qquad (13)$$

and adding the general equilibria equation for water

$$\frac{[H^+]\ [OH^-]}{[H_2O]} = 10^{-14.0} \qquad (14)$$

while taking the activity of H_2O as unity, the systems of equations can be solved as described by Garrels and Christ (1965).

To examine the influence of rainfall on the solution of the carbonate rocks, one must consider the chemical equilibria of the ions. From equation 11 we know that CO_2 and water ionize into H^+ and HCO_3^- forming H_2CO_3. From equations 11 and 12.

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{+2} + 2HCO_3^- \qquad (15)$$

which is the basic equation for the solution of $CaCO_3$. In the system, the equilibria are regulated by the CO_2 concentration; and changes in CO_2 will cause a shift of the equilibria. Taking the rainfall pH as 6.1 from table 5, or $[H^+] = 10^{-6.1}$ and substituting in equation 11

$$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{10^{-6.4}}{10^{-6.1}} = 10^{-0.3}. \qquad (16)$$

The equilibria of CO_2 is (from Garrels and Christ, 1965)

$$\frac{[H_2CO_3]}{PCO_2} = 10^{-1.47}, \qquad (17)$$

where P = partial pressure.

For a partial pressure of CO_2 in the atmosphere of the order of $10^{-3.5}$

$$[H_2CO_3] = 10^{-1.47} \times 10^{-3.5} = 10^{-5.0} \qquad (18)$$

and, substituting in equation 16

$$[HCO_3^-] = 10^{-0.3} \times 10^{-5.0} = 10^{-5.3}. \qquad (19)$$

Therefore the total amount of dissolved carbonates in rainwater would be

$$(CO_3^{-2})_{Sol} = [H_2CO_3] + [HCO_3^-] = 10^{-5.0} + 10^{-5.3} = 10^{-4.75} \qquad (20)$$

and the concentration of Ca^{+2} in equilibrium would be

$$[Ca^{+2}] = \frac{10^{-8.3}}{[CO_3]} = \frac{10^{-8.3}}{10^{-4.75}} = 10^{-3.55} \qquad (21)$$

which is equivalent to a maximum concentration of 11.2 mg/L of Ca^{+2} that can be dissolved by rainfall. Because the average concentration of calcium in rainfall from table 5 is 1.2 mg/L, we may conclude that the effective reactive ability of rainwater for calcite is almost totally available prior to the solutioning process on the limestone rocks. Once the reaction with the limestone is completed, a new equilibrium is reached. The nature of this mechanism is discussed in detail by Garrels and Christ (1965) who conclude that at a pH of 9.9 a concentration of $CaCO_3$ of 14 mg/L in the solute from the rainfall-calcite reaction will be in equilibrium —thus pointing out the low reactive capacity of rainwater. This reasoning is also followed by Birot and others (1967) who concluded that, to explain the high calcium content of some of the waters of the north coast limestone belt, additional CO_2 must be picked up from the soil by the percolating rainfall. In turn the CO_2 in the soil is obtained from the decomposition of organic acids into CO_2 and water. These are also the views first presented by Monroe (1966).

The relative importance of this enrichment in CO_2 from the breaking down of organic acids is examined by analyzing as an example the $CaCO_3$ dissolved from the Río Lajas basin which drains limestone terrane only. A mean annual base flow of about 0.1 m^3/s is computed from figure 35 adjusted for the mean annual rainfall. From a concentration-discharge correlation similar to the one shown in figure 42, an average concentration of 200 mg/L of $CaCO_3$, coinciding with the low-flow field-measured sample of table 5, is obtained—an annual load from base flow of 630 tonnes per year. From the previous data for rainfall at a maximum reactive value of 28 mg/L of $CaCO_3$ (11.2 mg/L of Ca^{+2}), and 0.1 m^3/s of base flow as the rainfall percolated, a total discharge load of 88 t/yr may be attributed to the effect of rainfall. If 88 t/yr $CaCO_3$ potential solution is by rainfall and 630 t/yr $CaCO_3$ is actual solution, then 542 t/yr $CaCO_3$ is derived from solution through CO_2 contributed from the soil. According to these data the enrichment in rainwater of CO_2 in the soil from the decomposition of organic acids is responsible for about 86 percent of the solution process, and the acidity of rainwater itself is responsible for 14 percent of the solution of the limestones. Birot and others (1967), from a series of samples collected during overland flow following a storm, estimated that at least three-fourths of the acidity was derived from CO_2 from the soil.

CARBONATE EQUILIBRIA

In calculating the degree to which the water of the north coast limestones is saturated with calcium carbonate, it must be realized at the outset that the computations are carried out with reference to pure calcite for which reasonable equilibrium constants are available. It is not known to what extent the computed results reflect field conditions, that is, whether the limestones depart substantially from pure components.

Back (1961) gives the two reactions

$$CaCO_3 = Ca^{+2} + CO_3^{-2} \tag{22}$$

and

$$HCO_3^- \rightleftharpoons CO_3^{-2} + H^+ \tag{23}$$

whose equilibrium constants are

$$K\ (CaCO_3) = \frac{[Ca^{+2}]\ [CO_3^{-2}]}{[CaCO_3]} \tag{24}$$

and

$$K\ (HCO_3) = \frac{[CO_3^{-2}]\ [H^+]}{[HCO_3^-]} \tag{25}$$

with $[CaCO_3] = 1$, and the basic definition of activity

$$[\ \ ] = m \cdot \gamma \tag{26}$$

where m is the molality and γ is the activity coefficient. Solving for $[Ca^{+2}]$ from equation 24, inserting $[CO_3^{-2}]$ from equation 25, and making use of equation 26, one obtains

$$m\ Ca = \frac{K(CaCO_3)}{K\ (HCO_3)} \cdot \frac{1}{\gamma Ca \cdot \gamma HCO_3} \cdot \frac{[H^+]}{mHCO_3^-} \tag{27}$$

Because interest is in the ratio of Ca (observed) to Ca (computed), equation 27 can be expressed as

$$\frac{mCa\ (obs.)}{mCa\ (comp.)} = \frac{K(HCO_3)}{K\ (CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 \cdot \frac{mCa\ (obs.)\ mHCO_3}{[H]} \tag{28}$$

and using the symbol S (saturation) for the left hand side of the equation, and expressing molality in units of milligrams per liter and [H] as pH

$$S = \frac{1}{2.44 \cdot 10^9} \frac{K(HCO_3)}{K(CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 \frac{Ca \cdot HCO_3}{10^{-pH}} \tag{29}$$

The ratio of the equilibrium constants and the product of the activity coefficients are a function of temperature and ionic strength, so that a function ϕ can be defined such that

$$\phi = 0.41 \frac{K(HCO_3)}{K(CaCO_3)} \cdot \gamma Ca \cdot \gamma HCO_3 = f(T,I) \tag{30}$$

where

$$I = \text{ionic strength} = 1/2 \Sigma m_i z_i^2, \tag{31}$$

where

m_i is the molality,

z_i is the charge of the ith ion in the solution, and

T is water temperature in degrees Celsius.

By keeping values of the ratio of the equilibrium constants near 1 (that is, taking out 10^{-2}) equation 29 becomes

$$S = \phi\ (T,I)\, Ca \cdot HCO_3 \cdot 10^{\{[pH]-11\}} \tag{32}$$

The function $\phi(T,I)$, with the equilibrium constants and the activity coefficients taken from Back (1961), is graphed in figure 44 versus the ionic strength and temperature. With this and equation 32 one can compute the degree of saturation with respect to calcite of the water from the limestone belt.

In a discussion of the errors involved in these computations, Back (1961) states that pH, bicarbonates, and temperature must be determined in the field. The data of table 5 on pH and bicarbonates are given as determined in the laboratory and in the field, augmented by pH data from Back (1961), and the correlation between the two sets of data are shown in figure 45. The concentration of bicarbonates determined in the field is higher than the concentration of those analyzed in the laboratory by at most 20 percent (excluding one point that is 40 percent higher than the laboratory). Most are well within 10 percent of those determined in the laboratory. The pH tends to be lower in the field, especially, as expected, in tests of water from springs. Those samples that show a lower laboratory pH are not readily explainable and as it occurred to Birot and others (1967) in their sampling of karstic water, cannot be ascribed to random instrumental or operator's errors.

As is apparent from equation 32, the pH is overwhelmingly significant in the computation of satura-

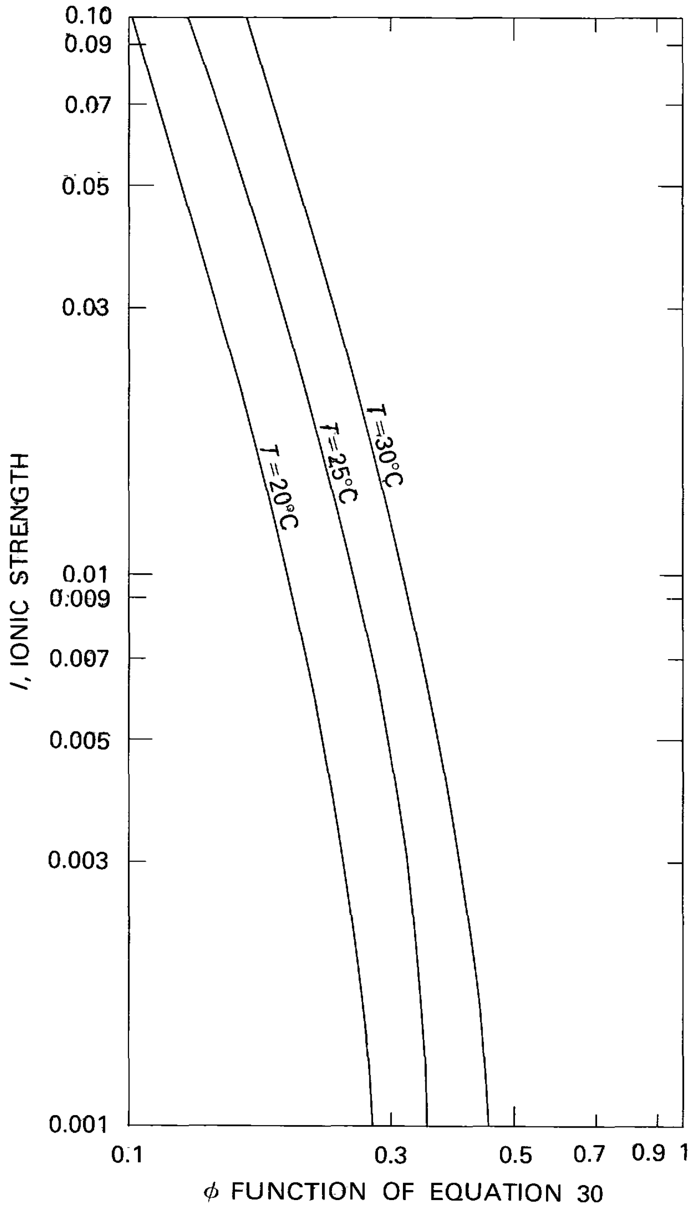

FIGURE 44.—Relation between ϕ of equation 30 and ionic strength and temperature.

tion. Further simplifications of equation 32 are possible from empirical expressions that relate the bicarbonate concentration and the ϕ function to the calcium concentration of the solution at an average temperature of 25°C. These relations are shown in figure 46, and the correlation between Ca and HCO_3 is well defined, with 95 percent of the points falling within an error band of ± 30 percent. The relationship Ca versus ionic strength shows larger scatter and it breaks down, as expected, for more concentrated water with ionic strength greater than 0.01. Still, the ϕ function of figure 44 shows that its range of values is quite restricted so that, for diluted solutions, even the approximate value of the ionic strength that can be obtained from the calcium versus ionic strength relation is sufficient to give workable values. So, by using the results of figure 46 saturation can be expressed as a function of calcium concentration and pH only as given by the equation

$$S = \phi'(\mathrm{Ca})^2\, 10^{(\mathrm{pH}-11)} \qquad (33)$$

where ϕ' is a function of calcium concentration for a temperature of 25°C.

The expression above is graphed in figure 47 with the data of tables 5 and 6 plotted therein. Also shown as vertical lines is the deviation between the more precise saturation values computed from equation 32 and those from the empirical approximation using calcium and pH data only. The results are nearly the same except for a few of the empirical saturation values which depart somewhat from the theoretical ones. In no case is the saturation boundary crossed (that is, all the theoretically unsaturated or oversaturated samples are also from the empirical approximation). The lake samples, as previously noted, are undersaturated and only one, spring-fed, approaches saturation. At the other extreme, all the ground water (from routine well-water analyses) is either supersaturated or near saturation. For a clearer discussion the saturation ratios (exclusive of well data) are plotted in figure 48 next to the sampling points. The streams are all undersaturated before entering the limestone belt and become saturated or supersaturated before reaching their mouth. The sampling was not extensive enough to determine whether the saturation is progressively increased or decreased in a downstream direction. During a trip down the Río Guajataca, travertine was seen along the stream channel, so it is evident that some precipitation of calcium carbonate takes place. The combination of degree of saturation in relation to the stream velocity that leads to the precipitation of travertine is unknown. There is an indication that water from the Cibao Formation is more supersaturated than that of other limestone formations, but the reasons for this are not known.

RECONSTRUCTION OF THE GEOLOGIC AND HYDROLOGIC HISTORY

Paleontological evidence from the sequence of about 1,400 meters of limestone and minor sedimentary clastics that are now exposed on the north coast of Puerto Rico indicates deposition started about middle Miocene according to Gordon (1959), or middle Oligocene to middle Miocene according to most investigators, and continued possibly until middle Pliocene according to G. A. Seiglic (oral commun., 1969). Assuming that middle Miocene, middle Oligocene, and middle Pliocene correspond to

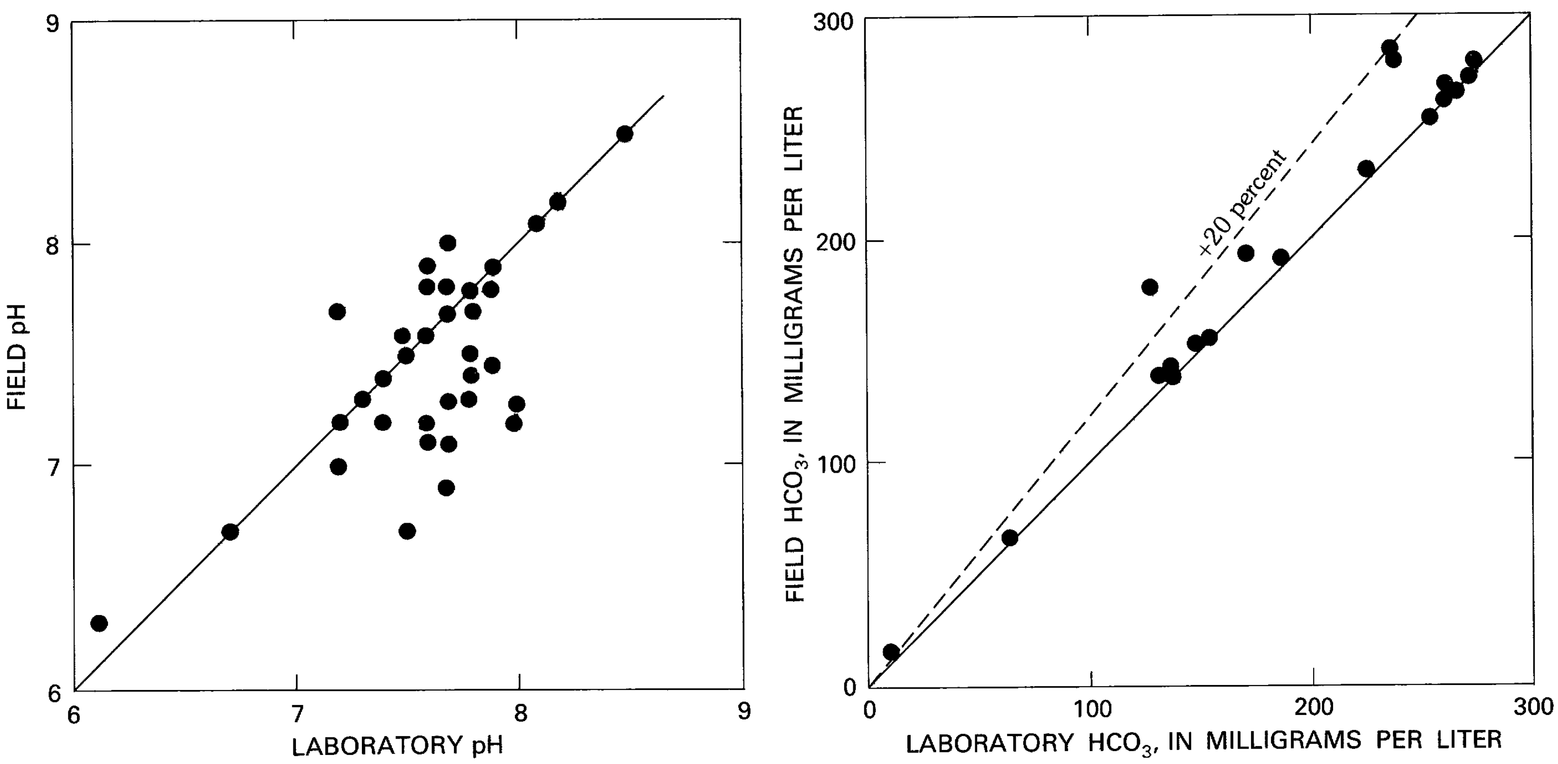

FIGURE 45.—Correlation between field and laboratory determinations of pH and bicarbonate concentration.

about 17, 32, and 5 million years ago, respectively, the rate of sedimentation would calculate to be about 0.12 mm per year (1,400 meters per 12 million years) or 0.05 mm per year (1,400 meters per 27 million years) making no adjustment for change of thickness resulting from compaction.

The rate of sedimentation based on a middle Miocene age for the oldest sediments appears to be too high if compared with maximum rates of sedimentation of 0.01 to 0.02 mm per year reported by Keunen (1950) for *Globigerina* ooze and the chalky deposits of the Paris basin. For this reason, the beginning of sedimentary deposition on the north coast of Puerto Rico is considered to be middle Oligocene in age—a view held in most of the literature. Sedimentation closed near the end of the Tertiary Period with the deposition of the Camuy Formation; the deposition of the Camuy was followed by or was contemporaneous with the arching up of the Puerto Rican platform.

On the basis of the hydrologic and geochemical data presented it is possible to determine, albeit roughly, the time when the limestones emerged from the sea and their dissolution began. Several assumptions and approximations are needed in making such an assessment:

1. The present bioclimatological conditions (vegetation cover and rainfall-evaporation) do not depart greatly from those of the past, either in quality or quantity.
2. It is possible to reconstruct the general configuration and height of the original limestone surface.
3. The physical and chemical properties of the dissolved material were not different from those measured on the material of the present surface.
4. No large vertical tectonic movement occurred, after the emergence of the limestones.
5. The lowering of the original limestone surface took place largely through the solution process.

Assumption 1 is justified by the fact that the limestone belt is presently as densely covered with vegetation as it can be and enrichment of CO_2 in the soil through the decomposition of organic matter should be at a maximum. Man's activities, with the accompanying increase of erosion and solution, are at a minimum within the general area and nearly absent in the more rugged part of the limestone belt. Therefore, the rock and water samples collected are free of or negligibly influenced by man. The rainfall-evaporation function has varied, no doubt, through geologic time. The consolidated sand dunes of the north coast bear testimony to both the lowered sea level of glacial times—hence to an increase of sand supply—and to lower rainfall (because under present rainfall conditions, vegetation grows readily nearly up to the strandline and would have trapped the sand available during periods of lower sea levels. However, glacial times would have increased the

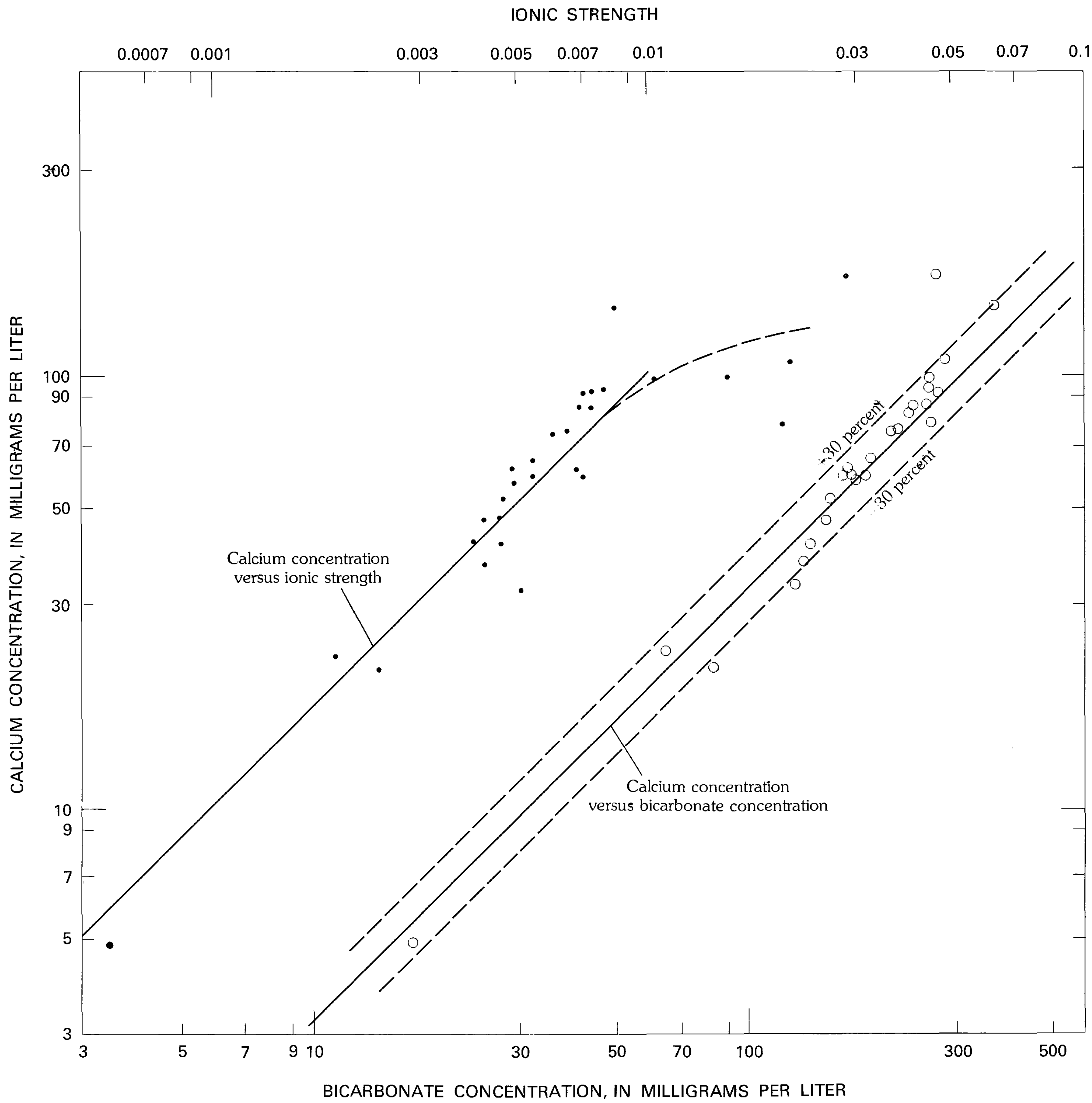

FIGURE 46.—Relation between calcium concentration and ionic strength and between calcium concentration and bicarbonate concentration.

limestone solubility through a lowering of temperature, so that some justification exists for using present rainfall-evaporation functions, and present calcium concentration values.

Assumption 2 is justified because the simple wedge structure and the uniformity of dip of the limestones permit a usable reconstruction of the height of the original surface. Of the other assumptions, 3 seems reasonable if some allowance is made for the more clastic nature of the original surface material especially toward the contact with the volcanic core; and 5 can accommodate with no great error the possible presence of an ancestral fluvial system formed on more clastic material, with lesser

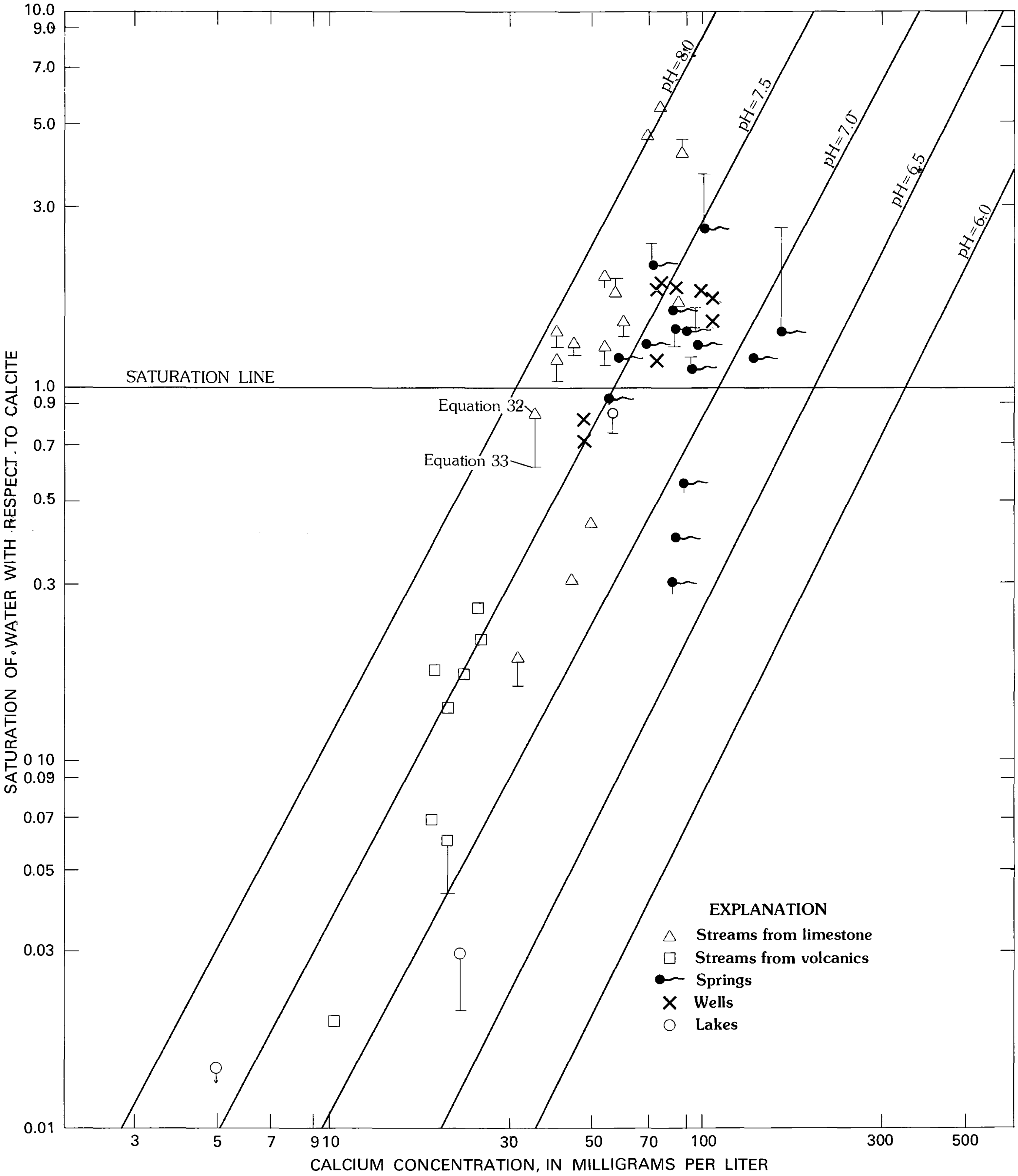

FIGURE 47.—Saturation of water with respect to calcite as a function of calcium concentration and pH. Vertical lines represent saturation values from equations 32 and 33 in text.

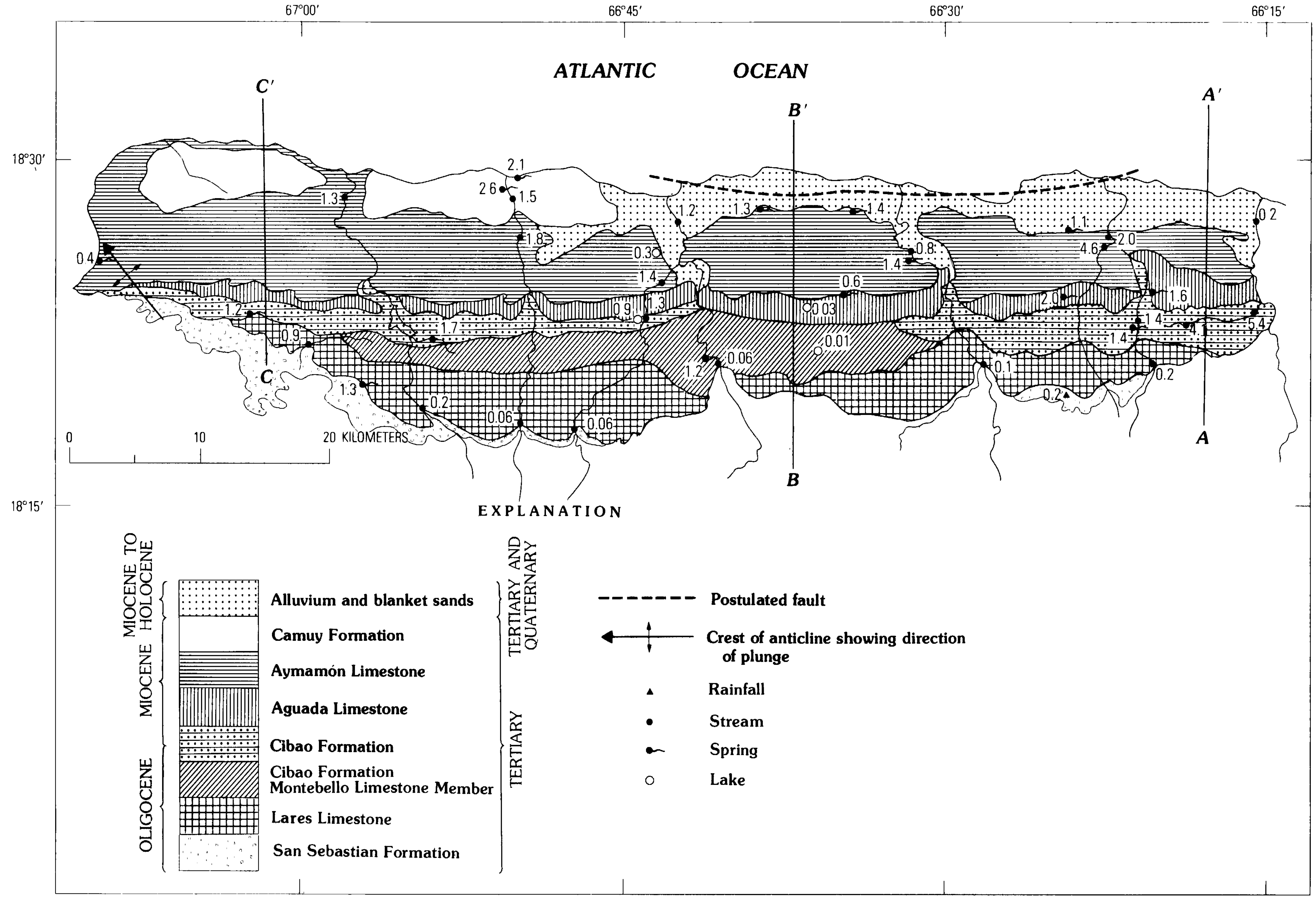

FIGURE 48.—Saturation ratio of waters from north coast limestone and volcanics.

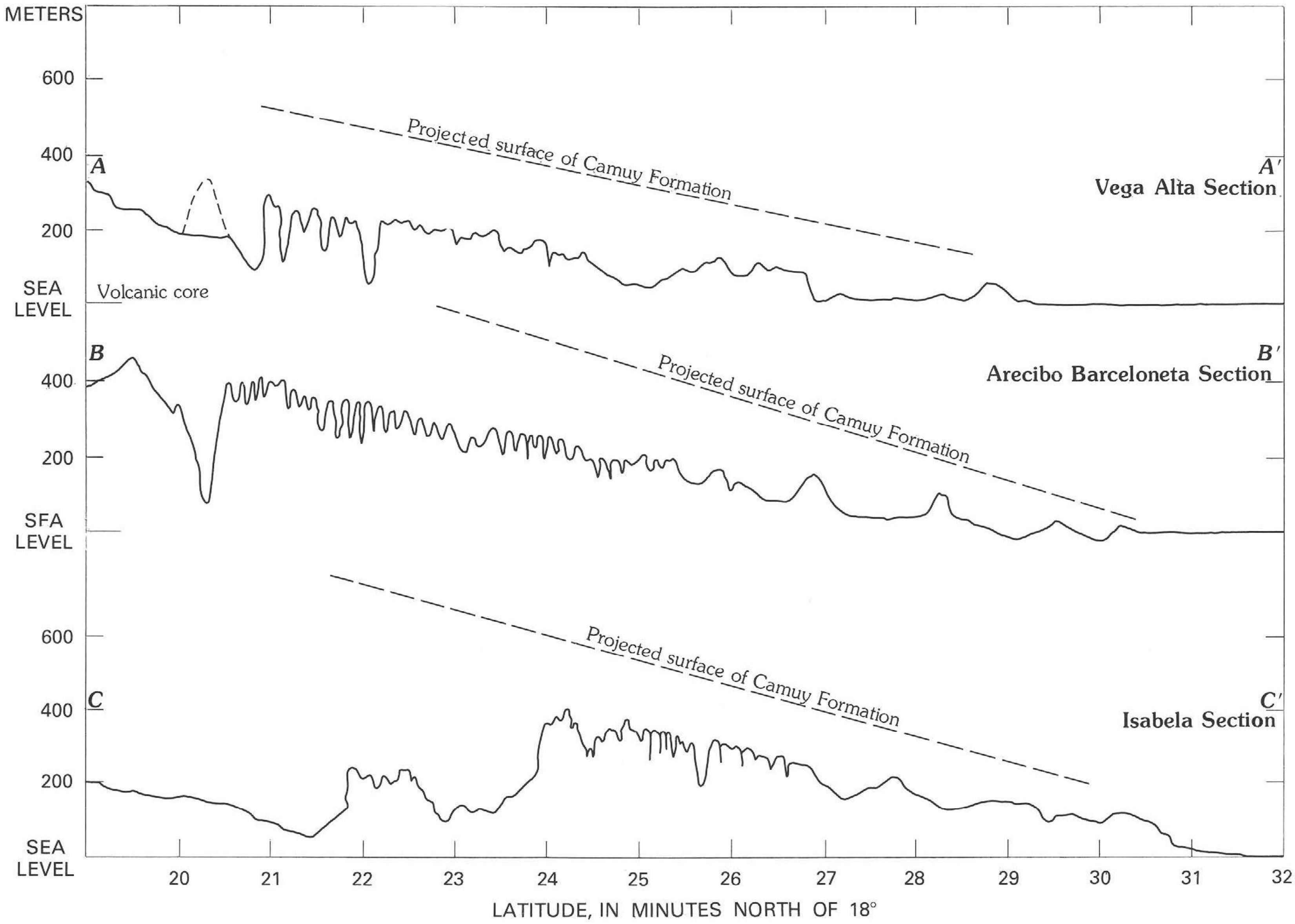

FIGURE 49.—Sections south-north through the limestone belt, with projected original surface of the Camuy Formation. (See figure 48 for location of sections.)

solution and more abrasion. No evidence is reported in the literature for or against assumption 4 other than possible tilting in Pleistocene time. The computations of the time when the limestones began to be dissolved shall be used to test this assumption.

An interpretation of profiles of the original surface is shown in figure 49 for three sections thought to be representative. The surface has been projected according to the dip of the formations and to their thinning southward as best as can be calculated from the detailed geologic maps of Monroe (1962, 1969a) and Briggs (1961), and from the few deep wells drilled in the area. The Camuy Formation is assumed to have been about 150 m thick near the coast, an estimated average based on the maximum thickness of 180 m for the Camuy given by Briggs and Akers (1965). The difference between the projected surface of the Camuy and the mean altitude of the present land surface (fig. 12) represents the amount of limestone removed since the time of emergence of the Puerto Rican platform. To compare the total volume of the calcium carbonate of the limestone removed by solution with the calcium carbonate concentrations measured in the water, the following factors are involved:

1. the calcium carbonate content.
2. the primary intergranular porosity.
3. the secondary porosity of the formation, accounting for the space between larger pieces of limestone; fractures, bedding planes or reef structures (figs. 50 and 51).

Data for 1 and 2 were obtained from table 4, and 0.1 was taken as the value of porosity for 3. Having obtained a slab thickness of pure calcium carbonate by the method just outlined, the next step was to obtain the thickness of calcium carbonate removed annually. For this, figure 23 was used together with

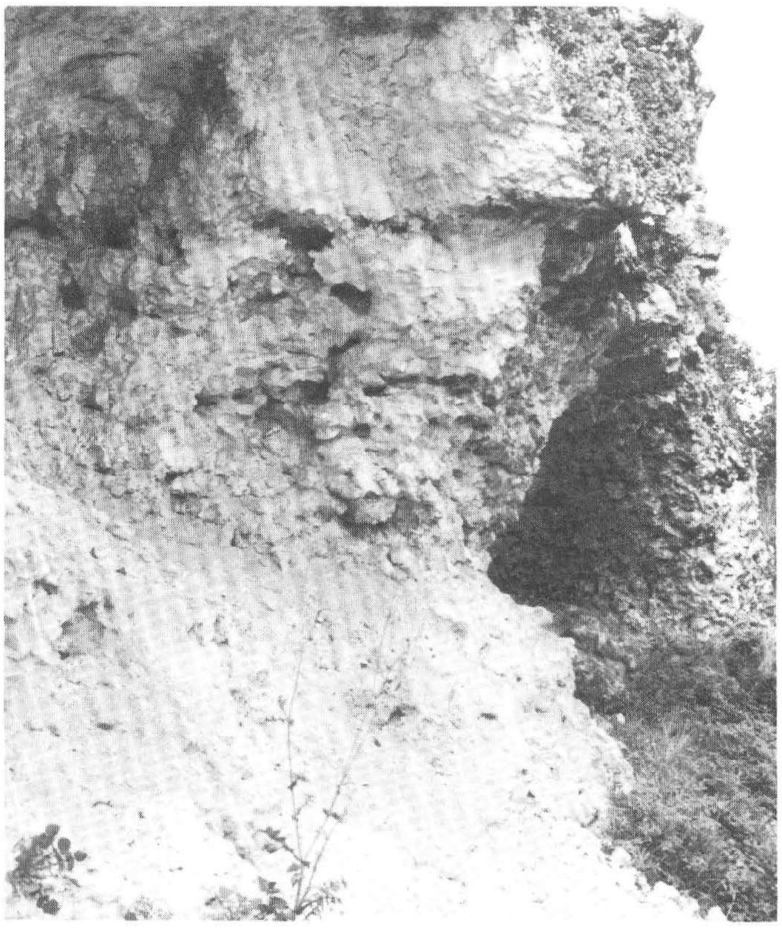

FIGURE 50.—Secondary permeability developed on chalky Aymamón Limestone. In this solution riddled limestone, water moves through much as through a sponge.

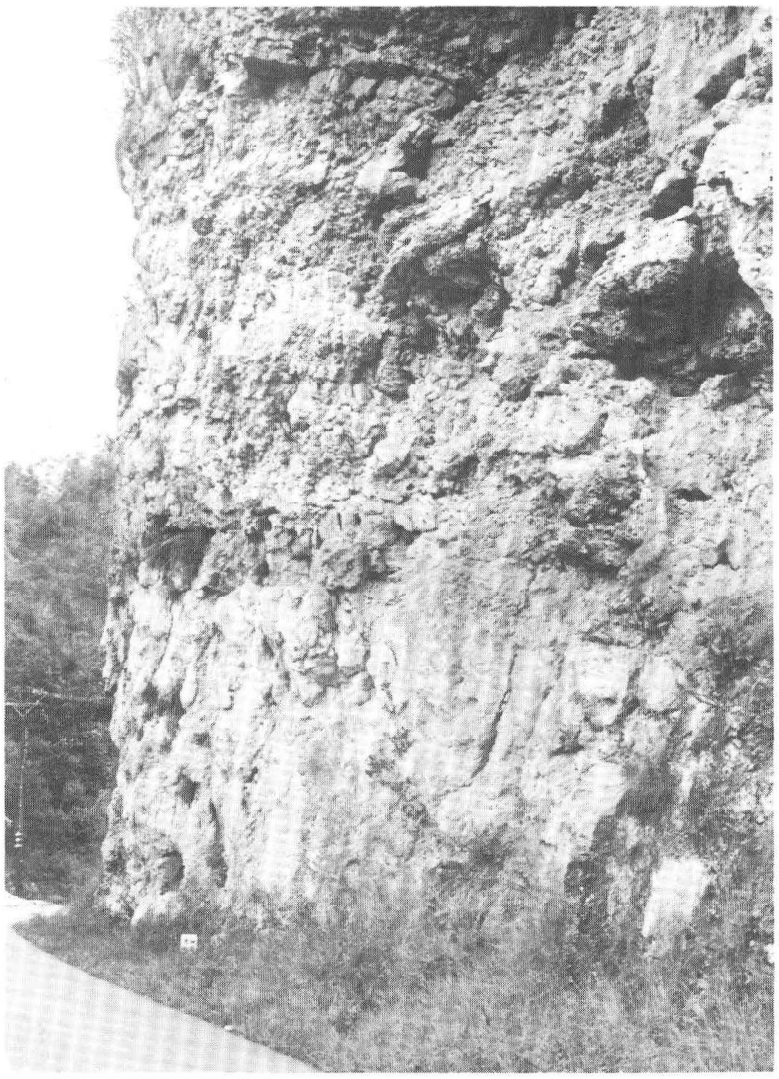

FIGURE 51.—Secondary permeability developed on Aguada Limestone. Water moves through openings between larger limestone clasts.

the average annual rainfall to compute the evapotranspiration and the subsequent discharge. The discharge is further assumed to carry an average concentration of 200 mg/L of $CaCO_3$ as obtained from the data of table 5. No adjustment was made for the $CaCO_3$ carried by rainfall—a negligible amount. An example is shown of the computations carried out for a piece of the cross section *B–B′* of figure 49 between latitude 18°22′ N. and 18°23′ N.

Altitude of original surface = 550 m
Mean altitude of present surface = 230 m
Thickness of removed slab = 320 m
Average $CaCO_3$ content = 0.85, average primary porosity = 0.15, average secondary porosity = 0.10
Thickness of equivalent $CaCO_3$ slab = $320 \times 0.85 \times 0.85 \times 0.90 = 210$ m
Average annual rainfall = 1,750 mm
Average annual evapotranspiration = 1,000 mm
Average annual outflow = 750 mm
Average concentration of $CaCO_3$ in outflow = 200 mg/L = 0.2×10^{-3} g/cm^3 = 0.074×10^{-3} (using a $CaCO_3$ density of 2.72 g/cm^3)
Average solution rate = 750 mm/yr $\times 0.074 \times 10^{-3} = 0.055$ mm/yr
Time needed to dissolve 210 m of $CaCO_3$ = 3.8 million years

This value of 3.8 million years is computed assuming only solution. Where fluvial drainage is present it is possible to compute the contribution to erosion of the abrasion process. In section *A–A′* of figure 49 between latitude 18°22′ N. and 18°23′ N. the karst surface is cut by a river. If we assume that the next 1-minute of latitude of the section immediately to the south underwent only solutioning from the same beginning time, we can write for the Vega Alta section:

Between latitude 18°21′ N. and 18°22′ N.

Solution rate × time = thickness of equivalent $CaCO_3$ slab, or 0.055 mm/yr $\times t_1 = 280$ m

Between latitude 18°22′N. and 18°23′ N.

(Solution rate + abrasion rate) × time = thickness of equivalent $CaCO_3$ slab, or

(0.055 mm/yr + abrasion rate) $t_2 = 290$ m

and, assuming that $t_1 = t_2$

$$\text{Abrasion rate} = 0.007 \text{ mm/yr}$$

and the relation between abrasion and solution rates is

$$\frac{\text{Abrasion rate}}{\text{Solution rate}} = \frac{0.007}{0.055}$$

or

$$\text{Abrasion rate} = 0.13 \text{ Solution rate.}$$

The calculations shown refer to an area where one small river has cut a canyon through the karst surface, perhaps through collapse of a former underground channel. The abrasion rate computed is probably a minimum.

The previous computations carried through in the area between latitude 18°21′ N. and 18°23′ N. of the Isabela section *C–C′* where a true fluvial system is present, give much larger results for abrasion: there

$$\frac{\text{Abrasion rate}}{\text{Solution rate}} = \frac{0.024}{0.063} = 0.38$$

or

$$\text{Abrasion rate} = 0.38 \text{ Solution rate}$$

and this can probably be considered a more significant ratio.

The solution rates and the time since solution began, computed for the three sections of figure 49, adjusted for abrasion rates where applicable, are shown in table 8. The variability in time since the onset of solution among the sections is probably due to sampling error except for the uniformly lower values of section *C–C′*. These lower values are thought to be indicative of the Pleistocene tilting and, taking an age of 3.6 to 4 million years as an average for the beginning of the erosion process or the time of emergence of the limestones, and 2.6 to 3.0 million years as the apparent age of the most seaward part of the Isabela section, the tilting can be dated as the difference in the two times, or about 1 million years ago.

Birot and others (1967) compute 2 million years as the time needed to erode a circular doline 100 m deep, and this is the same order of time computed here for an equivalent thickness of limestone.

The author's view is that tectonic movements have been responsible for the high Pleistocene terraces and eolianities described by Monroe (1968a) and Kaye (1959), but these investigators prefer eustatic movements (changes in sea level) as the explanation.

HISTORICAL DEVELOPMENT OF THE PUERTO RICAN KARST

According to the computations of the previous section, about 4 million years ago the north coast of Puerto Rico completed its emergence from the sea and the dissolution of the limestones began (it had probably started earlier near the contact of the limestones with the volcanic mountain core). A view of the area as it might have looked about 3.8 million years ago is shown in figure 53.

The drainage in the limestone belt in the west near the contact with the volcanics is assumed to have been southward to the ancestral Río Culebrinas, which was cutting a deep canyon at the volcanics-limestones contact. Subterranean drainage in a slight northwesterly direction is assumed to have been taken by all the rivers west of the city of Arecibo. All the rivers from the city of Arecibo east are presumed to have cut through the limestone belt by this time (fig. 52). It is further assumed that a mature karst existed in the east and that an incipient karst was forming in the west.

TABLE 8.—*Solution rates (in millimeters per year) and times (in million years) since solution began*

Latitude	Sections in figure 49: *A–A′* Solution rate (mm per yr)	*A–A′* Time since solution began	*B–B′* Solution rate (mm per yr)	*B–B′* Time since solution began	*C–C′* Solution rate (mm per yr)	*C–C′* Time since solution began
18°29′	----	--	----	--	0.028	2.6
28′	----	--	----	--	.032	3.0
27′	----	--	0.035	4.0	.035	3.0
26′	0.035	3.7	.040	3.7	.042	3.3
25′	.040	3.2	.040	4.1	.049	3.4
24′	.040	3.8	.045	4.2	.052	3.6
23′	.045	3.5	.050	3.8	.056	[1] 3.6
22′	.050	[1] 3.5	.055	3.8	.063	[1] 3.6
21′	.055	3.1	.060	4.0	.063	[1] 3.6
20′	----	--	.060	4.0	----	--

[1] Adjusted for abrasion.

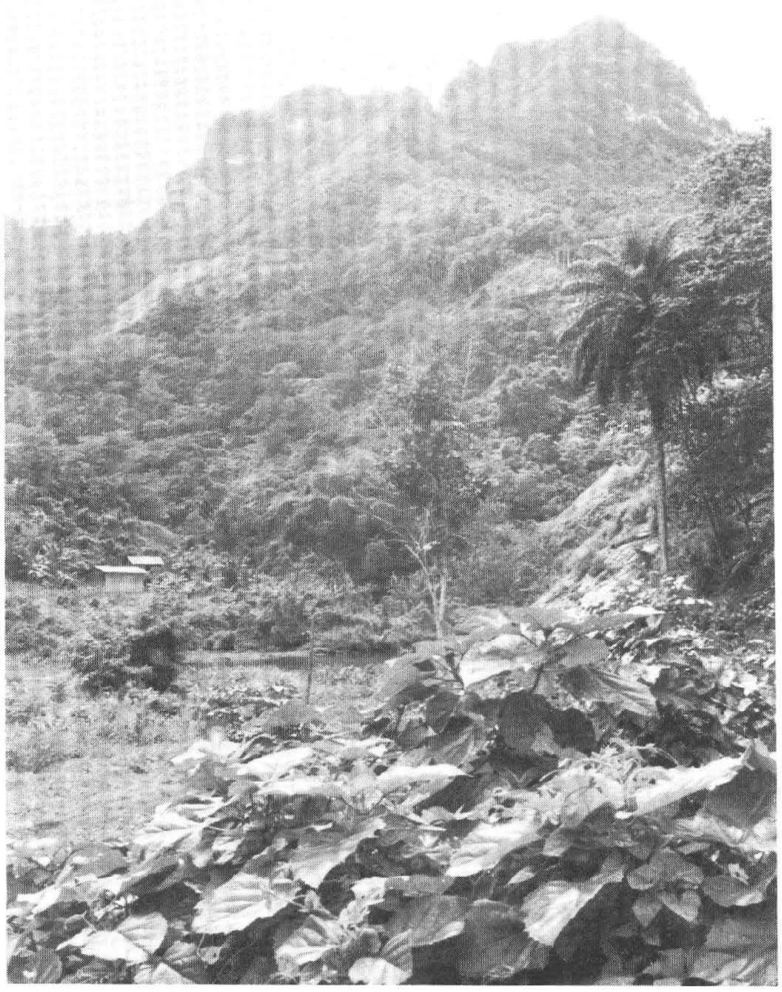

FIGURE 52.—Limestone knobs left as residuals on top of volcanic rocks by downcutting of the Río Grande de Arecibo.

Solution presumably continued to about 1 million years ago; during the process geomorphic development led to capture of part of the south-draining karst by the Río Guajataca, development of part of the Ríos Camuy and Tanamá, and the development of flood plains in the eastern rivers. At that time the karst between the Río de la Plata and the Río Grande de Arecibo is thought to have entered its final phase, characterized by the formation of mogotes covered by blanket sands weathered in situ or carried northward from higher altitudes. In the west, cockpit karst developed in the permeable formations, and a fluvial system formed on the more impermeable rocks.

About a million years ago tectonic activity raised the north coast limestones in the northwest and tilted eastward the entire Puerto Rican platform. The rise and tilt brought about a shift in the direction of drainage, as is interpreted from figure 54, a series of histograms of stream channel orientation for the various limestone formations. Qualitatively, attention is called to the multipeaked distribution of all the flow directions and to the flow directions

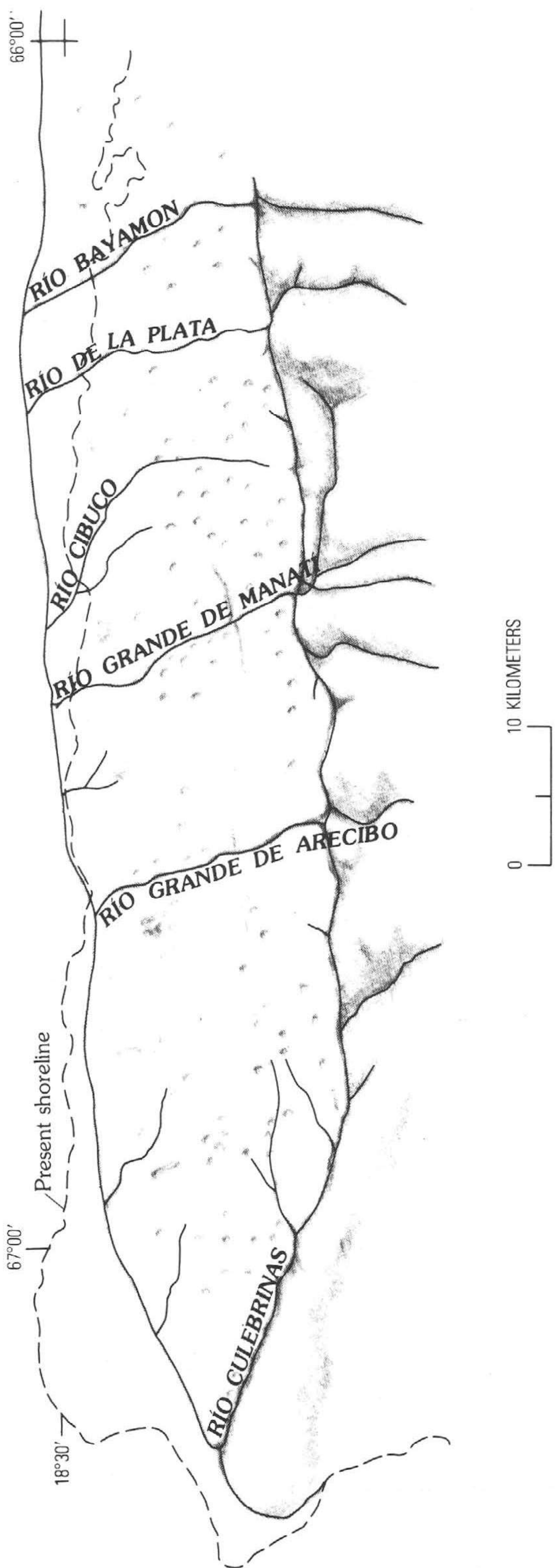

FIGURE 53.—A view of the north coast belt 3.8 million years ago.

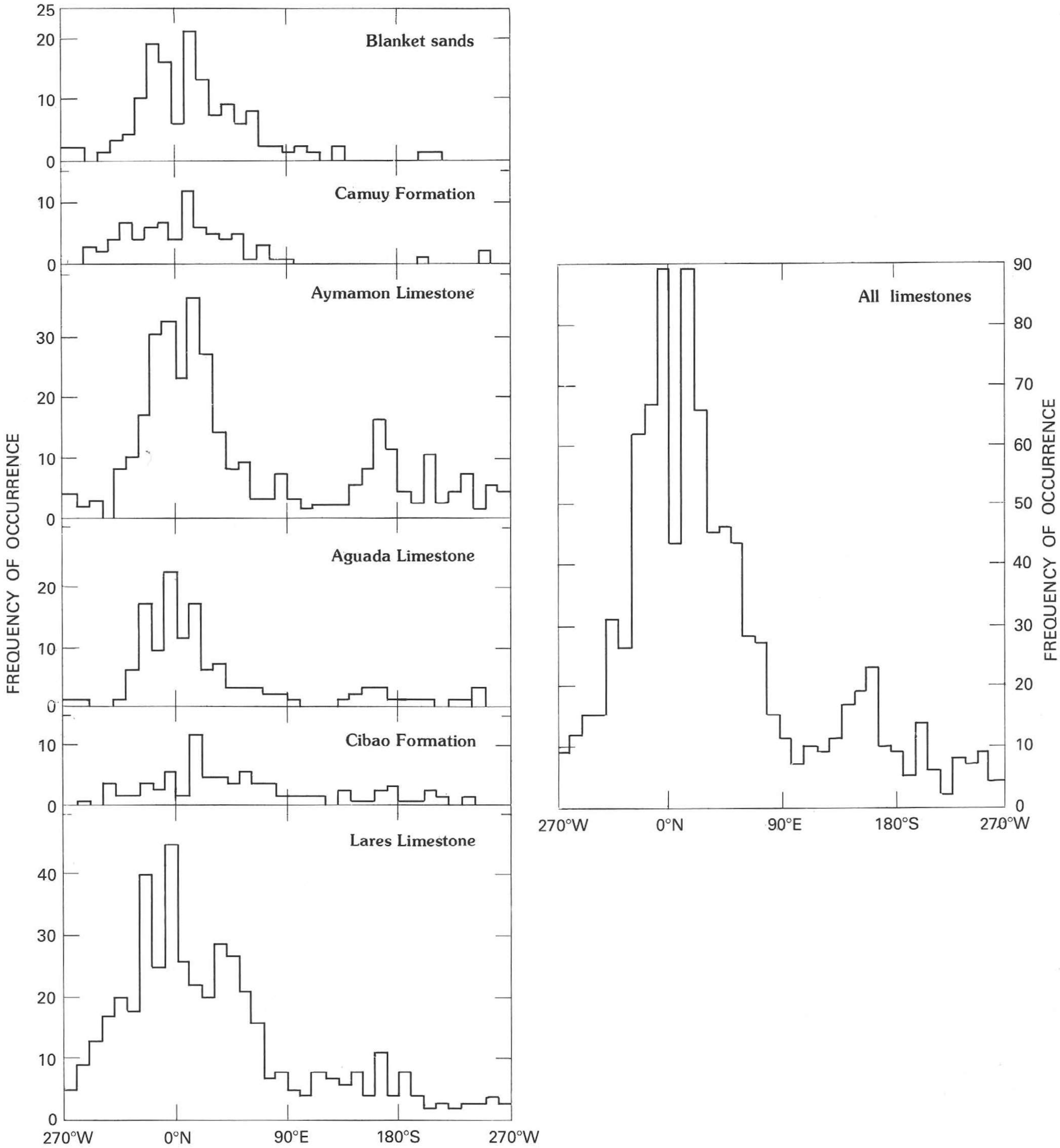

FIGURE 54.—Distribution of stream channel orientations in the north coast limestones.

of those formations exhibiting clearly multipeaked distribution .The main western peak in these cases (modal values of about $-10°$ or $350°$, is interpreted as a fossil drainage direction from pre-tilt times. Two formations are either single peaked (assuming that the ups and downs of the histograms are due to sampling errors) or weakly multipeaked: (1) the Camuy, which is the youngest, most lithologically variable, and most seaward formation, and (2) the Cibao, which is a formation that has a clearly developed fluvial system. The lack of a predominant peak in the histogram to show a preferential direction west of north is inferred to indicate that the abrasion process has erased the evidence of the vestigial drainage direction still present in the other formations. In the purer limestones the solution process has etched in depth the former paths of flow. It should also be noted in figure 54, that all mean values of the distributions would only indicate an orientation of stream channels in an eastward direction and thus fail to disclose the admittedly subjective assignment of some drainage to a westward direction as just discussed. The tilt of the Puerto Rican platform is also taken to have affected the directional pattern of subterranean drainage, leading to development of springs mainly on the west side of rivers, especially in the western part of the belt. The coastal swampy area east of Arecibo is also ascribed to the tilt, as is the raised shoreline west of Arecibo.

FACTORS OF KARSTIFICATION

The north coast Puerto Rican karst, with its peculiar landscape called "lunar" by Monroe (1968b) and, with Gallic sagacity, "á mamelons" by Birot and others (1967), is notably different from the classic karst of Yugoslavia: there are no uvalas (depressions 1 to 10 kilometers in diameter), no poljes, and karren or lapiez are scarce. Perhaps some forms of mogote karst are a local equivalent of the uvalas and poljes; certainly they do not look the same. Birot and others (1967) find it difficult to explain the differences of this karst from that of other areas, particularly that of the temperate zone. In a search for explanations temperate zone karst investigators suggest climatic differences, though they admit to having no final answer. Monroe, (1966) as already discussed, favors, lithologic and stratigraphic differences to explain the various landforms of the Puerto Rican karst; he has not yet compared this karst to that of other places. Traditionally, of course, climate, percentage of $CaCO_3$ in the rocks, and the regional structure have been set forth as the cause and, in particular, since most investigators of karst have been European, fracturing has invariably been suggested as the primary condition for the beginning of the karst. The Puerto Rican limestones of the north coast, however, are not obviously fractured as the European limestones are. Jointing is inconspicuous as can be seen from the photographs shown so far, including one (fig. 55) taken on a cut in the Lares Formation. There are, to be sure, open spaces between the larger pieces of limestone, through which water can percolate and even create vertical caves (fig. 56), but there are no vertical shafts or obvious fractures. The absence of joints, however, does not keep water from infiltrating; on the contrary it does so quite readily, much as it does in fine alluvial material or through soil, and even if the limestones had no void space between the larger clasts, water could infiltrate through the primary openings of the rocks. (See table 4.) The development of the karst only requires that water infiltrate—no significance is attached to the manner in which infiltration takes place.

Presently the limestones are being preferentially dissolved under the blanket sands because of the existence of the hardened limestone shell covering the mogotes, as explained by Monroe (1966). However, on a larger scale it may be argued, and Birot and others (1967) tacitly assume it, that there are regional fractures and joints such that dolines are formed at the intersection of the fracture planes and mogotes are formed in the area between the fractures. This view deserves testing, as clearly then there should be a preferential arrangement of

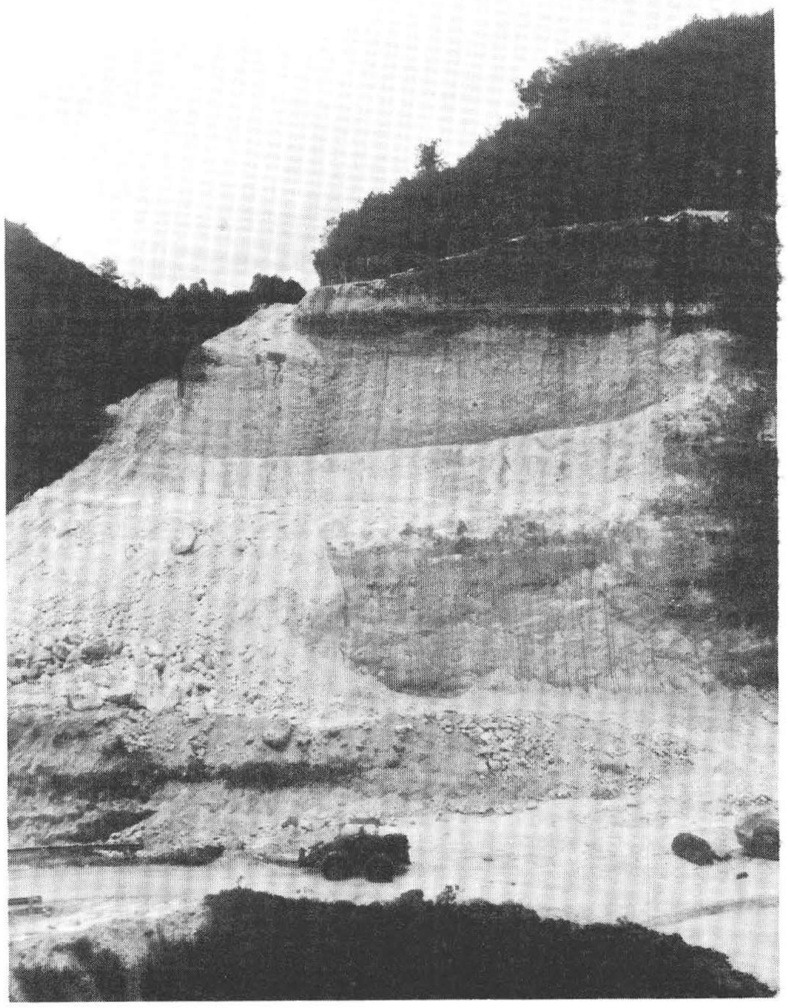

FIGURE 55.—A cut through a mogote of Lares Limestone. Note the absence of fracturing. (Photograph by Rafael Dacosta).

FIGURE 56.—Small cave in Aguada Limestone. Water percolates much as through soil layers—no fracturing.

dolines in some direction. A qualitative test of this interpretation is demonstrated in figure 57, which shows a random arrangement of dolines (drawn from a table of random numbers), two actual examples from the north coast karst, and an assumed geometrical arrangement of dolines. A distribution of orientations can be obtained by counting the number of dots recorded within a plastic strip (about 2.5 cm wide) superimposed and rotated on the various arrangements of dots of figure 57. Using six strips orientations and assuming equal count per orientation, valid intuitively for a random arrangement, a chi-square test can be used.

The results of this test, shown in table 9, indicate that dolines are located randomly within the space of the two sampled areas. As expected, the geometrical arrangement of dolines tested to be nonrandom. Therefore, it is concluded that water infiltrates through no preferential path and that dolines are randomly distributed. The flow directions that show preferential orientation at the scale of the entire belt resulted from the topographic gradient and were not the result of jointing or fracturing. (See Williams (1965), p. 67–80.)

Leopold and Langbein (1962) have investigated the development of river drainage networks and have derived by random walks river networks quite similar, at least on a gross scale, to the real ones. It appears that an equivalent condition is present in the karst of Puerto Rico through random arrangement of solutional features. If this is so then, it is not the "classical" European karst that we should look to for a more clear understanding of the beginning of karst development, and certainly it should not be taken as the standard to which other karsts are to be compared. The karst of the north coast of Puerto Rico, showing as it does, all degrees and shades of karstification, from the incipient stage forming on the raised platform of the northwest to the completed denudation of the northwestern coastal flats, offers a vast field of profitable investigation on its own. And because this karst appears to be the product of random solution on a structurally simple wedge and on relatively young unfractured limestones which, at places, seem to have the consistency of freshly deposited material (fig. 58), it may be regarded as the sequence of erosional stages which the limestone terrane goes through when newly emerged from the sea.

The question of rock hardness or density and fracturing is thought to be of crucial importance for determining the type of karst features that will develop on a carbonate-rock terrane. There are, for example, among the Cretaceous and older Tertiary limestones of Puerto Rico (fig. 1), areas where the rocks are fractured and indurated; in these areas the similarity (on a small scale) to the European karst becomes more apparent, for both karsts contain lapie fields and funnel-shaped dolines. Clearly the different morphologies cannot be explained by climatic differences because the climate where the Cretaceous and older Tertiary limestones are located is nearly the same as that of the north coast limestones. Even the dismissal of a lack of an extensive karst development on the limestone belt of the south coast because of an arid climate, may be erroneous as Moussa (1969) points out. Nonetheless one would expect climate to exert some influence on karst development and on its morphology in that the rate at which rock solution takes place, other things being equal, depends in part on the amount of net precipitation coming in contact with the limestones. Furthermore soils and vegetation are thicker and more abundant in humid than in arid areas and thus there is a better opportunity for the

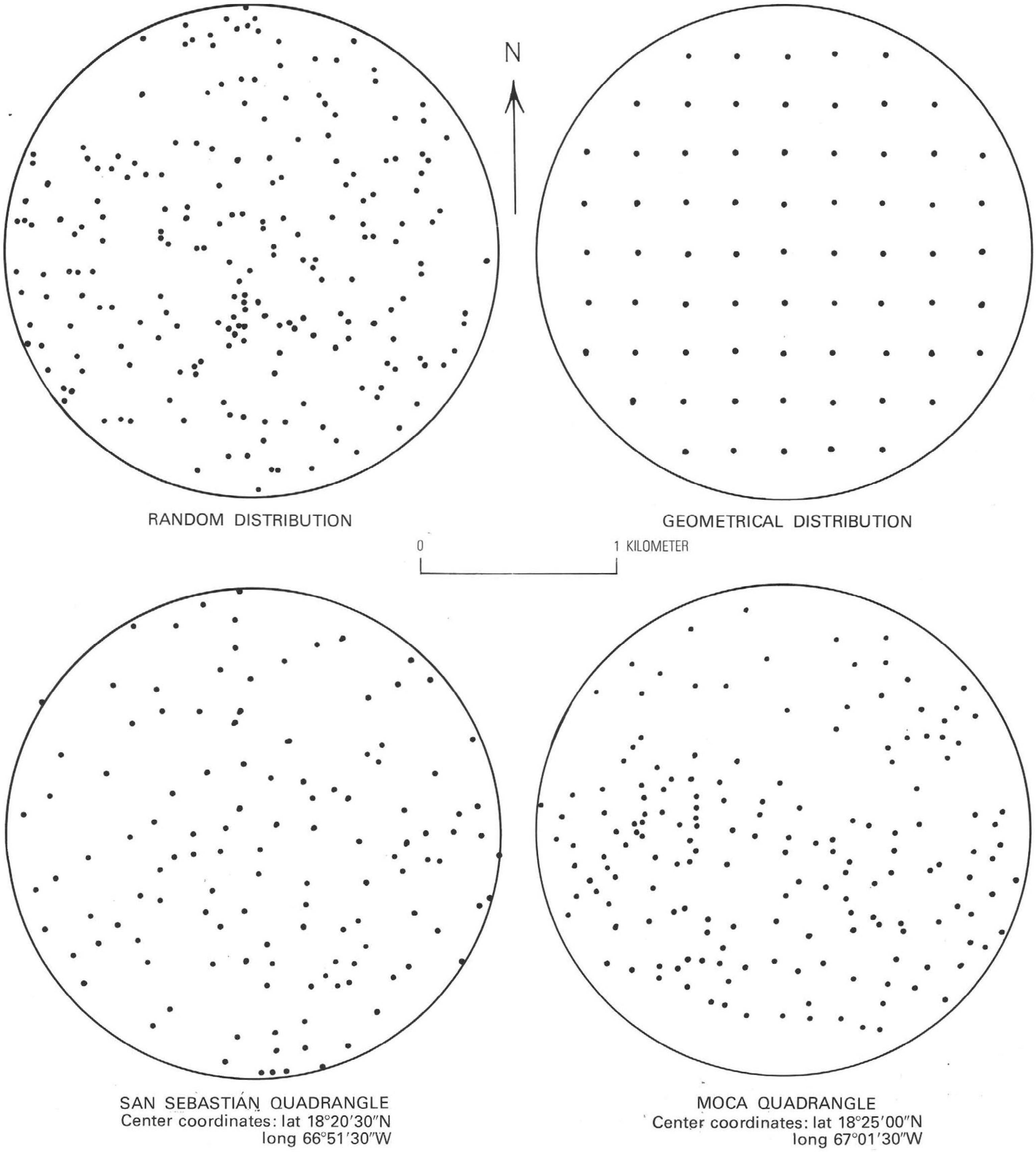

FIGURE 57.—Spatial distribution of dolines.

development of organic acids which contribute significantly to the solution process.

Clearly the $CaCO_3$ content of the rocks determines the threshold between the formation of a karst or a fluvial drainage (for example, the lithology of the Cibao Formation). Given that the limestones are sufficiently pure as to be readily dissolved by acidic water, it is thought that the two primary factors which determine the karst morphology at a given stage in time are vertical and lateral rock

TABLE 9.—*Chi-square test of doline orientation*
[Areal distribution shown in figure 57]

Orientation, degrees	Observed frequency, in percent				Theoretical frequency, in percent
	Random dolines	Grid-alined dolines	Actual dolines		
0–180	12	25	11	22	16.7
30–210	20	12	14	14	16.7
60–240	10	12	18	19	16.7
90–270	22	25	23	19	16.7
120–300	19	12	20	11	16.7
150–330	17	12	14	16	16.7
χ^2(5df)	6.67	13.54	5.95	4.73	---

permeability (either primary or from fracturing) and the primary porosity or rock density. Climate, lacking proof to the contrary, is tentatively placed at a lower level of importance.

SUMMARY AND CONCLUSIONS

The north coast limestone area of Puerto Rico is underlain by a sequence of six formations which range in age from middle Oligocene to middle Miocene (or as young as middle Pliocene(?)). These formations from oldest to youngest are known as San Sebastián Formation, Lares Limestone, Cibao Formation, Aguada and Aymamón Limestones, and Camuy Formation. All the formations, except for the first, which is mainly a claystone and the third which is a mixture of marl, chalk, sand, and clay, are nearly pure limestones. Little structural deformation is shown by the formations, and this broad mass of rocks can be described as forming a homocline gently inclined to the north.

All degrees of karst development can be found on the limestone surfaces except for the San Sebastián Formation and parts of the Cibao Formation; these two formations have developed a dendritic fluvial drainage. The surface and subsurface paths taken by precipitation falling on the karst are different from those found in fluvial drainage basins and even in alluvial ground-water provinces. In terms of the water balance, however, most of the

FIGURE 58.—The limestone is so soft, in places, that a knife is sufficient for this modern sculptor. Montebello Limestone Member of Cibao Formation at entrance of Arecibo Astronomical Observatory. (Photograph by Rafael Dacosta).

rainfall on the karst can be accounted for by streamflow or lagoonal discharge, when consideration is given to losses by evapotranspiration.

The climatic factors which condition this discharge are:

1. Average rainfall ranging from 1,550 mm on the coast to 2,300 mm at the higher elevations, or 1,800 mm as an overall average.
2. Incoming total solar radiation (direct plus diffuse sky), expressed as about 4,000 mm of evaporated water for cloudless sky or about 2,900 mm under the average cloud cover; resulting in an average potential evapotranspiration of about 1,500 mm.

For the average climatic conditions, the actual evapotranspiration is about 1,100 mm and the discharge is about 650 mm. The discharge may follow surface or subsurface paths whose pattern is controlled by the karst development. In the impure Cibao Formation and in the northwestern part of the Lares Limestone area, discharge is predominantly by surface drainage with subsequent infiltration in the karst of the Aguada Limestone, where the Cibao dips under it. Elsewhere in the karst the discharge is subsurface partly as transient tributary flow to those rivers alined in the general direction of the ground-water flow (south to north) and partly as saturated flow in the areas between the rivers.

The ground-water flow is under water-table conditions in the Aymamón and Aguada Limestones; discharge occurs in a strip near the coastline along a freshwater–seawater interface created by the difference in density between freshwater and seawater. East of Arecibo, much of the ground water discharges landward of the shoreline, in springs, lakes, and swamps, and is dissipated by evapotranspiration or by surface outflow to the sea. The direct discharge to the sea in this area probably emerges uniformly (rather than through springs) through the seabed and diffuses into the sea. West of Arecibo, and in increasing amounts toward Aguadilla, however, the ground-water discharge appears to be predominantly on the seaward side of the shoreline and may emerge in places as spring flow through the sea bottom.

In the downdip parts of the Montebello Limestone between Arecibo and Mantatí, the ground-water flow is under artesian conditions, confined by low-permeability layers of massive limestone and by certain nearly impermeable sections of the Cibao. The artesian flow emerges through submarine outflow areas at an unkown distance from the coast and possibly, in part, through the fault proposed by Briggs (1961) into the swampy areas of Caño Tiburones and Laguna Tortuguero.

There is an indication that the lateral permeability of the aquifer decreases exponentially with stratigraphic depth, ranging in value from about 1 cm/sec for the upper part of the Aymamón Limestone to 10^{-4} cm/sec for the basal Lares. No data are available for the vertical permeability although it can be inferred that it must be high because the water table is but a few meters above sea level in certain parts of the upper part of the Aymamón where the altitude of the land surface is more than 100 meters.

The water table is extremely flat in the most seaward Aymamón thus reflecting its high permeability. The increase in water-table gradient through the Aguada is ascribed to its relatively low lateral permeability and to the effect of the underlying impermeable Cibao. In the Cibao and the Lares the water table is again quite flat, possibly indicating that lateral flow through the water-table zone is less significant than downdip flow into the artesian system.

Streamflow from the volcanic terrane south of the limestones is increased during rainy periods by contribution from the karst, mainly by shallow transient subsurface flow through solution channels. The base-flow component of streamflow is less in basins in limestone than in volcanic terrane. On an annual basis, water-budget results indicate, however, that the flow of the rivers, after they have traversed the limestone belt, is about the same as it would have been had they continued flowing on volcanic terrane.

The flood plain provides a dampening effect on the storm runoff, absorbing part of the floodflow through bank storage, and releasing it later as base flow. However, one flood plain, the Río Grande de Arecibo, seems to be responsible for an overall apparent loss of flow. This loss is probably flow that bypasses this basin to emerge as spring flow in Caño Tiburones.

It is not possible to define a unique drainage area for that portion of the limestone belt that is drained by Caño Tiburones and the Río Grande de Arecibo because the base flow of Caño Tiburones is almost all ground-water flow from much of the belt to the south, whereas its direct runoff is from the area of the Caño itself. The best interpretation that can be made of the flow pattern and associated drainage areas of the north coast limestones is shown in figure 59.

The overwhelming effect of the limestones on the chemical quality of the water is to increase its bicarbonate and, therefore, its calcium concentration. Silica content in the limestone water is less than half (6–10 versus 15–30 mg/L) that found in the waters from the volcanic terrane.

The acidity of rainfall is insufficient to explain the measured quantity of $CaCO_3$ in the limestone water, and it is calculated that as much as 86 percent of the limestone solution takes place mainly through the enrichment of rainwater with CO_2 by the decomposition of organic material in the soil. Except for the water of lakes resting on terra rossa, most limestone waters are saturated or supersaturated with respect to calcite. Some of this calcite is probably reprecipitated as is evidenced by the crystalline limestone and the stalactitic deposits seen in most roadcuts. On the average, about 0.047 mm per year of $CaCO_3$ is discharged with the water flowing out of the limestones. Accordingly, the average land-denudation rate from solution is about 0.070 mm per year. Scant evidence indicates that abrasion in fluvial systems contributes about another 40 percent to the calculated denudation rate based on solution only.

A span of about 4 million years is computed as the time it would take present denudation rates to reduce a reconstructed original limestone surface to the present land surface. It is inferred, therefore, that the limestones of the north coast of Puerto Rico emerged from the sea about 4 million years ago. Some lower computed ages for the northwestern part of the limestone belt are thought to be indicative of later emergence related to the eastern tilting of the Puerto Rican platform as reported in the literature. By difference between the computed lower ages (about 3 million years ago) and the average, this eastern tilting of the Puerto Rican platform is considered to have occurred about 1 million years ago.

Geomorphic data on orientation of river courses indicate that the present drainage pattern, oriented slightly to the east and in accord with the topographic slope, is superimposed on a vestigial pattern slightly oriented to the west. These drainage patterns are thought to be supporting evidence for the tilting, as is the fact that karstic springs are most prevalent on the west side of river valleys.

An analysis of orientation and distribution of sinkholes reveals no preferred orientation. Thus surface solution is inferred to take place as an areally random process. The absence of preferred

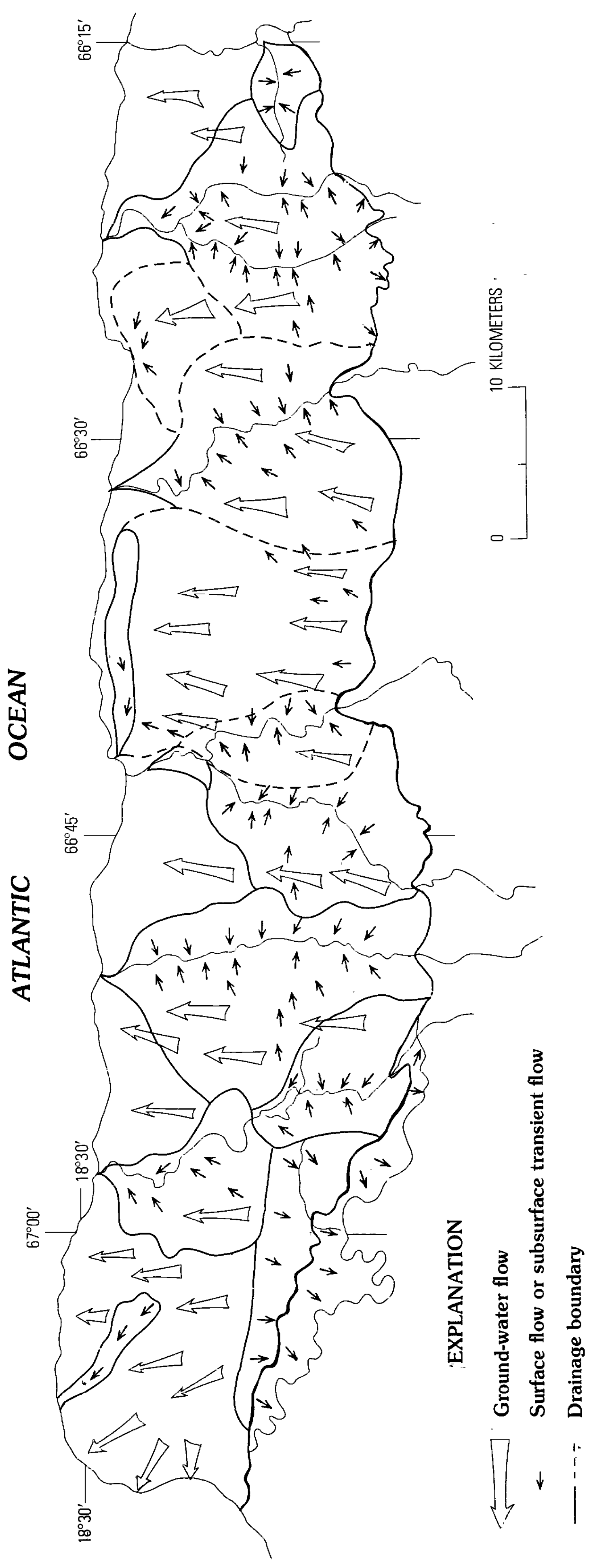

FIGURE 59.—Flow patterns and drainage areas of the north coast limestones.

orientation is taken to imply that large scale limestone joints are rare or absent.

Consideration of the processes that form the surface features of karst on soluble, unjointed, and unfractured limestones in Puerto Rico indicates that the primary controls are the distribution of lateral and vertical permeability and the primary porosity of the rocks. Climate is considered to be of lesser importance.

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Hydrogeology of the North Coast Limestone Aquifer System of Puerto Rico

By Jesús Rodríguez-Martínez

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San Juan, Puerto Rico
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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
mile (mi)	1.609	kilometer
square foot (ft^2)	929.0	square centimeter
square mile (mi^2)	2.590	square kilometer

Temperature: Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times °C + 32$$

Transmissivity: the standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form of this unit, foot squared per day (ft^2/d), is used for convenience.

Abbreviated water-quality units used in this report:

mg/L milligrams per liter
µS/cm microsiemens per centimeter at 25 degrees Celsius

Acronyms used in this report:

MSL Mean Sea Level
USGS U.S. Geological Survey

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Abstract

The North Coast Limestone aquifer system of Puerto Rico is composed of three regional hydrogeologic units: an upper aquifer that contains an underlying saltwater zone near the coast, a middle confining unit, and a lower aquifer. The upper aquifer is unconfined, except in coastal areas where it is locally confined by fine-grained surficial deposits. The upper aquifer is mostly absent in the Río Piedras area of northeastern Puerto Rico. The confining unit is composed of calcareous claystone, marl, chalky and silicified limestone, and locally clayey fine-grained sandstone. Test hole data indicate that the confining unit is locally leaky in the San Juan metropolitan area. An artesian zone of limited areal extent exists within the middle confining unit, in the central part of the study area. The lower aquifer mostly contains ground water under confined conditions except in the outcrop areas, where it is unconfined. The lower aquifer is thickest and most transmissive in the north-central part of the study area. Water in the lower aquifer is fresh throughout much of the area, but is brackish in some areas near San Juan and Guaynabo.

West of the Río Grande de Arecibo, the extent of the lower aquifer is uncertain. Data are insufficient to determine whether or not the existing multiple water-bearing units in this area are an extension of the more productive lower aquifer in the Manatí to Arecibo area. Zones of moderate permeability exist within small lenses of volcanic conglomerate and sandstone of the San Sebastián Formation, but in general this formation is not a productive aquifer.

Transmissivity values for the upper aquifer range from 200 to more than 280,000 feet squared per day. The transmissivity values for the upper aquifer generally are highest in the area between the Río de la Plata and Río Grande de Arecibo, where transmissivity values have been reported to exceed 100,000 feet squared per day in six locations. Transmissivity estimates for the lower aquifer are highest in north central Puerto Rico, where the Lares Limestone and the Montebello Limestone Member of the Cibao Formation have transmissivities as high as 500 and 3,600 feet squared per day, respectively.

INTRODUCTION

The North Coast Limestone aquifer system is an important source of ground water in Puerto Rico. It consists of a highly karstified carbonate platform sequence of middle Tertiary age and extends eastward 85 miles (mi) from Rincón, in western Puerto Rico, to Loíza in northeastern Puerto Rico (fig. 1).

This aquifer system is composed of three main hydrogeologic units: an upper aquifer and a lower aquifer, separated by a confining unit of variable thickness (Giusti, 1978). Although the upper aquifer has been developed extensively in some areas, relatively little is known about the aquifer system, particularly the lower aquifer. To gain a better understanding of this regional aquifer system, the U.S. Geological Survey (USGS), in cooperation with the Commonwealth of Puerto Rico Department of Natural and Environmental Resources, conducted a study of the hydrogeology of the North Coast Limestone aquifer system from 1983 to 1988.

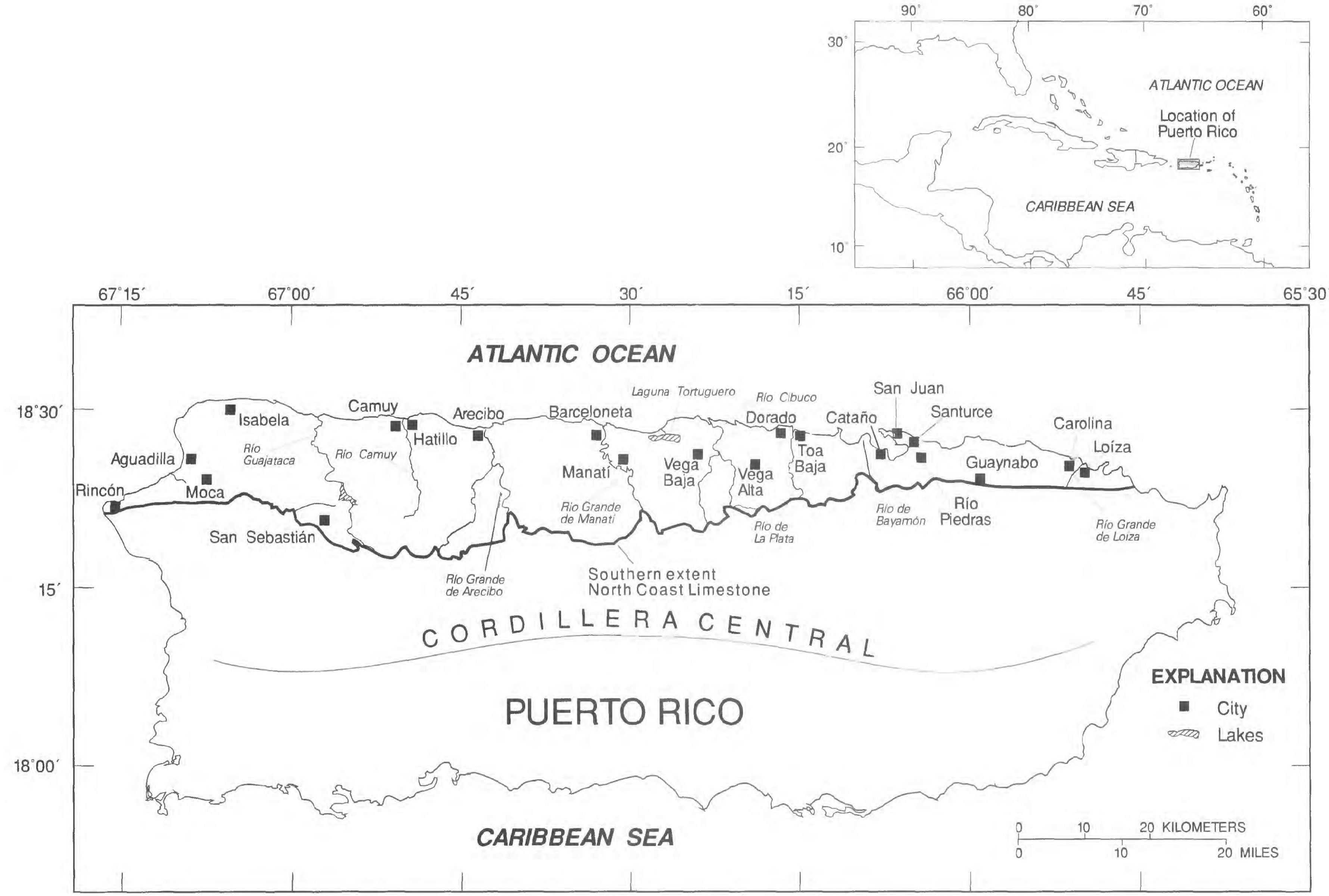

Figure 1. Areal extent of the North Coast Limestone of Puerto Rico.

Purpose and Scope

The purpose of this report is to describe the regional hydrogeologic units and the hydrogeologic framework of the North Coast Limestone aquifer system. The regional aquifers and confining units have been mapped on the basis of relative permeability and hydraulic continuity of geologic materials penetrated by a series of deep test wells and test holes drilled during the study (fig. 2). Lithologic, geophysical, and hydraulic data for the test wells and test holes and from other wells in the area were also used to prepare a series of hydrogeologic sections showing the variations in the lithology and thickness of the main hydrogeologic units in the study area. These hydrogeologic sections are presented in this report, along with maps showing the distribution of estimated ranges of transmissivity for the major aquifers in the North Coast Limestone.

Geographic Setting

The North Coast Limestone of Puerto Rico underlies about 700 mi^2 in the northern one-third of Puerto Rico and extends eastward from Rincón in the western part of the island to Loíza (fig. 1), a distance of about 85 mi. The North Coast Limestone extends from the Atlantic Ocean southward to a central east-west ridge that is part of the Cordillera Central Mountain Region. The outcrop area of North Coast Limestone is approximately 11 mi wide near Camuy and narrows to 2.25 mi near San Juan.

The North Coast Limestone is drained by eight major rivers that originate in the mountainous volcanic terrane to the south. These rivers flow predominantly north to the Atlantic Ocean.

The surface exposure sequence of middle Tertiary age is characterized by tropical karst topography. In the northwestern part of Puerto Rico, the karst topography is characterized by high relief and deeply entrenched river channels or rivers with subterranean courses in some areas. In the north-central part of the island, the land surface is characterized by numerous karst features including sinkholes and limestone hills (mogotes). In this part of the island, dissolution processes generally are still very active in the intermogotal areas. The karst topography in the eastern part of the island, which includes the municipalities of San Juan and Loíza, is in an older stage of development. There, the karst development is characterized by low topographic relief with little or no active dissolution of limestone, and by surface, rather than underground drainage (Monroe, 1976).

Previous Hydrogeologic Studies

The first study of the North Coast Limestone was conducted by McGuinness (1948), as part of a general reconnaissance of the ground-water resources of Puerto Rico. Subsequent hydrogeologic studies in the North Coast Limestone, prior to 1973, are summarized by Giusti (1978). In his report, Giusti discussed the hydrogeology of the North Coast Limestone karst, placing emphasis on the upper aquifer. Since 1973, a series of hydrologic investigations in parts of the North Coast Limestone have been carried out by the USGS in cooperation with various agencies of the Commonwealth of Puerto Rico (Anderson, 1976; Gómez-Gómez, 1984; Torres-González and Wolansky, 1984; Torres-González, 1985a and 1985b; Quiñones-Aponte, 1986; Gómez-Gómez and Torres-Sierra, 1988). None of these studies, however, described the hydrogeologic framework of the lower part of the aquifer system in detail.

Method of Study

The geologic and hydrogeologic framework of Puerto Rico's North Coast Limestone belt is based largely on core and hydrologic data collected from 15 deep test wells, mostly drilled to depths exceeding 1,500 ft (fig. 2 and table 1), and on lithologic as well as hydrologic data from three other existing wells. These deep test wells were drilled as part of a cooperative Commonwealth of Puerto Rico-USGS investigation to evaluate the water-resources potential and to map the extent of an artesian limestone aquifer of northern Puerto Rico. Cores were collected using a reverse-air dual tube drilling method that can be used to collect continuous core samples of 10-cm diameter. Limestone core samples considered

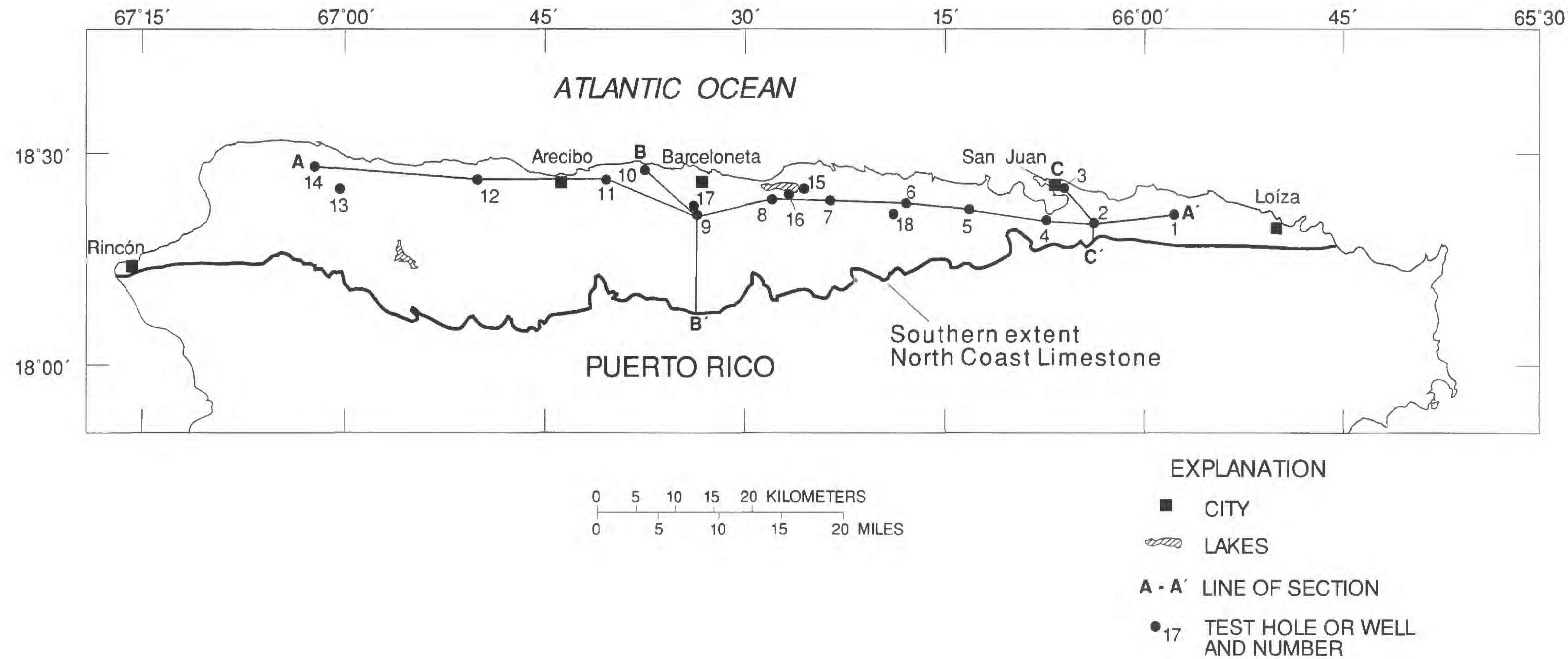

Figure 2. Location of test wells, test holes, and lines of section within the extent of the North Coast Limestone of Puerto Rico (the location and description of the test holes and wells are shown in table 1).

Table 1. Location and description of test holes, test wells, and supply wells in the study area used in this report
[--, indicates no data available; °, degrees; ', minutes; ", seconds]

Test well or hole number in figure 2	Location in figure 1	Local well or hole designation	Latitude	Longitude	Casing depth below land surface (feet)	Total depth below land surface (feet)
1	Loíza	NC-12	18°26'44"	65°55'31"	--	1,450
2	Río Piedras	NC-3	18°24'32"	66°02'33"	--	375
3	Santurce	NC-15	18°26'37"	66°04'22"	--	1,268
4	Guaynabo	NC-1	18°25'33"	66°06'45"	--	635
5	Toa Baja	NC-13	18°26'30"	66°12'23"	--	1,506
6	Dorado	NC-2	18°27'01"	66°18'22"	--	2,128
7	Vega Baja	NC-9	18°27'35"	66°23'43"	--	1,725
8	Interaquifer System (Manatí)	[1]IAS-1	18°27'32"	66°28'13"	--	2,700
9	Cruce Dávila (Barceloneta)	[2]NC-5	18°25'38"	66°34'12"	1,750	2,564
10	Islote, Arecibo	[3]CPR-4	18°29'29"	66°36'13"	--	6,934
11	Santana, Arecibo	--	18°27'01"	66°38'58"	--	1,520
12	Hatillo	NC-6	18°27'57"	66°49'26"	--	2,574
13	Isabela	NC-7	18°28'05"	67°02'58"	--	760
14	Isabela	NC-11	18°29'19"	67°03'13"	--	2,120
15	Manatí	NC-14	18°27'43"	66°25'22"	--	1,898
16	Manatí	NC-4	18°26'33"	66°26'26"	--	1,837
17	Barceloneta	NC-10	18°26'05"	66°34'44"	--	1,516
18	Vega Alta	NC-8	18°25'18"	66°19'43"	--	1,736

[1] Test hole drilled as part of the Interaquifer Project (C. Conde, U.S. Geological Survey, written commun., 1990).

[2] Test well drilled as part of the North Coast Limestone study and used as an observation well completed in the lower confined aquifer.

[3] Oil test well.

representative of a certain bed, or sequence of beds, were selected, slabbed and thin sectioned for study at the University of New Orleans. Analyses included the study of carbonate rock texture, porosity, fossil content, bedding, and identification of other possible depositional and diagenetic features.

The geologic framework for major rock units that lie buried in the subsurface (Ward and others, 1991) serves as the physical basis for the hydrogeologic framework described in this report. Major hydrogeologic units of the North Coast Limestone aquifer system were separated on the basis of relative permeability and hydraulic continuity. Field data from these 18 test wells and existing wells were used to compile maps that show the distribution of transmissivity within major aquifers and the position of the freshwater-saltwater interface. These data also were used to prepare hydrogeologic sections that show the thickness of the freshwater lens contained within the upper aquifer.

A chloride concentration of 500 milligrams per liter (mg/L) was used to delineate the boundary between the saltwater and freshwater zones of the upper aquifer. This concentration represents slightly saline water. Because of the absence of data on chloride concentrations in certain areas of the north coast, both surface resistivity and borehole geophysical data obtained from the test holes drilled for this study and from existing wells were also used in the delineation of the saltwater zone. The mixing zone of freshwater and saltwater where chloride concentrations exceed 500 mg/L is considered part of the saltwater zone in this report.

GEOLOGIC SETTING

The stratigraphic nomenclature of the middle Tertiary age sequence of rocks of the North Coast Limestone belt used in earlier USGS reports is that proposed by Monroe (1980). In a more recent study, Seiglie and Moussa (1984) proposed a somewhat different stratigraphic nomenclature that is based on paleontologic and lithologic data collected from two water wells in the Manatí area of north central Puerto Rico (fig. 3). However, the nomenclature of Monroe (1980) is largely used in this report because it is based on stratigraphic observations made along the entire north coast of Puerto Rico. One exception is reference to the mudstone unit of Seiglie and Moussa (1984) that occurs only in the subsurface.

A thick sequence of platform carbonates and minor clastics ranging in age from middle Oligocene to Miocene, constitute the sequence of middle Tertiary age rocks of the North Coast Limestone belt (fig. 4). These rock units make up a homoclinal sequence that dips gently northward (Monroe, 1980; Meyerhoff and others, 1983) at an average dip of three to four degrees; the dip ranges from two degrees near the coast to six or seven degrees where these rocks lie in contact with the volcanic core of Puerto Rico (Monroe, 1980). Local faulting and fracturing may be responsible for the apparent alignment of geomorphic features of the province, such as limestone hills (mogotes), sinkholes, and straight rivers segments (Meyerhoff and others, 1983).

The sequence of formations of late-middle Tertiary age of the North Coast Limestone is the product of several minor and major regressions and transgressions of the sea that occurred between Oligocene and Miocene time (Seiglie and Moussa, 1984). A variety of depositional environments are represented in the late Tertiary age sequence: fluvial, coastal marginal marine, and open-marine conditions (Seiglie and Moussa, 1984). Fore-reef and outer-shelf environments, indicative of deep-water conditions, are only locally represented (Seiglie and Moussa, 1984; Hartley, 1989; Scharlach, 1990).

A generalized east-west geologic section showing the major rock units of the north coast province is shown in figure 5. In ascending order these units are: the San Sebastián Formation, the Lares Limestone, the Mucarabones Sand, the Cibao Formation, the Aguada Limestone, the Aymamón Limestone, and the Camuy Limestone. The San Sebastián Formation consists of coastal and fluvial clastics, marginal marine clay, and inner platform limestone. The Lares Limestone consists of mid-platform, and minor inner- and outer-platform carbonate rocks. The Mucarabones Sand, which is in part chronostratigraphically equivalent to the Lares Limestone and the lower part of the Cibao Formation, consists of marginal marine quartz sand and minor fluvial clastics. The Cibao Formation is separated into the Montebello Limestone Member, an unnamed mudstone unit of Seiglie and Moussa (1984) and an unnamed upper part. The Montebello Limestone Member, the Río Indio Limestone Member, and the Quebrada Arenas Limestone Member consists of mid-platform limestones. The Río Indio Limestone and the Quebrada Arenas Limestone Members are made-up of inner and mid-platform carbonates containing terrigenous material. The mudstone unit consists of deep-water claystone and marl, and the uppermost part of the Cibao Formation consists of claystone, marl, and limestone containing terrigenous material. The Aguada Limestone is composed of inner- to middle-platform carbonates. The Aymamón Limestone is a mid-platform coral-rich limestone; and the Camuy Formation, the youngest unit, is mostly an inner platform chalk but locally includes minor terrigenous material.

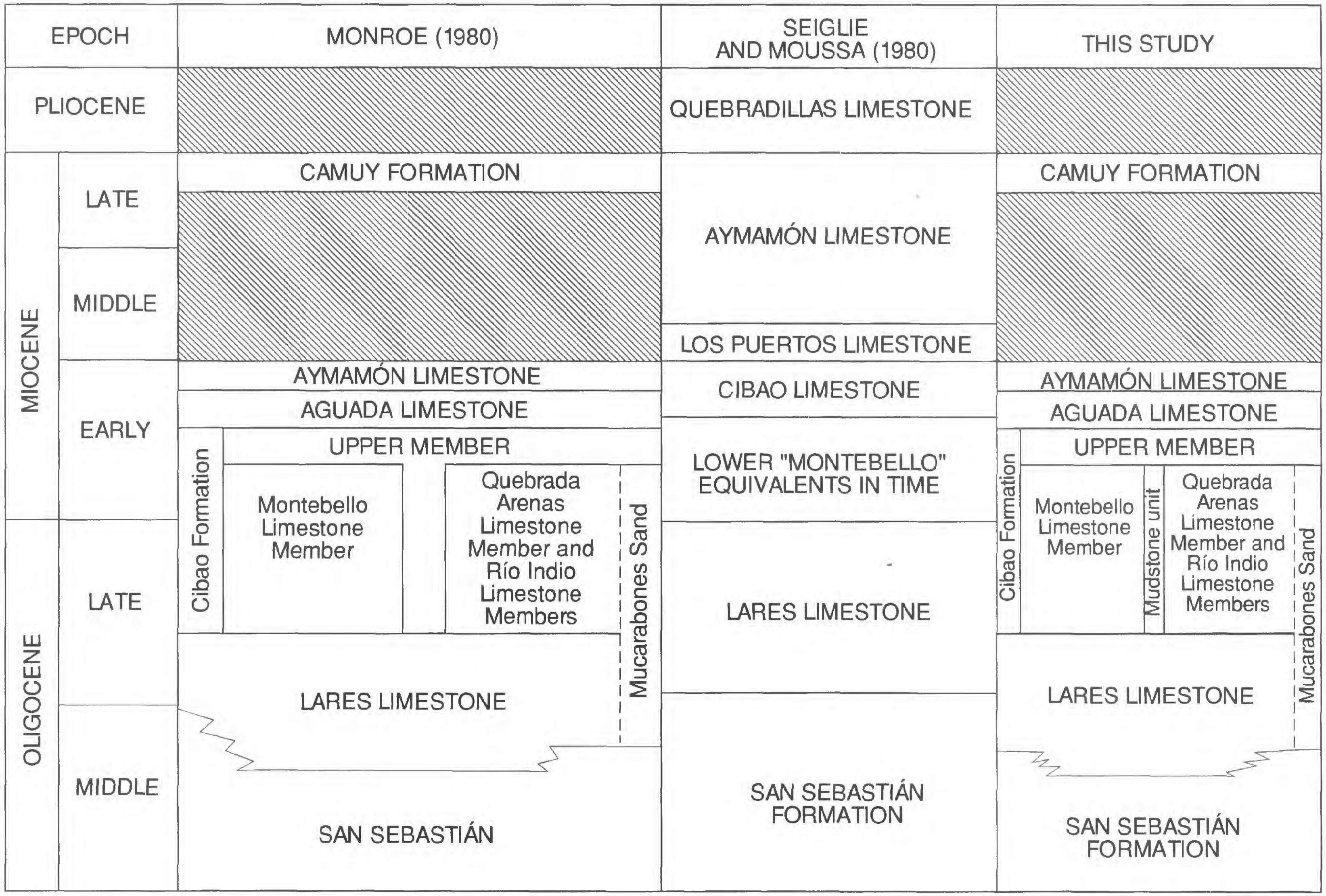

Figure 3. Stratigraphic nomenclature sequence of middle Tertiary age of the North Coast Limestone of Puerto Rico.

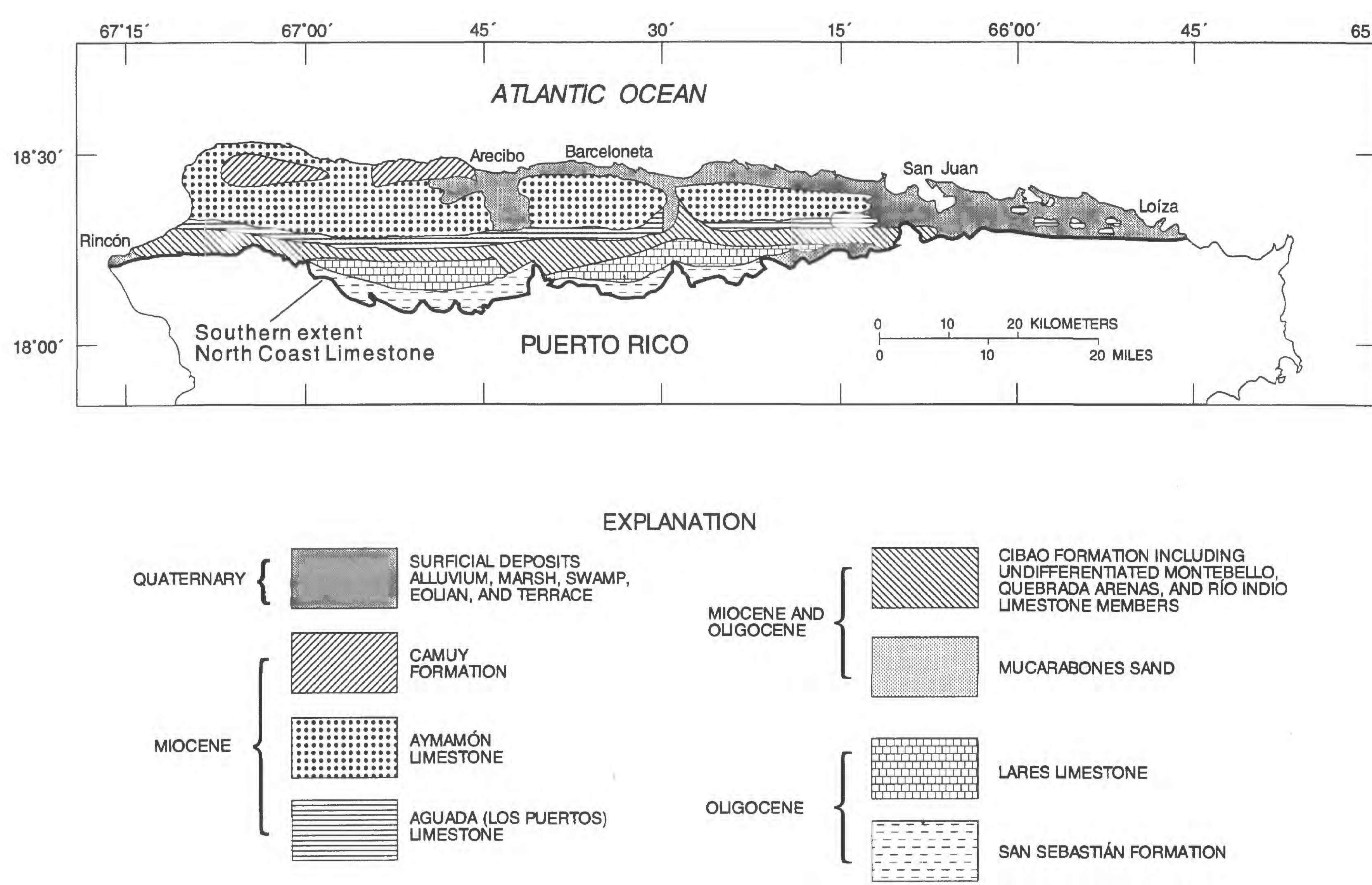

Figure 4. Generalized geologic map of the North Coast Limestone belt of Puerto Rico (modified from Monroe, 1980).

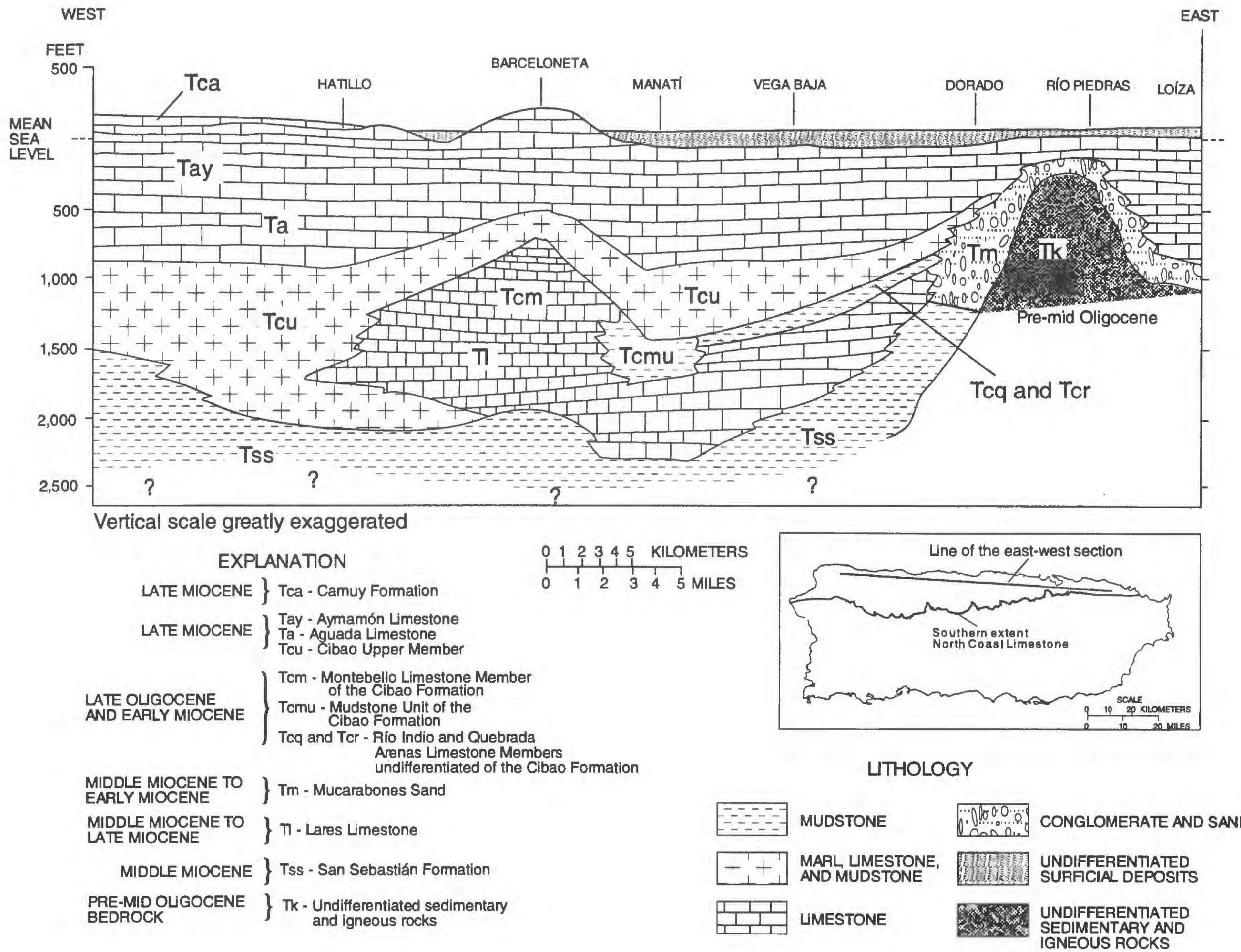

Figure 5. Generalized east-west geologic section sequence of middle Tertiary age of the North Coast Limestone belt of Puerto Rico.

Underlying basement rocks consist of Late Cretaceous and early Tertiary volcaniclastics (siltstone, sandstone, breccia, and conglomerate), minor limestone and minor amounts of igneous intrusive rocks (Monroe, 1980; Meyerhoff and others, 1983). Geophysical and geological evidence indicate that a number of structural highs have compartmentalized the middle Tertiary basin into a series of sub-basins (Meyerhoff and others, 1983; fig. 6). The vertical and lateral relations between the various sedimentary formations observed in the lower part sequence of middle Tertiary age; the San Sebastián Formation, the Lares Limestone, and the Cibao Formation seem to be controlled by the presence of these sub-basins (Meyerhoff and others, 1983; Hartley, 1989). The sedimentary facies of the Aguada (Los Puertos) and Aymamón Limestones and the Camuy Formation do not seem to be controlled by these sub-basins.

REGIONAL HYDROGEOLOGIC UNITS

The North Coast Limestone aquifer system is divided into three regional hydrogeologic units: an upper aquifer containing a basal saltwater zone in the coastal region, an intervening confining unit, and a lower aquifer. A local artesian zone also has been identified within the confining unit in some areas. The upper aquifer, which includes the freshwater part and the underlying saltwater zone near the coast, the confining unit, and the lower aquifer are discussed in the following sections.

Upper Aquifer

The upper aquifer mainly consists of the Aymamón Limestone and underlying Aguada (Los Puertos) Limestone, however, in some areas the upper aquifer also includes the uppermost permeable beds of the upper member of the Cibao Formation and overlying permeable surficial deposits (fig. 7). The upper aquifer contains water under unconfined conditions, except in coastal areas where it is locally confined by overlying silty and clayey surficial deposits. The upper aquifer contains a basal saltwater zone in much of the coastal areas of northern Puerto Rico (figs. 7 and 8).

The thickness of the upper aquifer along section A-A' (fig. 7) ranges from about 450 ft in the Arecibo and Barceloneta area to about 1,075 ft in the Isabela area to the west and about 925 ft near Manatí to the east. East of Vega Baja it decreases to about 650 ft in the Toa Baja area. The upper aquifer is absent in some parts of the Río Piedras area. In the San Juan metropolitan area, the upper aquifer where locally present, is thin and well yields are small. The Aymamón and the Aguada (Los Puertos) Limestones have been extensively eroded by karstification east of Toa Baja, and many of the thin erosional remnants have little hydrologic importance. In the area of Loíza, the upper aquifer is present as a continuous unit and has a thickness of about 750 ft.

The base of the upper aquifer is primarily defined by the uppermost strata of terrestrial clastics and argillaceous limestone of the upper member of the Cibao Formation. However, in the Hatillo-Isabela area the base of the upper aquifer seems to coincide with the lower boundary of the karstic zone located in the Aguada Limestone where this geologic unit is characterized by a significant decrease in porosity and increase in the clayey content of the rocks.

The freshwater zone on section A-A' of the upper aquifer is thickest in the area between the Río Grande de Arecibo and Río Grande de Manatí with a maximum thickness of about 500 ft (fig. 7). The freshwater part in the coastal zones of the San Juan metropolitan and Loíza areas is either absent or present with a thickness that does not exceed 30 ft. In the Guaynabo area, along section A-A', the upper aquifer is mostly brackish and saline. In north-south sections B-B' and C-C', the maximum thickness of the freshwater zone is greatest in the interstream areas of the southern extent of the freshwater-saltwater interface (figs. 8 and 9).

The freshwater zone of the upper aquifer is underlain by a basal zone of saltwater along the coast. The landward extent of this saltwater zone is not known for the entire north coast, but is about 6 mi in the Barceloneta area (fig. 8). In the Santurce-San Juan area, the landward extent could be about 3 mi (fig. 9). The position of the

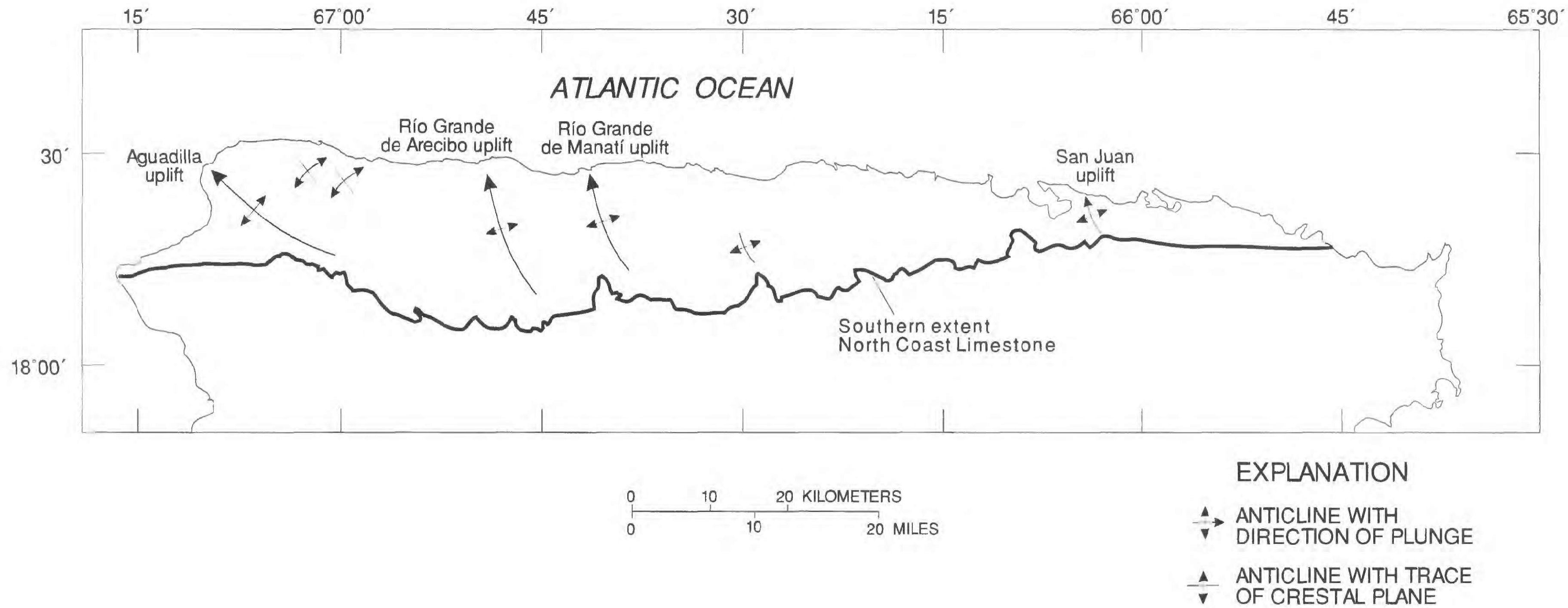

Figure 6. Major structural features of the North Coast Limestone belt of Puerto Rico (modified from Meyerhoff and others, 1983).

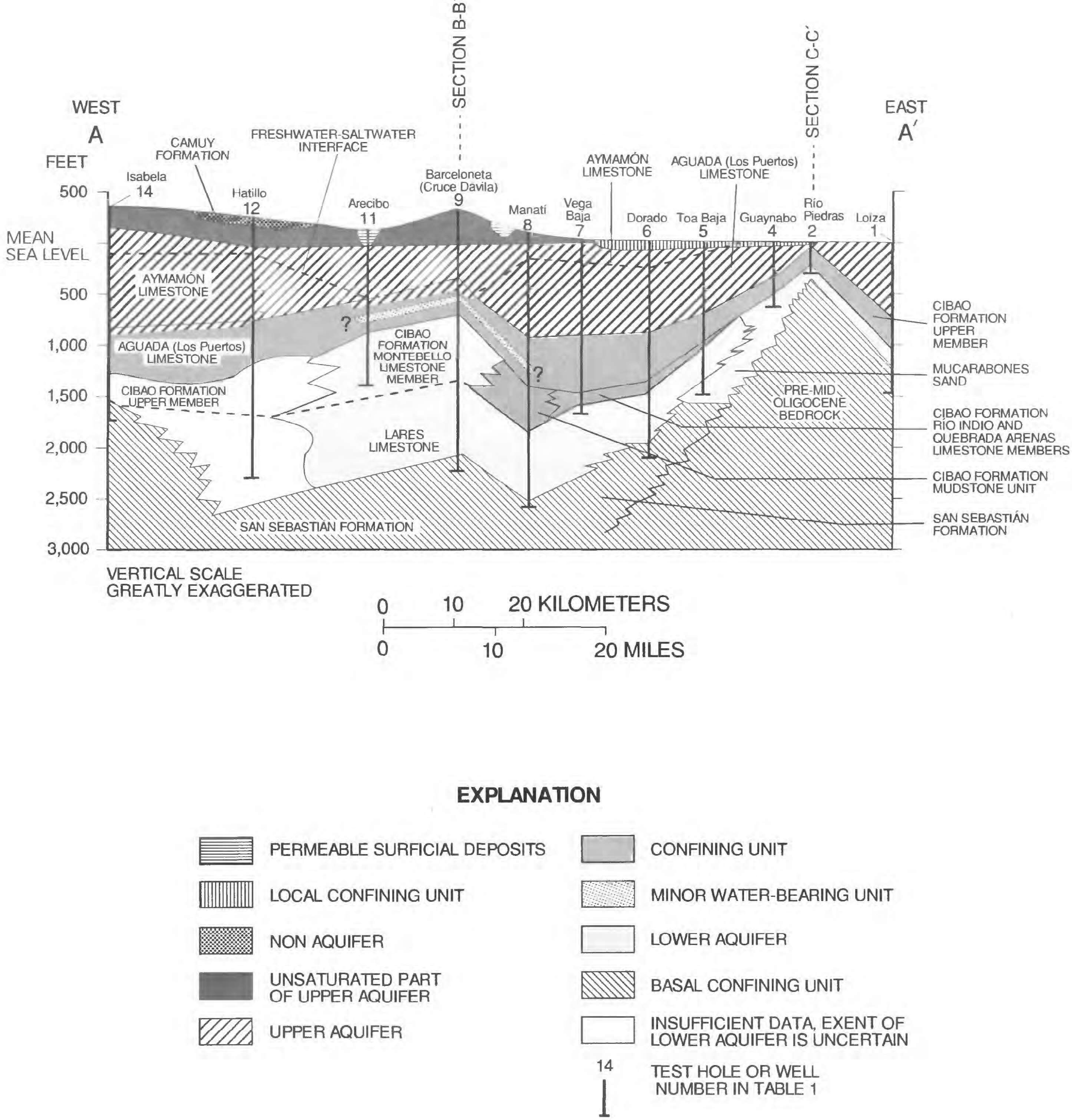

Figure 7. Hydrogeologic section A-A' (section line shown in figure 1).

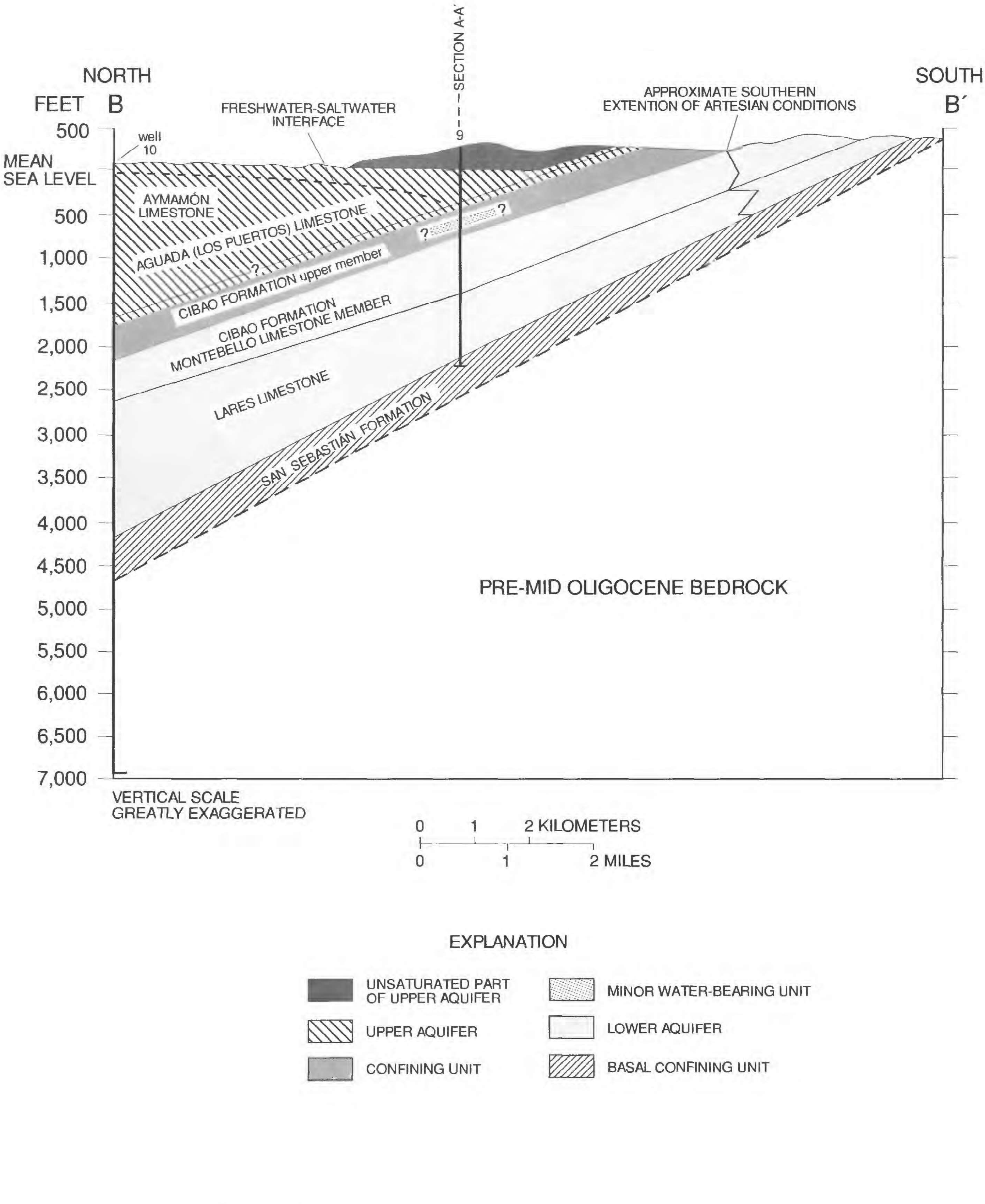

Figure 8. Hydrogeologic section B-B' (section line shown in figure 2).

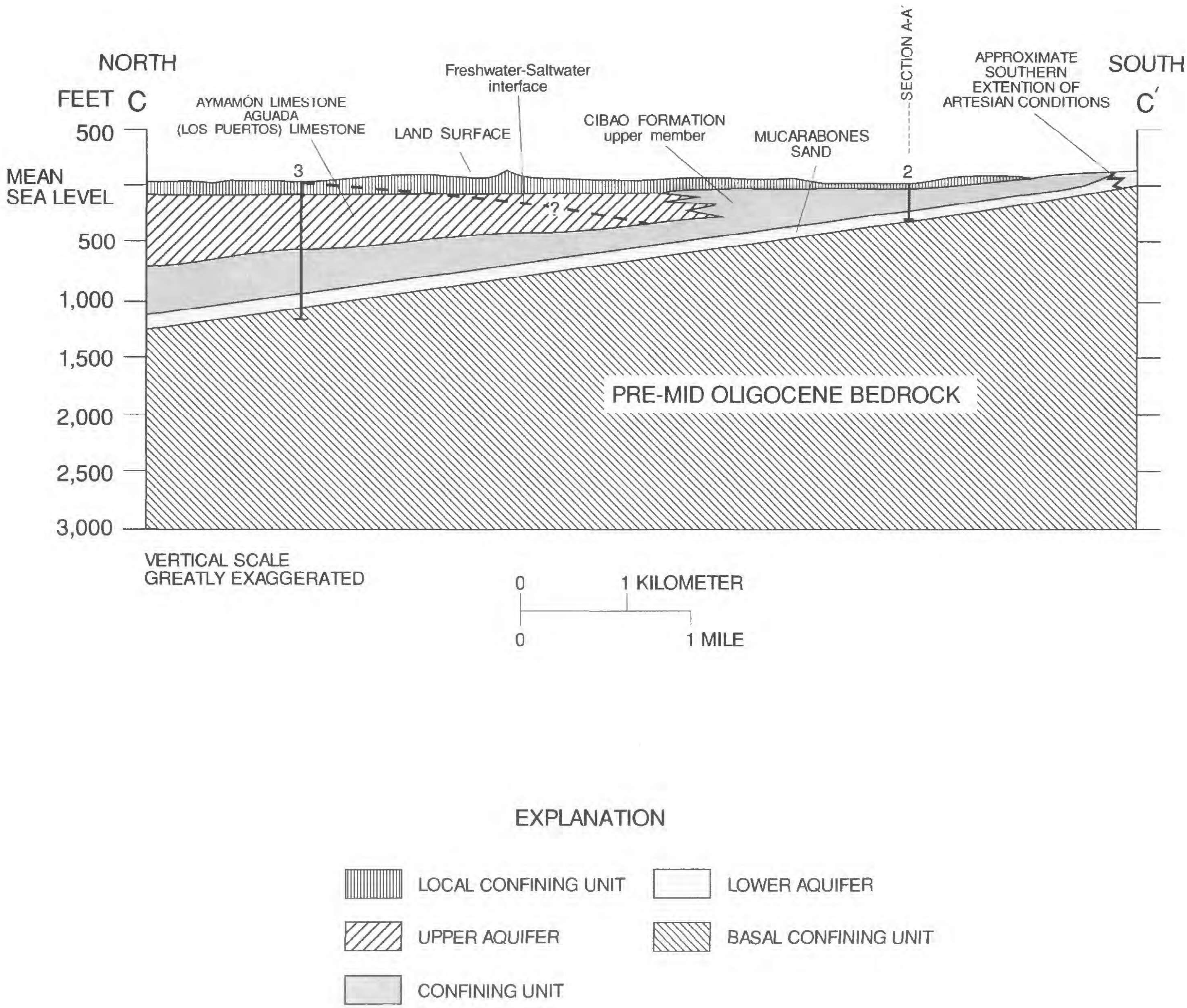

Figure 9. Hydrogeologic section C-C' (section line shown in figure 2).

freshwater-saltwater interface (fig. 10) is a function of the hydraulic properties of the aquifer, the effects of pumping, and large rivers that function as drains.

The most permeable of the geologic units that constitute the upper aquifer is the Aymamón Limestone (Giusti, 1978). The estimated hydraulic conductivity of this geologic unit ranges from 57 to 570 ft/day (Giusti, 1978). The hydraulic conductivity within the Aymamón Limestone generally diminishes with depth. The decrease in hydraulic conductivity is probably related to a maximum effective depth to which karstification will occur within the aquifer. Because hydraulic conductivity can vary with depth, use of site specific values of hydraulic conductivities to determine the transmissivity of the upper aquifer is not appropriate. Transmissivity values determined from aquifer tests or specific capacity data reflect the vertical variations in hydraulic conductivity and are used in this report to describe the regional transmissive properties of the freshwater zone of the upper aquifer. In some localities, site specific values of transmissivity may not be in good agreement with regional transmissivity, because locally transmissivity can reflect the irregular distribution of cavernous porosity.

The areal distribution of transmissivity in the freshwater zone of the upper aquifer is controlled, in part, by the depositional environment, diagenesis, and fractures in the Aymamón and Aguada (Los Puertos) Limestones. Another factor controlling transmissivity is the thickness of the freshwater lens.

Transmissivity estimates are available in most areas underlain by the freshwater zone of the upper aquifer. Estimates are sparse, however, for the areas east of the Río de La Plata and west of the Río Camuy. The transmissivity and hydraulic conductivity of the aquifer are not well documented for these areas. Available transmissivity estimates for the freshwater zone of the upper aquifer range from 200 to more than 280,000 ft^2/d (F. Gómez-Gómez and S. Torres-González, U.S. Geological Survey, written commun., 1990; fig. 11).

The maximum transmissivity of the freshwater zone of the upper aquifer (more than 280,000 ft^2/d) is in the area between the Río Grande de Arecibo and the Río de La Plata, where the transmissivity of this zone is reported to exceed 100,000 ft^2/d at six locations in this area. These high transmissivity values probably are the result of the cavernous porosity and enhanced dissolution along bedding planes, joints, and fractures. Also in this area the Aymamón Limestone is mostly a grainstone-packstone and coral boundstone and has as much as 25 percent total porosity (Hartley, 1989; Scharlach, 1990). Locally, the transmissivity of minor water-bearing units underlying the San Juan metropolitan area range from 200 ft^2/d (Rullán well) to 500 ft^2/d (Banco de Ponce well) (I. Padilla, U.S. Geological Survey, written commun., 1990).

Confining Unit

Although the upper member of the Cibao Formation is the principal rock-stratigraphic unit of the middle confining unit, the upper boundary of the confining unit does not always coincide with its top. For example, the uppermost part of the Cibao Formation is reef limestone (wackestone-packstone) in the Barceloneta and Arecibo areas (test wells 9 and 11, respectively). In these areas, the upper part of the upper member of the Cibao Formation is considered part of the upper aquifer (figs. 7 and 8).

The areal and vertical extent of the confining unit are well known in the Arecibo to Manatí area, but are less precisely known east and west of this area. The confining unit gradually thickens east of Barceloneta (fig. 7). Between Manatí (test well 8) and Vega Baja (test hole 7), the confining unit consists of the upper member of the Cibao Formation, the underlying Quebrada Arenas and Río Indio Limestone Members, and the mudstone unit. In this area, the confining unit ranges in thickness from 250 ft at test well 9 in Barceloneta to about 925 ft at test well 8 in Manatí. At test hole 6 near Dorado, the confining unit includes the Río Indio Limestone and the Quebrada Arenas Limestone Members and the upper member of the Cibao Formation and is about 600 ft thick. The confining unit is about 225 ft at test hole 2 near Río Piedras east of Dorado.

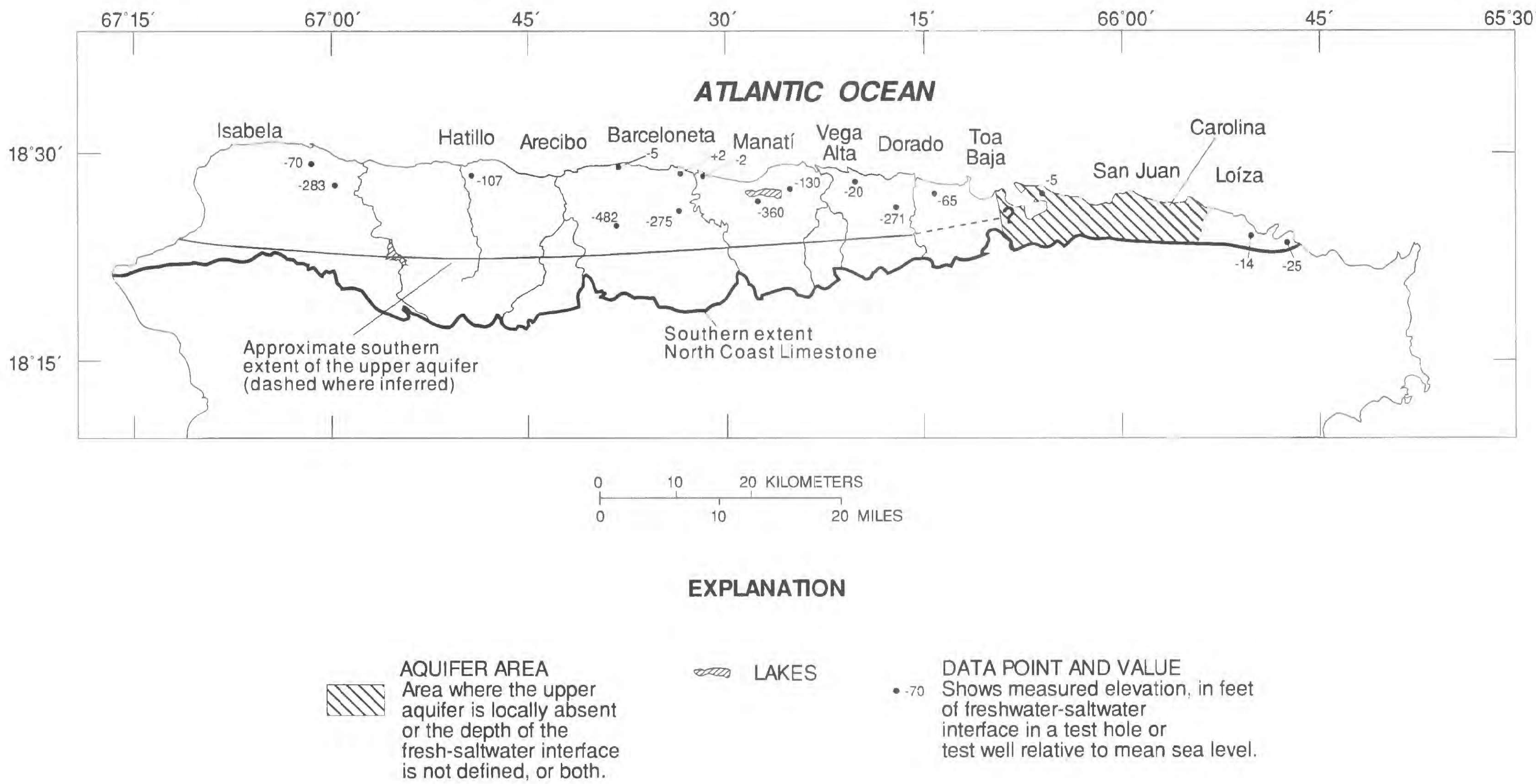

Figure 10. Elevation of the regional freshwater-saltwater interface in the upper aquifer.

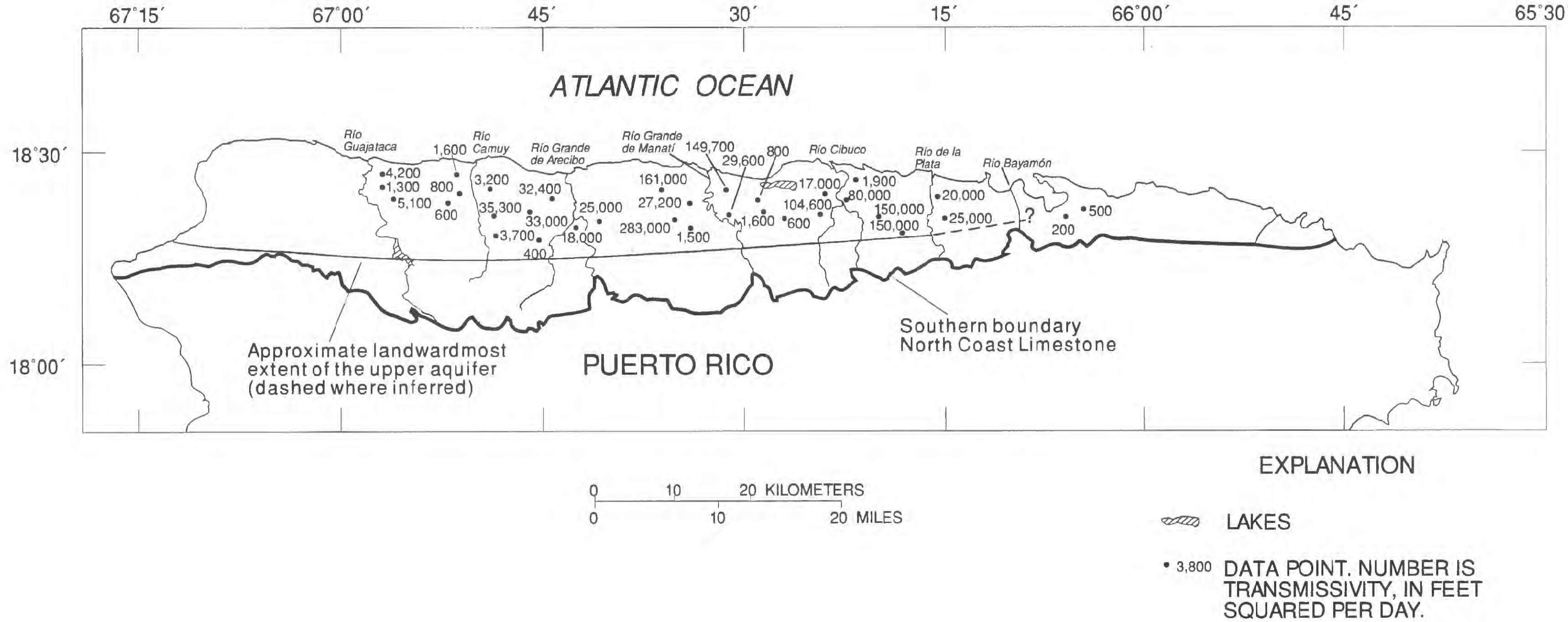

Figure 11. Estimates of transmissivity for the freshwater zone of the upper aquifer F. Gómez-Gómez, U.S. Geological Survey, written commun., 1992.

Hydrologic and lithologic data collected at test holes 3 and 4 indicate the probable leaky nature of the confining unit in the easternmost part of the North Coast Limestone aquifer system. In these test holes, the variations of specific conductance and water level (head) with depth, as well as the lithologic nonhomogeneity of the confining unit, indicate possible upward movement of water from the lower aquifer into the upper aquifer (Rodríguez-Martínez and others, 1991).

An artesian water-bearing zone of local extent exists within the confining unit near water well 11 in Arecibo, observation well 9, and test well 8 south of Manatí (fig. 7). This local water-bearing zone consists mostly of coral-bearing wackestones and packstones and is about 50-ft thick.

Lower Aquifer

The lower aquifer of the North Coast Limestone was first identified in 1968, when two disposal wells were drilled in the Cruce Dávila area of Barceloneta (Giusti, 1978). The aquifer contains water under artesian pressure throughout the area where it is overlain by the middle confining unit. Where the aquifer crops out, in the recharge areas near the southernmost outcrop belt of the mid-Tertiary sequence, however, the lower aquifer contains water under water-table conditions.

The lithology of the lower aquifer is most homogeneous in the area between Arecibo and Manatí. In that area, the aquifer consists of the Lares Limestone and the Montebello Limestone Member of the Cibao Formation (figs. 7 and 8). Core samples collected from observation well 9 indicate that the aquifer consists of skeletal wackestone-packstone and packstone-grainstone that were deposited in a carbonate middle platform environment. The Lares Limestone is generally much finer-grained than the Montebello Limestone Member of the Cibao Formation. The hydraulic conductivity of the lower aquifer, particularly the Montebello Limestone Member, is greater in the Arecibo to Manatí area than elsewhere in the study area. No hydraulic separation between the two limestone units was observed in the Arecibo to Manatí area.

West of Río Grande de Arecibo, the extent of the lower aquifer is uncertain. The terrigenous character of the Lares Limestone in the Hatillo and Isabela areas and the increased stratigraphic complexity of the Cibao Formation west of Arecibo, suggest that multiple confining and water-bearing strata of unknown areal and vertical extent exist in this area. Because only 3 out of the 18 test holes and wells used in this study were drilled west of Río Grande de Arecibo, it is not known if these water-bearing strata are an extension of the more productive lower aquifer in the Manatí to Arecibo area. Zones of moderate permeability are known to exist locally in the westernmost part of the mid-Tertiary age sequence within small lenses of volcanic conglomerates and sandstones of the San Sebastián Formation, but in general, this formation is not a good aquifer.

In the area between Manatí and Dorado, the lower aquifer is composed solely of the Lares Limestone (fig. 7). The Lares Limestone in this area is a moderately to highly terrigenous and mostly fine-grained wackestone-packstone, which is predominantly argillaceous at its base (Scharlach, 1990). The Montebello Limestone Member of the Cibao Formation grades by facies change to an age-equivalent calcareous mudstone, marl, and a highly argillaceous wackestone unit in the area between Manatí and Vega Baja. In this area, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation are more argillaceous and silty than in their outcrop areas, and consequently, are part of the confining unit (Scharlach, 1990). The Quebrada Arenas and the Río Indio Limestone Members are, in part, stratigraphically equivalent to the Montebello Limestone Member that exists to the west. East of Toa Baja, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation grade by facies change to the Mucarabones Sand. East of Toa Baja, the lower aquifer includes rocks that are part of the Mucarabones Sand (fig. 7). In this area, the Lares Limestone gradually thins and grades to the Mucarabones Sand, a calcareous marine sandstone with local lenses of volcanic conglomerate (Scharlach, 1990). The lower aquifer also includes permeable units in the upper part of the San Sebastián Formation, in and near the area where the San Sebastián Formation crops out.

In the area of San Juan and Guaynabo (test hole 4) and Río Piedras (test hole 2), the lower aquifer is composed mostly of the Mucarabones Sand (figs. 7 and 9). The Mucarabones Sand in this area consists of sandstone and gravel of terrestrial origin. In San Juan and to the east, the water in the lower aquifer is brackish in some areas.

Transmissivity estimates for the lower aquifer are available from only a few aquifer tests and specific capacity tests (fig. 12). In the Río Grande de Arecibo to Río Grande de Manatí area, the transmissivities of the Lares Limestone at two sites were 150 and 500 ft^2/d (fig. 12). Transmissivity values for the Lares Limestone in other areas range from 20 to 330 ft^2/d (fig. 12). Reported transmissivity values for the Mucarabones Sand, which is stratigraphically equivalent to the Lares Limestone in the San Juan metropolitan area, range from 850 to 1,000 ft^2/d (Anderson, 1976). The transmissivity of the Montebello Limestone Member is highest in the Río Grande de Arecibo to the Río Grande de Manatí area, where it ranges from 625 to 3,600 ft^2/d (fig. 12). West of the Río Grande de Arecibo, the reported transmissivity of the Montebello Limestone Member ranges from 370 to 680 ft^2/d. In this area, the unit becomes increasingly chalky and is similar in lithology to the upper member of the Cibao Formation.

SUMMARY

The hydrogeology of the North Coast Limestone aquifer system was studied by the U.S. Geological Survey in cooperation with the Commonwealth of Puerto Rico Department of Natural and Environmental Resources during 1983 to 1988. During this study, 15 deep test holes and wells were drilled into bedded carbonate and clastics deposits of middle Oligocene to Miocene age that underlie the north coast of Puerto Rico. Lithologic cores collected from these test holes and test wells were analyzed to describe the stratigraphic and hydrogeologic framework of the area. Data from three other existing water wells collected during previous studies also were used in the delineation of the regional hydrogeologic units.

An upper aquifer, a lower aquifer, and a middle confining unit constitute the hydrogeologic units of the North Coast Limestone aquifer system. The upper aquifer consists mainly of the Aymamón Limestone and the Aguada (Los Puertos) Limestone and locally includes part of the upper member of the underlying Cibao Formation and the overlying alluvium. This upper aquifer is present along much of the north coast of Puerto Rico, but is largely absent in the Río Piedras area. A saltwater zone underlies the freshwater zone of the upper aquifer in the coastal region. The upper aquifer contains water under water-table conditions, except in the coastal region where it is locally confined by overlying fine-grained material. The extent of the lower aquifer west of Arecibo is uncertain. It is not known if the existing multiple water-bearing units west of Arecibo are an extension of the more productive aquifer in the Arecibo to Manatí area.

The confining unit consists of the upper member, the Quebrada Arenas Limestone and the Río Indio Limestone Members of the Cibao Formation, and the mudstone unit. The confining unit generally consists of low permeability rocks; however, in an area that extends from Manatí to Arecibo it locally contains a water-bearing zone that is under artesian conditions. Data from test holes 3 and 4 indicate that the confining unit possibly is leaky in the San Juan metropolitan area and that water from the lower aquifer is moving into the upper aquifer in that area.

The lower aquifer is composed of the Lares Limestone, the Montebello Limestone Member of the Cibao Formation, and the outcrop areas and shallow facies of the San Sebastián Formation. The lower aquifer is thickest and most transmissive in the north-central part of the study area. West of the Río Grande de Arecibo, the extent of the lower aquifer is not known. Multiple water-bearing units and intervening confining units of limited extent exist in the Hatillo to Isabela area but it is not known if these water-bearing units are extensions of the lower artesian aquifer in the Manatí to

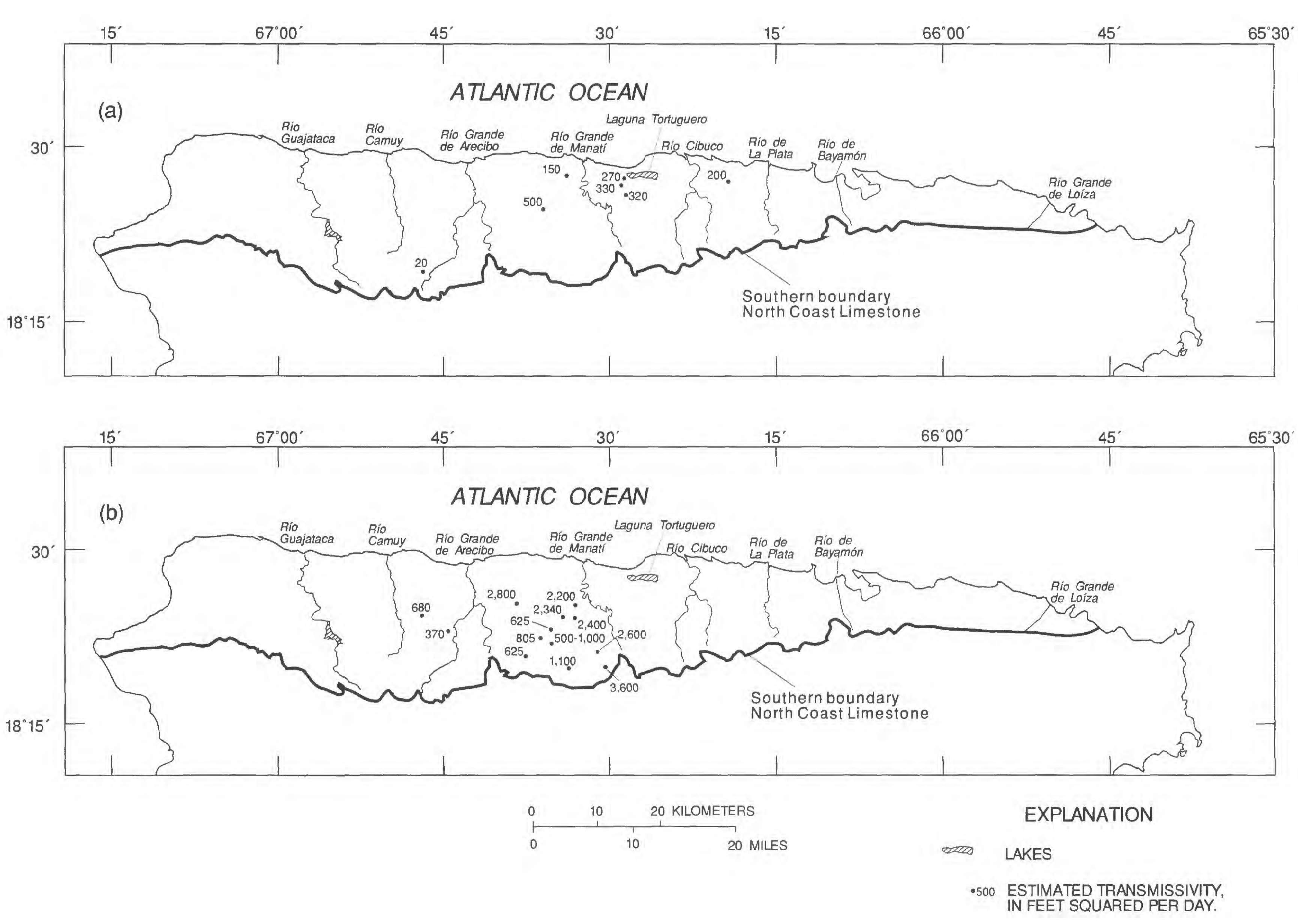

Figure 12. Estimated transmissivity for the lower aquifer in the North Coast Limestone aquifer system of Puerto Rico: (a) the Lares Limestone and (b) the Montebello Limestone Member of the Cibao Formation (F. Gómez-Gómez, U.S. Geological Survey, written commun., 1991).

Arecibo area. In an area that extends from Manatí to Dorado, the lower aquifer is composed of rocks that are part of the Lares Limestone. In the area of Toa Baja and further east, the limestone rocks that make up the lower aquifer grade by facies change to the more terrigenous Mucarabones Sand. East of Toa Baja the lower aquifer consists of the Mucarabones and contains water that ranges from fresh to brackish.

The transmissivity values for the freshwater zone of the upper aquifer are highest in the Río Grande de Arecibo to the Río de La Plata area. Transmissivities values for the upper aquifer exceed 100,000 ft^2/d in six locations in this area and have been reported to exceed 280,000 ft^2/d at one site near Barceloneta. Locally, the transmissivity values of minor water-bearing units within the upper aquifer underlying the San Juan metropolitan area range from 200 to 500 ft^2/d. In the lower aquifer, the Lares Limestone has transmissivity values of 150 and 500 ft^2/d at two sites in the Río Grande de Arecibo to the Río Grande de Manatí area. In other areas the transmissivity values for the Lares Limestone range from 20 to 330 ft^2/d. The estimated transmissivity of the Mucarabones Sand in the San Juan metropolitan area ranges from 850 to 1,000 ft^2/d. The transmissivity values of the Montebello Limestone Member of the Cibao Formation are highest in the Río Grande de Arecibo to Río Grande de Manatí area and range from 625 to 3,600 ft^2/d. West of the Río Grande de Arecibo transmissivity data for the Montebello Limestone Member are sparse, but values at two sites were 370 and 680 ft^2/d.

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United States Department of Agriculture

NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

San Juan Area, Puerto Rico

October 3, 2019

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

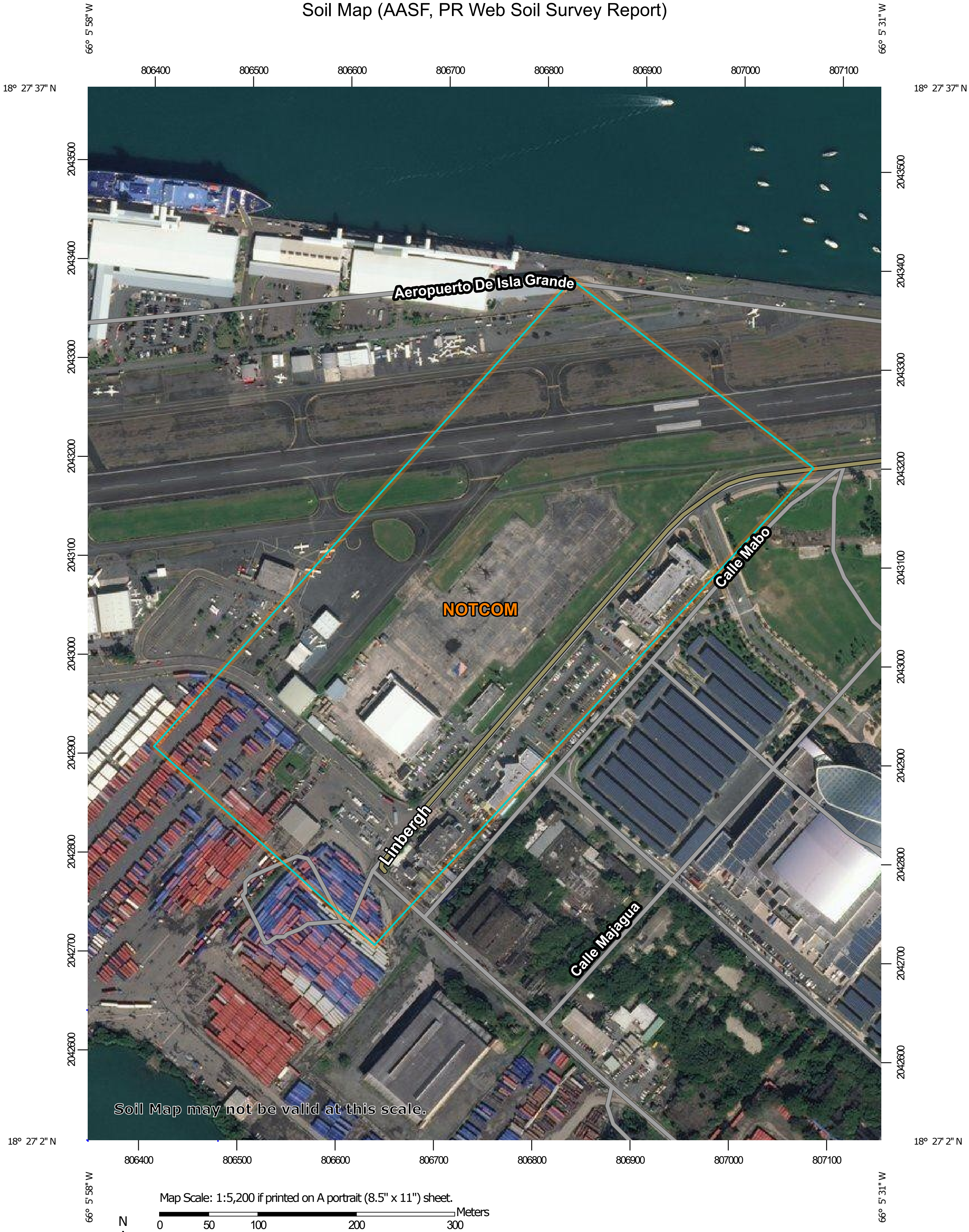
Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

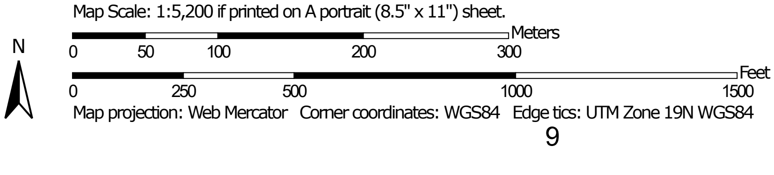
Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map (AASF, PR Web Soil Survey Report)



Map Scale: 1:5,200 if printed on A portrait (8.5" x 11") sheet.



Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 19N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: San Juan Area, Puerto Rico
Survey Area Data: Version 13, Sep 16, 2019

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Feb 22, 2004—Apr 27, 2016

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend (AASF, PR Web Soil Survey Report)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
NOTCOM	No Digital Data Available	48.9	100.0%
Totals for Area of Interest		**48.9**	**100.0%**

Map Unit Descriptions (AASF, PR Web Soil Survey Report)

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

San Juan Area, Puerto Rico

NOTCOM—No Digital Data Available

Map Unit Composition

Notcom: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Notcom

Properties and qualities

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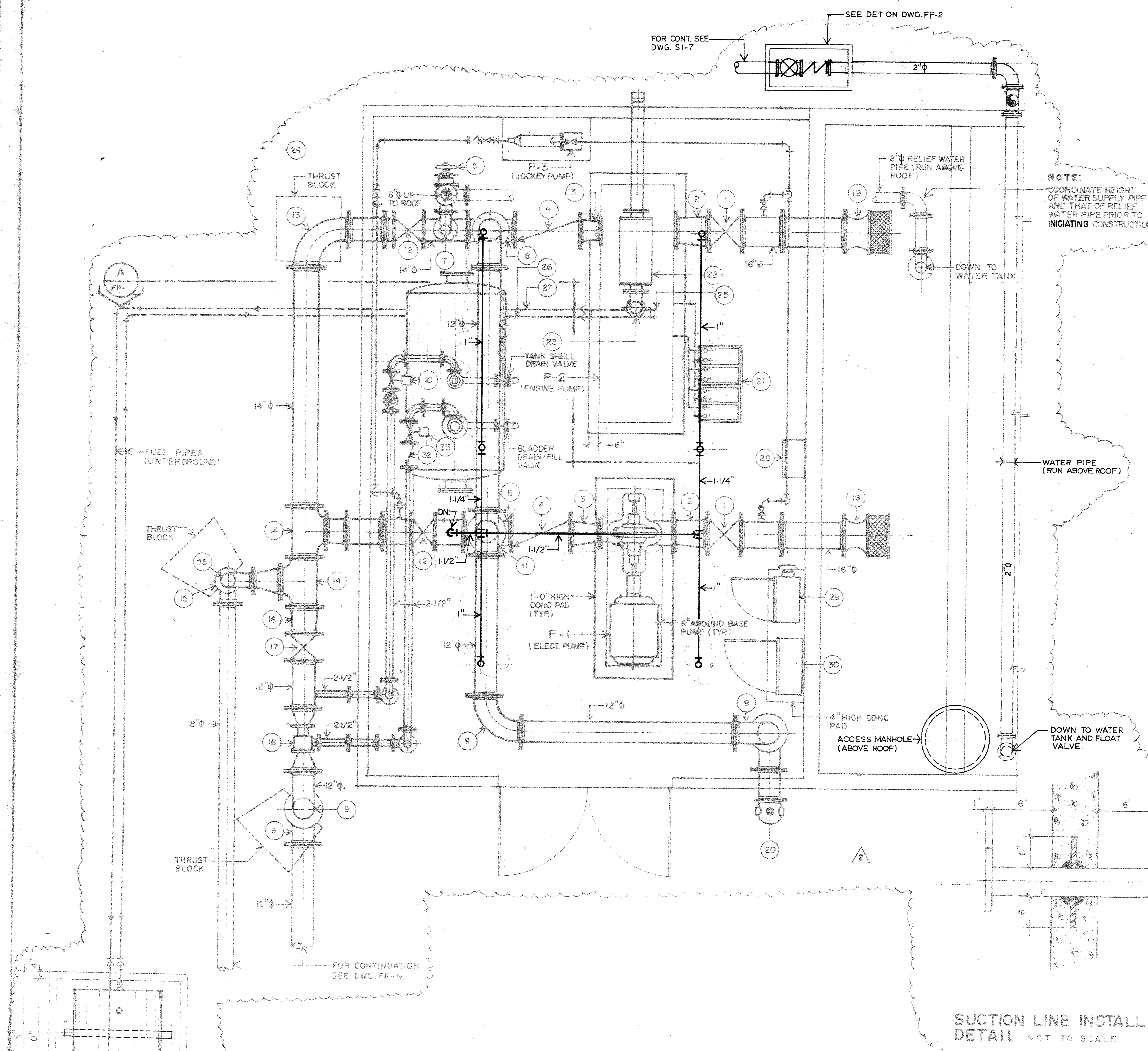
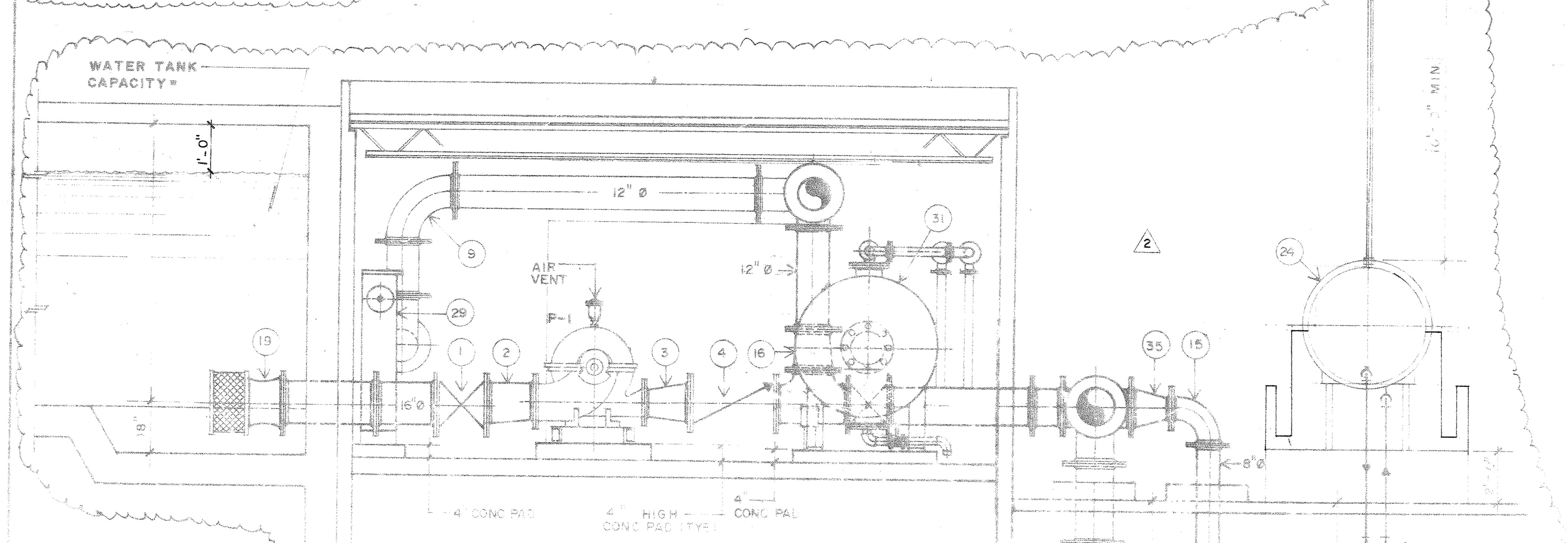


FIRE PUMP - HOUSE PLAN
SCALE: 3/8" = 1' - 0"



SECTION (A / FP-3)

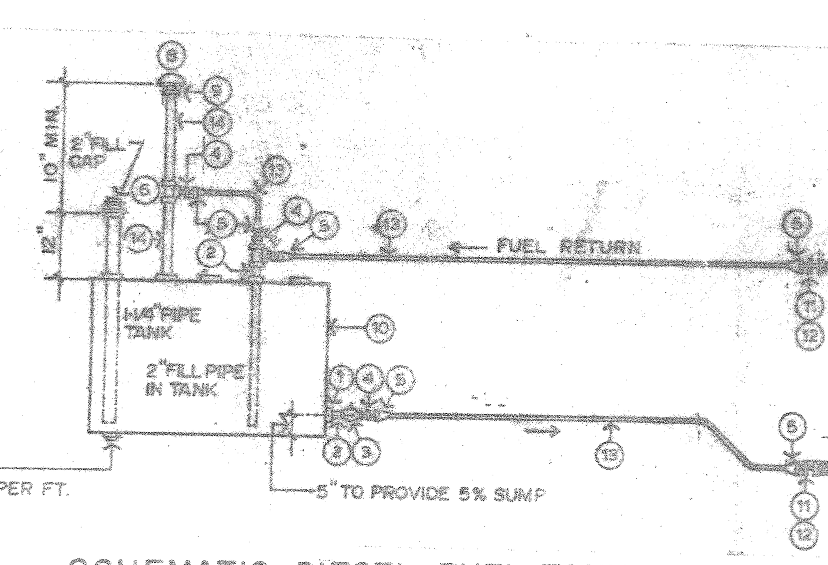
LEGEND: (2)

MKD.	DESCRIPTION
1	16" O.S. & Y. GATE VALVES
2	16" x 14" ECCENTRIC REDUCER
3	14" x 10" CONCENTRIC REDUCER
4	14" CHECK VALVE
5	8" RELIEF VALVE
6	14" x 14" x 8" RELIEF VALVE TEE
7	8" RELIEF VALVE ELBOW
8	14" x 14" x 12" TEE
9	12" LONG RADIUS ELBOW
10	AUTOMATED CONTROL VALVE
11	12" x 12" x 12" TEE
12	14" O.S. & Y. GATE VALVE
13	14" LONG RADIUS ELBOW
14	14" x 14" x 14" TEE
15	8" LONG RADIUS ELBOW
16	14" x 12" CONCENTRIC REDUCER
17	12" O.S. & Y. GATE VALVE
18	6" x 6" PROPORTIONER
19	FOOT VALVE
20	12" HOSE VALVE HEADER
21	BATTERY W/ RACKS
22	MUFFLER — OUTSIDE VENT
23	FLEXIBLE EXHAUST
24	DIESEL FUEL TANK (ABOVE GROUND) PAD MOUNTED (500 GALS. MIN.)
25	ENGINE FUEL CONNECTION
26	ENGINE FUEL INLET
27	ENGINE FUEL RETURN
28	JOCKEY PUMP CONTROLLER
29	ENGINE CONTROLLER
30	ELECT. PUMP CONTROLLER
31	HORIZONTAL BLADDER TANK
32	2 1/2" CHECK VALVE
33	AUTOMATED CONCENTRATE CONTROL VALVE (2 1/2")
34	PIPE STAND SUPPORT
35	14" x 8" CONCENTRIC REDUCER
36	AUTOMATED CONTROL VALVE

PERFORMANCE OF WATER PUMPS

PUMP DESIGNATION	CAPACITY G.P.M.	TOTAL HEAD (FT.) H_2O	EFFICIENCY (% MIN.)	SPEED MAX. R.P.M.	MOTOR H.P.	ELECTRICAL CHARACTERISTICS	USE	PUMP SELECTED
P-1	4000	289	65	1750	400	460V-3Ø-60 CY	FIRE	ALLIS CHALMERS 14"x10 x 20F WITH 3406 TA ENGINE
2								
P-3 (JOCKEY PUMP)	875	—	—	3550	1			ALLIS CHALMERS SERIES H4 MODEL NO. 1H4818

(2)

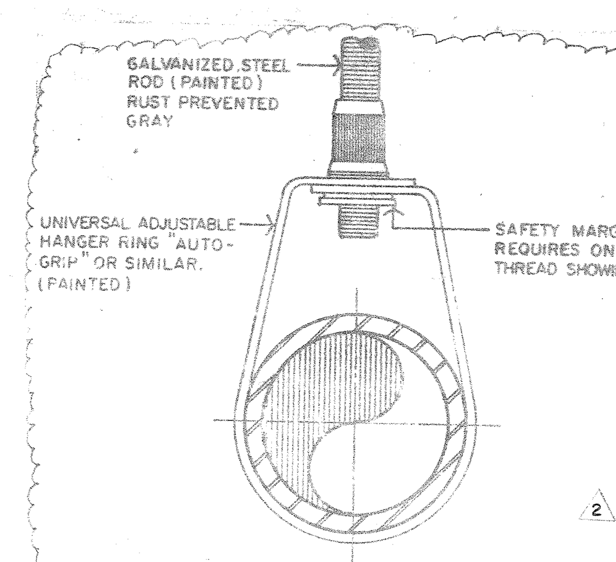


SCHEMATIC DIESEL FUEL TANK
NOT TO SCALE

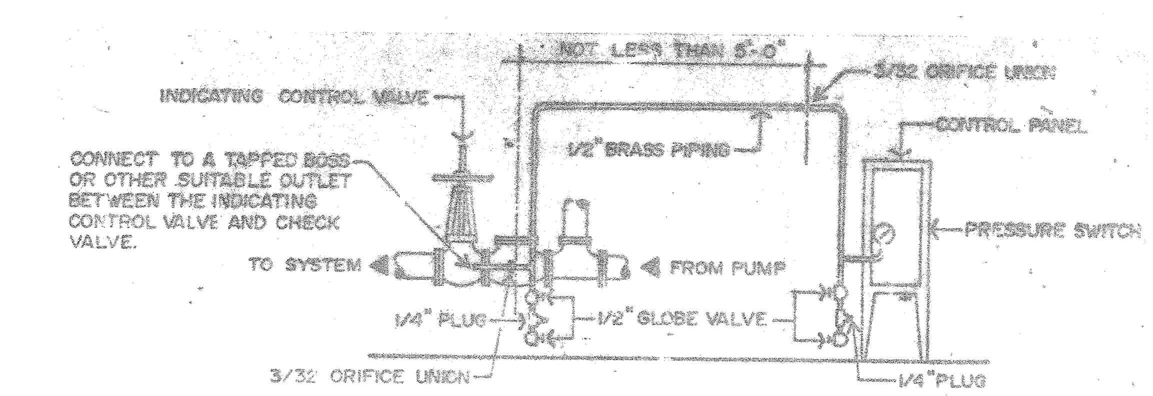
LEGEND:

MKD.	QTY.	DESCRIPTION
1	1	1-1/4" x 1/2" REDUCING COUPLING
2	2	1/2" CLOSE NIPPLE
3	1	1/2" LOCK COCK
4	4	3/8" TUBE x 1/2" PIPE THRD. CONNECTOR
5	6	3/8" TUBE NUT
6	1	1-1/4" x 1-1/4" x 1/2" PIPE TEE
7	1	1/2" PIPE TEE
8	1	2" FLAME ARRESTOR
9	1	2" x 1-1/4" BUSHING
10	1	FUEL TANK
11	2	3/8" TUBE x 1/4" PIPE THRD. CONNECTOR
12	2	3/8" TUBE x 3/8" PIPE THRD. CONNECTOR
13		
14		

SUCTION LINE INSTALLATION DETAIL NOT TO SCALE



HANGER RING DETAIL
NOT TO SCALE



SCHEMATIC SENSING LINE
NOT TO SCALE

(1) ADDENDUM NO. 3
18. ON DWG. FP-3:

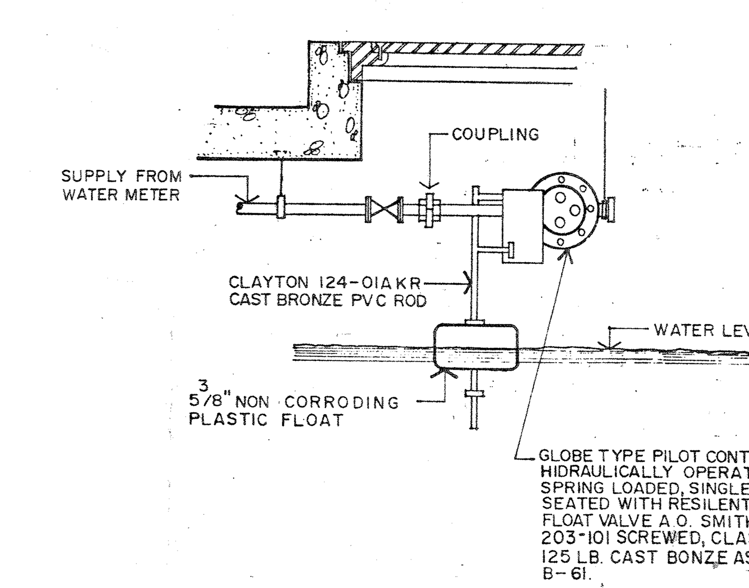
a. On the pump house plan items identified as P-1 include the electrical motor (125 horse power and pump item (4) of legend and P-2 includes diesel motor and pump (item 4) of legend.

b. On the LEGEND (Item Mk'd (4) shall read:

"Fire Pump rated 1000 G.P.M. @ 125 psi fairbanks morse model 12M-7000F".

c. On Table "Performance of Water Pumps" pump P-1 and P-2 on pump selected shall read:

"Fairbanks & Morse Model 12M-7000F".



FLOAT VALVE INSTALLATION DETAIL NOT TO SCALE

FIRE PUMP, SECTION AND DETAILS

JAIME ZENO & ASSOCIATES

NO.	DATE	BY	REVISIONS DESCRIPTION
1	28/AUG/90		ADD. NUM. 3: PUMP ITEMS REVISED.
2	15/JUN/90		FIRE PUMP HOUSE

ARMY AVIATION SUPPORT FACILITY
ISLA GRANDE — PUERTO RICO

DESIGNED BY / DRAWN BY / CHECKED BY / DATE

BASORA & RODRIGUEZ
ARCHITECTS-PLANNERS

47 FP
66 3

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

1.1. Identification of the preparation

Product Name:	"SILV-EX Foam Concentrate"
Chemical Name:	N/A – This is a mixture/preparation.
CAS No.:	N/A – This is a mixture/preparation.
Chemical Formula:	N/A – This is a mixture/preparation.
EINECS Number:	N/A – This is a mixture/preparation.

1.2. Use of the preparation

The intended or recommended use of this preparation is as a FIRE EXTINGUISHING AGENT.

1.3. Company identification

Manufacturer/Supplier:	ANSUL INCORPORATED
Address:	One Stanton Street, Marinette, WI 54143-2542
Prepared by:	Safety and Health Department
Phone:	715-735-7411
Internet/Home Page:	http://www.ansul.com
Date of Issue:	September, 2003

1.4. Emergency telephone

CHEMTREC 800-424-9300 or 703-527-3887

2. COMPOSITION/INFORMATION ON INGREDIENTS

2.1.

Ingredient Name:	Proprietary mixture consisting of sodium and ammonium salts of fatty alcohol ether sulfates (C8-C18), higher alcohols, and water. Not otherwise specified.
Chemical Formula:	N/A – This is a mixture/preparation.
CAS No.:	N/A – This is a mixture/preparation.
EINECS Number:	N/A – This is a mixture/preparation.
Concentration, Wt %:	>70 %.
Hazard Identification:	See Heading 3.
Ingredient Name:	Diethylene Glycol Monobutyl Ether (a).
Chemical Formula:	$C_4H_9O(CH_2CH_2O)_2H$.
CAS No.:	112-34-5.
EINECS Number:	203-961-6.
Concentration, Wt %:	18 %.
Hazard Identification:	See Heading 3.
Ingredient Name:	Ethanol (Ethyl Alcohol).
Chemical Formula:	CH_3CH_2OH.
CAS No.:	64-17-5.
EINECS Number:	200-578-6
Concentration, Wt %:	8 %.
Hazard Identification:	See Heading 3.

(a) This chemical is subject to reporting requirements of SARA Title III Section 313 and 40 CFR Section 372.

3. HAZARDS IDENTIFICATION

FOR HUMANS:

Product:

EU Classification:		Irritant – Xi; Flammable – F.
R Phrases:	11	Highly flammable.
	36	Irritating to eyes.
S Phrases	2	Keep out of the reach of children.
	7	Keep container tightly closed.
	16	Keep away from sources of ignition – No smoking.
	24	Avoid contact with skin.
	26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

Components:

Diethylene Glycol Monobutyl Ether:

EU Classification:		Irritant – Xi.
R Phrases:	36	Irritating to eyes.
S Phrases:	2	Keep out of the reach of children.
	24	Avoid contact with skin.
	26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

Ethanol (Ethyl Alcohol):

EU Classification:		Flammable – F.
R Phrases:	11	Highly flammable.
S Phrases:	2	Keep out of the reach of children.
	7	Keep container tightly closed.
	16	Keep away from sources of ignition – No smoking.

Limit Values for Exposure:

Diethylene Glycol Monobutyl Ether:

OSHA PEL (General Industry) 8 hour TWA:	None established.
MAK (DE) Limit value:	100 mg/m^3.
Short term exposure limit value (8 times, 5 minutes):	200 mg/m^3.

Ethanol (Ethyl Alcohol):

ACGIH TLV-TWA:	1000 ppm.
OSHA PEL (General Industry) 8 hour TWA:	1000 ppm (1900 mg/m^3).

Neither this preparation nor the substances contained in it have been listed as carcinogenic by National Toxicology Program, I.A.R.C., or OSHA.

AS PART OF GOOD INDUSTRIAL AND PERSONAL HYGIENE AND SAFETY PROCEDURE, avoid all unnecessary exposure to the chemical substance and ensure prompt removal from skin, eyes, and clothing.

SIGNS AND SYMPTOMS:

Acute Exposure:

Eye Contact:	May cause mild to moderate transient irritation.
Skin Contact:	May cause mild transient irritation and/or dermatitis.
Inhalation:	Not an expected route of entry.
Ingestion:	Irritating to mucous membranes. Large oral doses could produce narcosis.
Chronic Overexposure:	Possible problems with kidneys, lungs, gastrointestinal, spleen, behavioral (sleep, motor, headache), lungs, gastrointestinal, liver, endocrine, blood, developmental.

Diethylene Glycol Monobutyl Ether did not interfere with reproduction. However, body weights of newborn animals were decreased.

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE: Diseases of the kidney and liver.

FOR ENVIRONMENT:

As much as possible, keep from being washed into surface waters.

4. FIRST AID MEASURES

Eye Contact:	Wash with water for a minimum of 15 minutes. If irritation persists, seek medical attention.
Skin Contact:	Wash affected area with soap and water. If irritation persists, seek medical attention.
Inhalation:	Remove from exposure. If irritation persists, seek medical attention.
Ingestion:	Dilute by drinking large quantities of water.

5. FIRE-FIGHTING MEASURES

This preparation is an extinguishing media.
There are NO extinguishing media which must not be used for safety reasons.
NO special protective equipment is needed for fire-fighters.

6. ACCIDENTAL RELEASE MEASURES

For personal protection: Prevent skin and eye contact, see Heading 8.
Clean up: Use an absorbent material such as diatomaceous earth, sawdust, etc., and sweep up, see Heading 13.
As much as possible, keep from being washed into surface waters.

7. HANDLING AND STORAGE

7.1. Handling

Care should be taken in handling all chemical substances and preparations.
See incompatibility information in Heading 10.

7.2. Storage

NO special conditions are needed for safe storage.
See incompatibility information in Heading 10.
Store in original container. Keep tightly closed until used.
As much as possible, keep from being washed into surface waters.

7.3. Specific use

The intended or recommended use of this preparation is as a FIRE EXTINGUISHING AGENT.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1. Exposure limit values

Limit Values for Exposure:

Diethylene Glycol Monobutyl Ether:	
OSHA PEL (General Industry) 8 hour TWA:	None established.
MAK (DE) Limit value:	100 mg/m^3.
Short term exposure limit value (8 times, 5 minutes):	200 mg/m^3.
Ethanol (Ethyl Alcohol):	
ACGIH TLV-TWA:	1000 ppm.
OSHA PEL (General Industry) 8 hour TWA:	1000 ppm (1900 mg/m^3).

8.2. Exposure controls

8.2.1. Occupational exposure controls

8.2.1.1. Respiratory protection
None expected to be needed. Mechanical ventilation is recommended.

8.2.1.2. Hand protection
Use chemical resistant gloves when handling the preparation.

8.2.1.3. Eye protection
Chemical goggles are recommended.

8.2.1.4. Skin protection
Standard fire fighting safety equipment should provide all protection which is necessary.

8.2.2. Environmental exposure controls

As much as possible, keep from being washed into surface waters.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1. General information

Appearance:	Pale straw yellow, clear liquid.
Odor:	Mild, sweet odor.

9.2. Important health, safety, and environmental information

pH:	7.0-8.5.
Boiling point/boiling range:	65-70 °C (initial boiling).
Flash point:	40 °C PMCC.
Flammability (solid/gas):	Flammable.
Explosive properties:	Not explosive.
Oxidizing properties:	Not an oxidizer.
Vapor Pressure:	Not determined.
Relative Density (Water = 1):	About 1.
Solubility:	
– Water solubility:	Completely soluble.
– Fat solubility:	Not soluble.
Partition coefficient, n-octanol/water:	Not determined.
Viscosity:	2-10 Cs.
Vapor density (Air = 1):	Not determined, but <1.
Evaporation rate (Butyl acetate = 1):	Approx. 0.005.

9.3. Other information

Auto-ignition temperature:	Does not ignite.

10. STABILITY AND REACTIVITY

10.1. Conditions to avoid

There are NO known conditions such as temperature, pressure, light, shock, etc., which may cause a dangerous reaction.

10.2. Materials to avoid

Reactive metals, electrically energized equipment, any material reactive with water, or strong oxidizers.

10.3. Hazardous decomposition products

Normally stable.

Hazardous polymerization will NOT occur.

Not known, however, carbon monoxide and oxides of nitrogen and sulfur may be produced during fire conditions.

Hydrogen sulfide may be produced during bacterial decomposition under anaerobic conditions.

11. TOXICOLOGICAL INFORMATION

Product: The toxicity of the product mixture has not been determined.

Components:

Diethylene glycol monobutyl ether:

Toxicity Data:	Oral (rat) LD_{50}	5,660 mg/kg. [Dow Chemical Co.].
	Oral (rat) LD_{50}	9,623 mg/kg. [EINICS ESIS].
	Dermal (rabbit) LD_{50}	4,000 mg/kg. [Dow Chemical Co.].
	Dermal (rabbit) LD_{50}	2,764 mg/kg. [EINICS ESIS].
Irritation Data:	Eye (rabbit)	20 mg/24 hrs. Moderate. [EINICS ESIS].
	Eye (rabbit) Draize test	Highly irritating. [EINICS ESIS].
	Skin (rabbit)	1000 mg/kg/day Moderate with edema, fissuring, and leathery appearance. [EINICS ESIS].
Target organs:	Kidney, blood, liver, lungs, gastrointestinal, spleen.	

Ethanol:

Toxicity Data:	Oral (rat) LD_{50}	7,060 mg/kg
	Inhalation (rat) LC_{50}	20,000 ppm/10 hrs
Irritation Data:	Skin (rabbit)	400 mg open Mild
	Eye (rabbit)	500 mg/24 hrs Moderate
Target organs:	Behavioral (sleep, motor, headache), lungs, gastrointestinal, liver, endocrine, blood, developmental.	

12. ECOLOGICAL INFORMATION

12.1. Ecotoxicity

Components:

Diethylene glycol monobutyl ether:

Fish,	Lepomis marcrochinus:	LC_{50} (96 hrs)	1,300 mg/L.
	Carrassius auratus:	LC_{50} (24 hrs)	2,700 mg/L.
Daphnids,	Daphnia magna:	EC_{50} (24 hrs)	3,184 mg/L.
Algae,	Scenedesmus subspicatus:	EC_{50} (96 hrs)	>100 mg/L.

Ethanol:

Fish,	Oncorhynchus mykiss:	LC_{50} (24 hrs)	11,200 mg/L.
	Alburnus alburnus:	LC_{50} (96 hrs)	11,000 mg/L.
Daphnids,	Daphnia magna:	EC_{50} (24 hrs)	10,800 mg/L.

12.2. Mobility

Diethylene glycol monobutyl ether:

Should not partition from a water column to organic matter contained in sediments and suspended solids.

Ethanol:

Its low octanol/water partition coefficient indicates that its absorption to soil will be low.

12.3. Persistence and degradability

Diethylene glycol monobutyl ether:

Indirect photodegradation is about 50% in 3.5 hours.
Aerobic degradation with adapted activated sludge is 60% after 28 days.
COD = 2080 mg/g substance.
BOD5 = 250 mg O_2/g substance.
Theoretical oxygen demand = 2.17 mg/mg.

Ethanol:

Indirect photodegradation is about 50 % in 6 hours.
Aerobic degradation with adapted activated sludge is 74% after 5 days.
COD = 1700 mg/g substance.
BOD5 = 0.8 kg/L.

12.4. Bioaccumulative potential

Diethylene glycol monobutyl ether:

Should not bioaccumulate. Estimated bioaccumulation factor (log BCF) = 0.46.

Ethanol:

Will not bioaccumulate.

12.5. Other adverse effects

Ozone depletion potential:	None.
Photochemical ozone creation potential:	None.
Global warming potential:	None.

13. DISPOSAL CONSIDERATIONS

As much as possible, keep from being washed into surface waters.

Dispose of in compliance with national, regional, and local provisions that may be in force.

14. TRANSPORT INFORMATION

Hazard Class or Division: Not hazardous.

For additional transport information, contact Ansul Incorporated.

As much as possible, keep from being washed into surface waters.

15. REGULATORY INFORMATION

EU Classification:		Irritant – Xi; Flammable – F.
R Phrases:	11	Highly flammable.
	36	Irritating to eyes.
S Phrases:	2	Keep out of the reach of children.
	7	Keep container tightly closed.
	16	Keep away from sources of ignition – No smoking.
	24	Avoid contact with skin.
	26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

Limit Values for Exposure:

Diethylene Glycol Monobutyl Ether:

OSHA PEL (General Industry) 8 hour TWA:	None established.
MAK (DE) Limit value:	100 mg/m^3.
Short term exposure limit value (8 times, 5 minutes):	200 mg/m^3.

Ethanol (Ethyl Alcohol):

ACGIH TLV-TWA:	1000 ppm.
OSHA PEL (General Industry) 8 hour TWA:	1000 ppm (1900 mg/m^3).

EINECS Status:	All components are included in EINECS inventories or are exempt from listing.
EPA TSCA Status	All components are included in TSCA inventories or are exempt from listing.
Canadian DSL (Domestic Substances List):	All components are included in the DSL or are exempt from listing.

Environmental restrictions:	None are known.
Restrictions on Marketing and Use:	None are known.

Refer to any other national measures that may be relevant.

16. OTHER INFORMATION

(HMIS) HAZARDOUS MATERIAL IDENTIFICATION SYSTEM RATINGS:

HEALTH:	1	4. Severe Hazard
FLAMMABILITY:	2	3. Serious Hazard
REACTIVITY:	0	2. Moderate Hazard
		1. Slight Hazard
		0. Minimal Hazard

(WHMIS) CANADIAN WORKPLACE HAZARDOUS MATERIAL IDENTIFICATION SYSTEM RATINGS:

This product is rated **D2B – Product may irritate eyes, skin or mucous membranes.**

Format is from directive 2001/58/EC.
EINECS data is from http://exb.jrc.it/existing-chemicals/
Data used to compile the data sheet is from Ansul Material Safety Data Sheet, February, 2002.

The EU Classification has been changed in accordance with Directive 1999/45/EC and information in the EINICS ESIS files (Existing Substances Information System).
Toxicological information added from the EINICS ESIS (Existing Substances Information System) and from Dow Chemical Company.
A rating under WHMIS has been added, following the Canadian guidelines.
Limit values for exposure for diethylene glycol monobutyl ether were changed, based on EINICS ESIS data.

17. DISCLAIMER

N/A = Not Applicable NDA = No Data Available

MSDS available at http://www.ansul.com

MATERIAL SAFETY DATA SHEET

CHEMGUARD 3% AFFF C-303 Revision Date: 1/25/2006

1. PRODUCT IDENTIFICATION

Chemical Family: Surfactant mixture; fire fighting foam concentrate
Aqueous Film Forming Foam

Product name: Chemguard 3% AFFF C-303

Manufacturer: Chemguard, Inc.
204 South 6th Ave.
Mansfield, TX 76063
emergency phone: 817-473-9964

2. COMPOSITION / INFORMATION ON INGREDIENTS

		ACGIH/PPM		OSHA/PPM	
CAS NO.	Common Name	TWA	STEL	PEL	% by wt
7732-18-5	water				85% - 90%
57018-52-7	propylene glycol t-butyl ether	not established			2% - 4%
7487-88-9	magnesium sulfate	N/A	N/A	N/A	1% - 2%
proprietary mixture	proprietary hydrocarbon surfactant	N/A	N/A	N/A	proprietary
proprietary mixture	proprietary fluorosurfactant	N/A	N/A	N/A	proprietary

3. HAZARDS IDENTIFICATION

Routes of entry: Dermal, inhalation and ingestion
Potential Health Effects: May cause skin and eye irritation.

Carcinogenicity: Not a carcinogen.

4. FIRST AID MEASURES

Ingestion: Do not induce vomiting. Call a physician.
Inhalation: Remove to fresh air.
Skin: Rinse with water. Wash with soap and water. Contaminated clothing should be washed before re-use.
Eyes: Rinse with water. Call a physician.

5. FIRE FIGHTING MEASURES

Flash Point:	>150°F
Flammable Limits in air (lower % by volume):	not evaluated
Flammable Limits in air (upper % by volume):	not evaluated
Auto-ignition Temperature:	not evaluated

General Hazards: None known.
Fire Fighting Equipment: Self contained breathing apparatus
Fire Extinguishing Media: Water, Foam, Carbon Dioxide, Dry Chemical, Halon
Fire and Explosion Hazards: Decomposition products may be toxic.
Hazardous Combustion Products: oxides of nitrogen, sulfur and carbon

6. ACCIDENTAL RELEASE

Contain spills. Vacuum or pump into storage containers, absorb smaller quantities with absorbent materials, and dispose of properly. Washing area with water will create large amounts of foam.

Dispose of released and contained material in accordance with local, state, and federal regulations. Release to local waste treatment plant only with permission.

7. HANDLING AND STORAGE

Store in original container, or appropriate end-use device. Store at temperatures of 35 - 120 degrees F. If the material freezes, it may be thawed without loss of performance.

8. EXPOSURE CONTROLS, PERSONAL PROTECTION

Eye Protection: Wear side-shield safety glasses.
Skin Protection: Wear latex gloves.
Respiratory Protection: Use organic vapor respirator if needed.

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point:	205° - 212°F
Melting Point:	30° F
Specific Gravity:	1.012 g/ml
Vapor Pressure (mm Hg):	N/A
pH	7.0 - 8.5
Flash Point (PMCC):	>150°F
Vapor Density (air = 1)	N/A
Solubility in water:	100%
Appearance:	clear amber liquid
Odor:	slight solvent odor

10. STABILITY AND REACTIVITY

Stability: Stable
Incompatibility: Strong oxidizers
Hazardous Polymerization: Will not occur.
Decomposition Products: Oxides of nitrogen, sulfur, carbon.

11. TOXICOLOGICAL INFORMATION

Eye Irritation: (Rabbits) mild irritant
Skin Irritation: (Rabbits) minimal irritant

Inhalation Toxicity:	not evaluated
Sensitization:	not evaluated
Teratology:	not evaluated
Mutagenicity:	not evaluated
Reproduction:	not evaluated
Acute Oral Effects (Rats):	not evaluated

12. ECOLOGICAL INFORMATION

	CONCENTRATE	SOLUTION (AS USED)
Chemical Oxygen Demand:	210,000 mg/l	6,300 mg/l
Biological Oxygen Demand (20 day):	79,800 mg/l	2,394 mg/l
Biodegradability (B.O.D./C.O.D.)	38%	38%
Total Organic Carbon:	33,600 mg/l	1008 mg/l
LC50 (96 hour pimephales promelas)	233 ppm	7767 ppm
LC50 (48 hour, daphnia magna)	1110 ppm	37,000 ppm

13. DISPOSAL CONSIDERATIONS

Dispose in accordance with local, state, and federal regulations. Discharge to waste treatment plants only with permission. Anti-foam agents may be used to reduce foaming in waste streams.

14. TRANSPORTATION INFORMATION

Department of Transportation proper shipping name: not regulated

15. REGULATORY INFORMATION

All ingredients are on the TSCA inventory.
No components are reportable under SARA Title III, sec. 313
No components are priority pollutants listed under the U.S. Clean Water Act Section 307 (2)(1)
Priority Pollutant List (40 CFR 401.15).
No components are reportable under **CERCLA**.

16. OTHER INFORMATION

NFPA Hazard Ratings		HMIS Identification System
1	Health Hazard Rating	1
1	Flammability Rating	1
0	Instability/Reactivity Rating	0

CHANGE LOG:

Revision 2 - Revision date changed.

MATERIAL SAFETY DATA SHEET

CHEMGUARD 3% AR-AFFF C-333 Revision Date: 1/26/2006

1. PRODUCT IDENTIFICATION

Chemical Family: Surfactant mixture; fire fighting foam concentrate
Aqueous Film Forming Foam

Product name: Chemguard 3% AR-AFFF C-333

Manufacturer: Chemguard, Inc.
204 South 6th Ave.
Mansfield, TX 76063
phone: 817-473-9964

2. COMPOSITION / INFORMATION ON INGREDIENTS

		ACGIH/PPM		OSHA/PPM	
CAS NO.	Common Name	TWA	STEL	PEL	% by wt
7732-18-5	water				80% - 85%
112-34-5	diethylene glycol monobutyl ether	not established			2% - 5%
	proprietary hydrocarbon surfactant				proprietary
	proprietary fluorosurfactant	N/A	N/A	N/A	proprietary
	polysaccharide gum	N/A	N/A	N/A	1% - 2%

3. HAZARDS IDENTIFICATION

Routes of entry: Dermal, inhalation and ingestion
Potential Health Effects: May cause skin and eye irritation.

Carcinogenicity: Not a carcinogen.

4. FIRST AID MEASURES

Ingestion: Do not induce vomiting. Call a physician.
Inhalation: Remove to fresh air.
Skin: Rinse with water. Wash with soap and water. Contaminated clothing should be washed before re-use.
Eyes: Rinse with water. Call a physician.

5. FIRE FIGHTING MEASURES

Flash Point:	no flash to boiling
Flammable Limits in air (lower % by volume):	not evaluated
Flammable Limits in air (upper % by volume):	not evaluated
Auto-ignition Temperature:	not evaluated

General Hazards: None known.
Fire Fighting Equipment: Self contained breathing apparatus
Fire Extinguishing Media: Water, Foam, Carbon Dioxide, Dry Chemical, Halon
Fire and Explosion Hazards: Decomposition products may be toxic.
Hazardous Combustion Products:

6. ACCIDENTAL RELEASE

Contain spills. Vacuum or pump into storage containers, absorb smaller quantities with absorbent materials, and dispose of properly. Washing area with water will create large amounts of foam.

Dispose of released and contained material in accordance with local, state, and federal regulations. Release to local waste treatment plant only with permission.

7. HANDLING AND STORAGE

Store in original container, or appropriate end-use device. Store at temperatures of 35° - 120° F. If the material freezes, it may be thawed without loss of performance.

8. EXPOSURE CONTROLS, PERSONAL PROTECTION

Eye Protection: Wear side-shield safety glasses.
Skin Protection: Wear latex gloves.
Respiratory Protection: Use organic vapor respirator if needed.

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point:	212 degrees F.
Melting Point:	30° F
Specific Gravity:	1.018 g/ml
Vapor Pressure (mm Hg):	N/A
pH	7.0 - 8.5
Flash Point (PMCC):	no flash to boiling
Vapor Density (air = 1)	N/A
Solubility in water:	100%
Appearance:	opaque, thick liquid
Odor:	very slight solvent odor

10. STABILITY AND REACTIVITY

Stability: Stable
Incompatibility: Strong oxidizers
Hazardous Polymerization: Will not occur.
Decomposition Products: Oxides of nitrogen, sulfur, carbon.

11. TOXICOLOGICAL INFORMATION

Eye Irritation: (Rabbits) mild irritant
Skin Irritation: (Rabbits) minimal irritant

Inhalation Toxicity:	not evaluated
Sensitization:	not evaluated
Teratology:	not evaluated
Mutagenicity:	not evaluated
Reproduction:	not evaluated
Acute Oral Effects (Rats):	not evaluated

12. ECOLOGICAL INFORMATION

	CONCENTRATE	SOLUTION (AS USED)
Chemical Oxygen Demand:	250,000 mg/l	7,500 mg/l
Biological Oxygen Demand (20 day):	174,000 mg/l	5,220 mg/l
Biodegradability (B.O.D./C.O.D.)	70%	70%
Total Organic Carbon:	5,700 mg/l	171 mg/l
LC50 (96 hour pimephales promelas)	not determined	not determined
LC50 (48 hour, daphnia magna)	not determined	not determined

13. DISPOSAL CONSIDERATIONS

Dispose in accordance with local, state, and federal regulations. Discharge to waste treatment plants only with permission. Anti-foam agents may be used to reduce foaming in waste streams.

14. TRANSPORTATION INFORMATION

Department of Transportation proper shipping name: not regulated

15. REGULATORY INFORMATION

All ingredients are on the TSCA inventory.
No components are reportable under SARA Title III, sec. 313
No components are priority pollutants listed under the U.S. Clean Water Act Section 307 (2)(1) Priority Pollutant List (40 CFR 401.15).
No components are reportable under **CERCLA**.

16. OTHER INFORMATION

NFPA Hazard Ratings		HMIS Identification System
1	Health Hazard Rating	1
0	Flammability Rating	0
0	Instability/Reactivity Rating	0

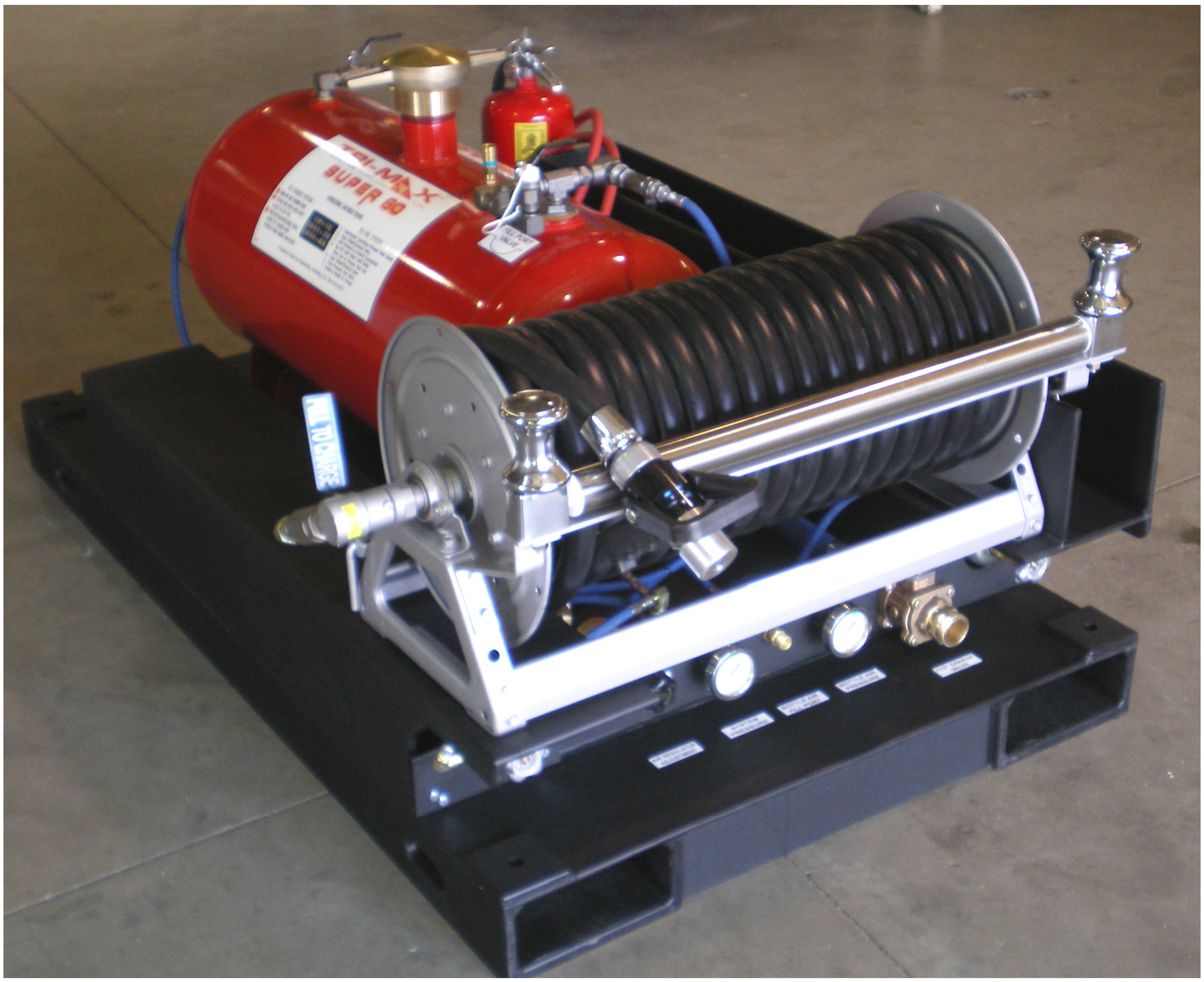
Change Log:

Revision 2, 1/26/06

Revision date changed.

Flammability rating changed from 1 to 0.

TRI-MAX SUPER-60 SKID
COMPRESSED AIR FOAM SYSTEM



OPERATIONS, TRAINING, & MAINTENANCE MANUAL

January 1, 2010

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1-1. MANUFACTURER:

A. The TRI-MAX SUPER 60 SKID is manufactured by:

Kingsway Industries, INC
6680 Lockheed Dr. Suite B
Redding, CA 96002

Phone: (530) 722-0272
Fax: (530)722-0450
E-mail: support@trimax.us
Website: www.trimax.us

B. The manufacturer is totally committed to supporting the owners and operators of the TRI-MAX SUPER 60 SKID system. Don't hesitate to contact the factory either by telephone, E-Mail, FAX, or the Website if you have a problem that you can't solve or have a product improvement idea. The TRI-MAX website has a Comment/Assistance Page for obtaining product information, providing customer feedback, and soliciting technical assistance.

1-2. WARRANTY: The TRI-MAX 60 has a 2-year limited warranty to be free from defects in material and workmanship beginning on the date of delivery. The manufacturer's liability is limited solely to the repair or replacement of the defective part and does not include labor. The warranty card that accompanies the unit should be returned to the manufacturer. The manufacturer shall in no way be liable for any incidental or consequential damages which may result from any defects in material or workmanship or from the breach of any express or implied warranty. The manufacturer does not warranty the performance of the system impacted by environmental conditions, abuse and end user competence. If the optional protective cover is purchased with and used on the system, the Limited 2-Year Warranty shall be extended to a 5 year period. Individuals with a warranty claim should contact the manufacturer and provide the Serial Number for the system which can be found on the data plate on the foam tank.

All new or remanufactured Kingsway/Tri-Max systems come with a 2 year manufacturer's warranty against defects in materials and workmanship, which starts from the date of purchase. This warranty can be extended to a standard setting 5 year period with the purchase of the appropriate weather cover if included in the original purchase agreement. If a defect is found during the warranty period, Kingsway will make it right. However, you the customer also have a part to play in the warranty. Very simply - the warranty will be void if the required preventative checks and simple periodic maintenance procedures required in the appropriate Operators Manual are not performed and documented by Kingsway qualified, trained and certified personnel. Copies of these inspections must be provided with any warranty claim submission. Kingsway provides the appropriate training and certification free of charge at our factory in Redding, California. Come visit us. When lives and futures depend on equipment choices, you'll choose Kingsway/Tri-Max!

1-3. WARNINGS, CAUTIONS, NOTES & CALL OUTS: Are used to emphasize important and critical instructions and are used for the following conditions:

A. **WARNING**: An operating procedure, practice, etc., which if not correctly followed could result in personal injury or loss of life.

B. **CAUTION**: An operating procedure, practice, etc., which, if not strictly observed, could result in damage to, or destruction of, equipment.

C. **NOTE**: An operating procedure, condition, etc., which it is essential to highlight.

C. **CALL OUT**: A notation used to explain the difference of the TM SUPER-60 and the TRI-MAX 60 LP standard units in a procedure or any other information listed. See example CALL OUT box.

STANDARD UNIT CALL OUT
This is an example of a CALL OUT box that will be used to point out a difference between the Super 60 and the Standard 60 LP

1-4. MANUAL CHANGES AND REPRODUCTION:

A. MANUAL CHANGES:

(1) The manufacturer will provide equipment update changes to this manual. Each change will be consecutively numbered and have an effective date. The change summary sheet should be filed in the front section of the manual prior to the Table of Contents.

(2) This manual and the associated updates will be posted on the TRI-MAX web site.

(3) Users can help improve this manual by providing any errors, inconsistencies, helpful information, or recommended improvements to the manufacturer. All recommendations submitted should reference the appropriate Chapter/Paragraph (if applicable) and the name and contact (phone, e-mail, fax, etc) for the person submitting the information.

B. REPRODUCTION: Reproduction of all information, illustrations, and checklists in this manual is authorized.

CHAPTER 2

SYSTEM DESCRIPTION

2-1. GENERAL INFORMATION:

The TRI-MAX SUPER 60 SKID Compressed Air Foam fire suppression system uses compressed air to propel fire fighting foam. Thousands of tight radius bubbles quickly cool and smother a fire by providing a thick vapor-sealing blanket of foam that virtually eliminates re-ignition. The TRI-MAX Super-60 is unique system that has two hoses that can be discharged simultaneously or independently of one another. The Standard TRI-MAX 60LP does not have the dual discharge capability, this is the main difference between the TR-MAX Super-60 and TRI-MAX 60LP.
The foam will adhere to horizontal and vertical surfaces. This system allows the operator to seal a fuel spill and flammable vapors with foam thus reducing or eliminating a potential fire. The 60 gallon system produces approximately 1200 gallons of finished foam. It takes approximately 4 minutes, in the full open position, to fully discharge the 1200 gallons of finished foam. The system will discharge the foam approximately 75-85 feet in a no wind condition allowing fire-fighting personnel without protective clothing to avoid thermal injuries. There is an approximate 25% reduction in discharge distance using the Freeze Protected Foam solution at -40 degrees F/C due to the increased viscosity of the foam. The system can easily be serviced by the operator. Trained personnel can accomplish all maintenance except the hydrostatic pressure testing of the Air Cylinders, Premix Tank, and the Discharge Hose.

2.2. SPECIFICATIONS: SEE <u>CALL OUT</u>

A. Height: 32 ¾ inches Width: 52 inches Length: 70 inches
B. Loaded Weight: 1130 LBS Empty Weight: 630 LBS
C. Premix Tank: 60 gallon capacity
D. Finished Foam Capacity: Approximately 1200 gallons
E. Finished Foam Discharge Rate: 1” hose approx 250-300 gpm, 1.5” hose approx 450 gpm.
F. Discharge Duration:
1” Discharge hose approx 3 min 45 sec.,
1.5” discharge hose approx 1 min 45 sec.
G. Foam Discharge Distance: 75-85 feet in a no wind condition from 1” rubber booster line (50-60 feet at –40 degrees F/C using freeze protected foam solution)
H. Air Cylinder (Industrial): Two (2) 150 CF 2250 psi
I. Regulator: Adjustable pressure 0-400 psi
J. Dispensing Hose: 100 feet of 1” hard rubber booster and 1.5” collapsible hose.
K. Hose Length (max): 200 feet per discharge side.
L. Pressure Relief Valve: 200 psi
M. Ball Valves: 400 psi
N. Check Valves: Two one-way
O. Recharge Time: 6-8 minutes

TR-MAX 60LP CALL OUT

The 60LP model does not have two hoses, therefore the 1.5” discharge hose specifications do not apply.

2-3. TRANSPORTING:

The TRI-MAX SUPER 60 SKID should be thoroughly secured when transporting in trailers and vehicles. The bottom of the frame has holes that allow a fork lift to move the system (see components). Other sections of the system should not be used for these purposes. Utilize the frame when re-positioning the system. Do not push on any of the components (i.e. gauges regulators etc.) when moving the system.

2-4. SYSTEM COMPONENTS:

1. **3" WATER/CHEMICAL FILL PORT** is located on top of the PREMIX TANK and allows solution to enter the Premix Tank. The Water/Chemical fill port is fitted with a twist on cap with a pressure seal. Always ensure this cap is tightly securely after serving the unit. Do not over tighten fill port cap.

2. **AIR CYLINDER REGULATOR** adjusts the air flow from the Air Cylinders for the system. The regulator maintains a 0-175 psi system operating pressure and has been set to an operational pressure of 150-160 psi. The regulator's operational temperature range is -40 to +160 degrees F.

3. **AIR CYLINDER VALVES** are located on the Air Cylinder positioned at either side of the control panel. An internal over pressure relief valve opens and vents the Air Cylinder if the internal pressure reaches 3360 psi. An air pressure indicating gauge is mounted on the main control panel, and on Air Cylinder Valves.

4. **FOAM CHARGE VALVE(S)** fills the discharge hose with pressurized foam when placed in the open position. The valve should be positioned in the full open position (handle is in line with the hose) for all operations and closed (handle is perpendicular to the hose) at all other times. On the TRI-MAX Super-60 Unit, when using 1.5" line, ensure that the entire length of hose is deployed.

5. **FOAM DISCHARGE HOSE** is 1 inch inside diameter x 100 feet rubber booster line or attach Wild land collapsible hose if longer length is desired. The Arctic Hose is to be used in extreme cold temperatures. A combination of hose sections up to 200 feet can be used without system performance degradation.

5A. **FOAM DISCHARGE HOSE** is 1.5 inch inside diameter x 100 ft collapsible hose. A combination of hose sections up to 200 feet can be used without system performance degradation. This hose is not installed on the standard TRI-MAX 60LP unit.

6. **FOAM DISCHARGE NOZZLE(S)** have a 2 position hand activated lever. Forward is closed and aft is full open. The valve is marked with open and closed decals. The 1.5" Collapsible hose may be equipped with standard smooth bore CAF nozzle or Coarse to Fine adjustable fan nozzle.

7. **PREMIX TANK** has a capacity of 60 gallons and is ASME approved. The Serial number for the system is stamped on a data plate on the tank. Mounted to the tank are the Pressure Vent Valve, Water/Chemical Fill Port, Refill Port, and Pressure Relief Valve. The tank pressure normal operating range is 100-170 psi.

8. **AIR CYLINDERS** are standard 150 CF INDUSTRIAL style 2250 psi tanks pressure tested at 2250psi. The system has 2 Air Cylinders, located on either side of the unit encased within the frame. They. One cylinder is capable of activating the system but for maximum efficiency using both discharges, it is recommended that both cylinders be turned on simultaneously. Compressed air or nitrogen can be used in the air cylinders.

9. **PRESSURE VENT VALVE** is located on top of the Premix Tank. The valve is used in the foam refill process and to depressurize the system after use. The valve is closed when it is perpendicular to the plumbing and is open when parallel (in-line) with the plumbing.

10. **PRESSURE RELIEF VALVE** is located on top of the Premix Tank. The static pressure in the PREMIX TANK may increase during warm weather if the unit is left in the direct sunlight. When the system is pressurized for operation, the Premix Tank pressure may exceed 200 psi. If this happens, the Pressure Relief Valve will open and vent any excess pressure. Some agent may appear on the ground, however, the function or the operation of the system is not affected.

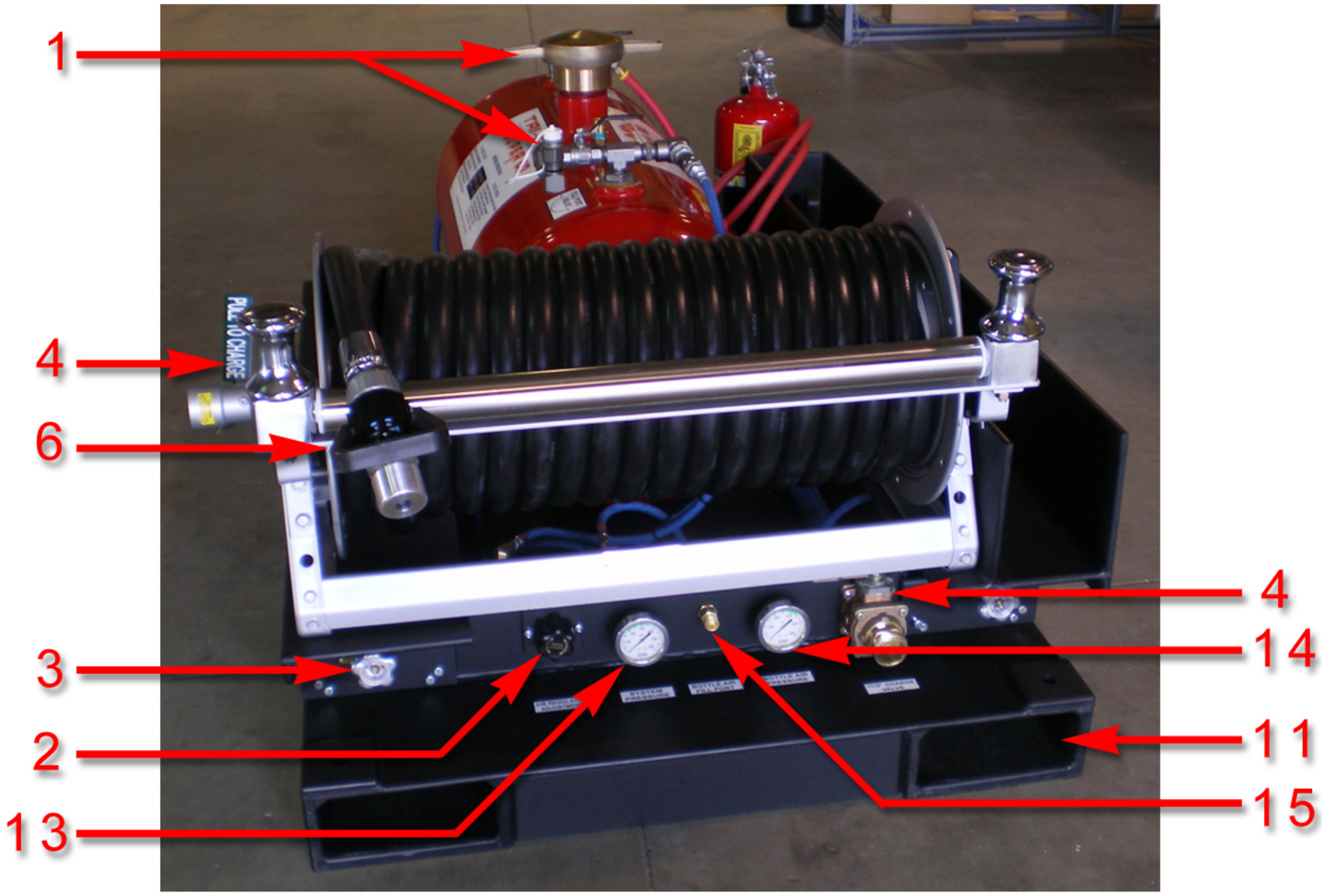
11. **LIFT OPENING** is located on the front-bottom of the unit and should be used for all lifting and lifting needs. No other part of the frame should be used for these purposes.

12. **MANUAL HOSE REEL** is mounted on the front of the system and holds 100 feet of 1 inch rubber booster hose.

13. **AIR CYLINDER HIGH PRESSURE GAUGE:** is used to show the Air Cylinder Pressure. When testing the Air Cylinder Pressures this gauge should read between 2000-2250 psi.

14. **OPERATION SYSTEM PRESSURE GAUGE:** Shows the System operating pressure in the PREMIX TANK. Normal pressure should read 100-175 psi.

15. **SINGLE POINT AIR CYLINDER RE-CHARGE PORT:** Is equipped with a dust cover that will be removed during Air Cylinder re-charge procedure.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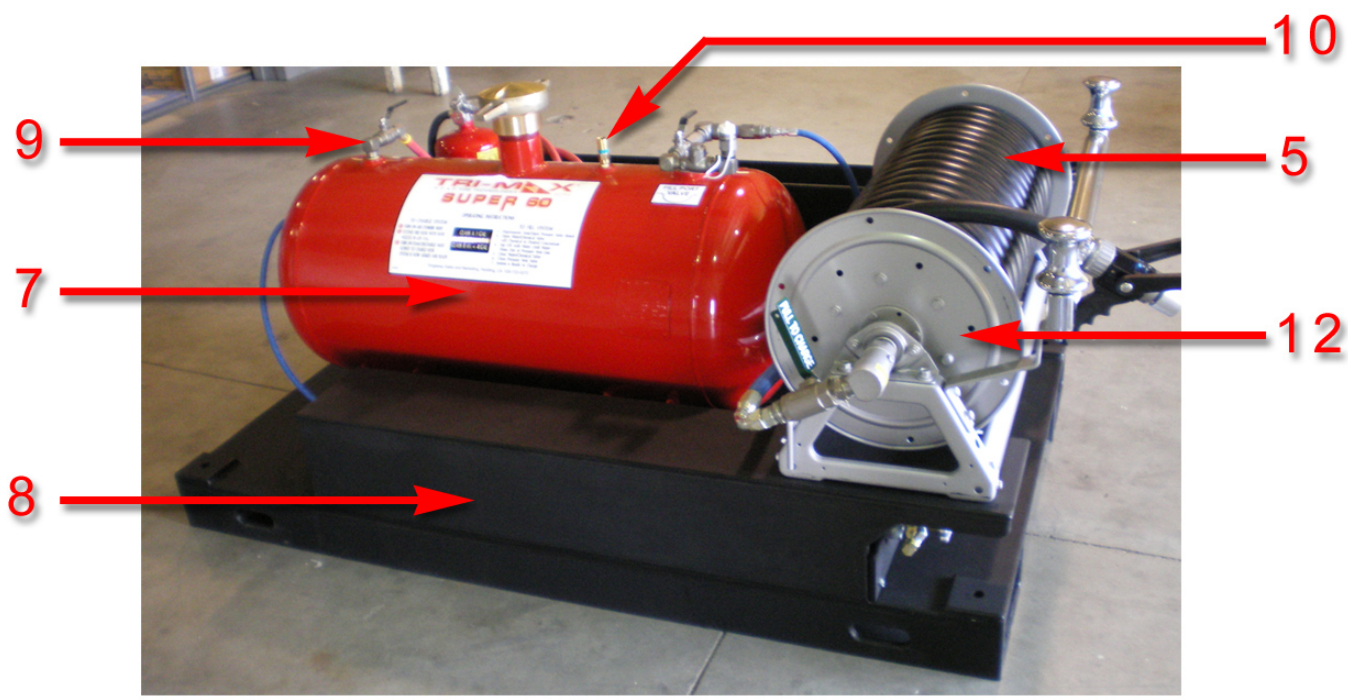
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TRI-MAX
SUPER 60
PULL TO CHARGE

CHAPTER 3

OPERATING INSTRUCTIONS

3-1. INITIAL SETUP:

The TRI-MAX SUPER 60 SKID comes fully assembled and the Air Cylinders are charged unless the unit is shipped by air freight. The 60-gallon Premix Tank must be filled prior to use and testing. Users should turn on the Air Cylinder Valve(s) and verify there is 2000-2250 psi pressure. The Air Cylinders should be refilled or "topped off" if the cylinder pressure is less than 2000 psi reading on the Air Cylinder High Pressure Gauge. The proper Aqueous Film Forming Foam (AFFF) solution should be selected based on operational ambient temperatures prior to putting the unit in service. Liquid dish soap can be used in the Premix Tank if training is going to be conducted. The dish soap does not harm the system and can be mixed with the AFFF without any performance degradation.

3-2. FOAM SOLUTION PRODUCTS:

A. The TRI-MAX SUPER 60 SKID can use any type of AFFF fire suppression foam chemical solution. Recommended foam chemicals include Class A foam, Class B foam, Fire-Trol or Terra Foam, and Freeze Protected AFFF Foam solution when operated in sub freezing temperatures. Terra Foam provides 24 hour extended structure protection. Class B MC-1 Hazmat approved foam contains enzyme emulsifier that breaks down petroleum products and makes them potable. All recommended foams are EPA, USDA, and OSHA approved.

B. The following amounts of foam solution should be added to the 60 gallon Premix Tank:

(1) Class A (Wild land) foam : 1 gallon
(2) Class B 3% solution: 2 gallons
(3) Class B 6% solution: 4 gallons
(4) Liquid Dish soap or Training Foam solution (Training only): 2 gallons
(5) Freeze Protected AFFF solution: 60 gallons
(6) Other foam products: Follow the foam manufacturer's recommendation.

C. It is recommended that freeze protected foam solution be used in the concentrate form when positioning the units outside during freezing weather. The TRIMAX Freeze Protected Foam solution provides protection down to the -40 degrees C/F. Freeze protected solutions should be used at full strength and not mixed with water.

3-3. SYSTEM DEPRESSURIZATION

<u>CAUTION</u>

Ensure the Premix Tank is depressurized and the Air Cylinders are closed before conducting any maintenance on the system.

A. Close the Air Cylinder Valves.

B. Close the Foam Charge Valve (if open).

C. Open the Pressure Vent Valve slowly to relieve the Premix Tank and gauge pressures.

D. Close the Pressure Vent Valve.

3-4. PREVENTATIVE MAINTENANCE CHECKS & SERVICES (PMCS)

A. Recommend the PMCS CHECKLIST be completed every month.

B. Personnel completing the PMCS should be thoroughly familiar with the TRI-MAX SUPER 60 SKID system and the information in this manual.

C. Recommend a tag be maintained on each unit that indicates the date and the initials of the individual completing the PMCS, the type and ratio of the AFFF in the Premix Tank, and the location of the MSDS for an emergency situation.

TRI-MAX SUPER 60 SKID
PREVENTATIVE MAINTENANCE CHECKS AND SERVICES (PMCS)
CHECKLIST

DATE COMPLETED___________________

NAME _______________________ SIGNATURE____________________________

_____ 1. Conduct a visual inspection of the system for chaffing lines, loose lines, dirt, corrosion or damage. Check that the O-ring is not protruding where the Air Cylinder valve screws into the Air Cylinder. If the O-ring is protruding, the cylinder should be removed and the O-ring replaced.

_____ 2. Conduct System pressure Check.

A. Turn on one air cylinder and note pressure. Close the air cylinder and check the pressure on the remaining air cylinder.

(1) Conduct a leak check if either Air Cylinder pressure is below 2000 psi:

(a) Turn on Air Cylinder(s) with low pressure.
(b) Spray a light soap solution on all air lines and fittings.
(c) Tighten fittings, replace O-rings, or replace leaking component.

(2) Remove, recharge, and reinstall Air Cylinders

(Continued on following page)

TRI-MAX SUPER 60 SKID PMCS CHECKLIST
(Continued)

B. Check the Premix Tank level.

(1) Open the Water/Chemical and Pressure Vent Valves.
(2) Fill up the Premix Tank if low.
(3) Close the Water/Chemical Valves.

_______ 3. Note any other problems:

3-5. NORMAL OPERATING INSTRUCTIONS

WARNING

The TRI-MAX SUPER 60 SKID discharges foam solution at a high pressure. A sudden pressure surge could cause the operator to lose control of the hose if the nozzle and hose are not held securely when the Foam Discharge Nozzle is opened. Open the nozzle slowly to the full open position.

Consult the foam manufacturer's MSDS for the proper precautions and treatments if the foam is sprayed into the facial area (eyes, nose, and mouth).

NOTE

It is recommended that the air cylinders normally be left in the closed position.

The TRI-MAX Super-60 is equipped with two hoses, one 1" booster line and one 1.5" collapsible line. Both Hoses may be simultaneously discharged, or discharged independently.

A. Ensure the Foam Discharge Nozzle(s) is in the closed (forward) position.

B. To operate one hose independently, open one (1) Air Cylinder by turning the valve counter clockwise. To discharge BOTH hoses simultaneously ensure both Air Cylinders are opened by turning both the Air Cylinder Valves counter clockwise.

TRI-MAX 60LP CALL OUT
B. Open one (1) Air Cylinder by turning the valve counter clockwise. SKIP step C on the TRI-MAX 60LP standard unit.

C. Fully Extend 1.5" hose if it is to be charged.

D. Turn on the Foam Charge Valve(s) of the hose intended to be discharged slowly to the full open position (handle should be in line with the hose). The 1" booster hose Foam Charge Valve is located on the hose reel, and the brass 1.5" collapsible hose Foam Charge Valve fitted to the TRI-MAX Super-60 is located adjacent to the High Pressure Air Cylinder Gauge.

E. Aim the Nozzle at the base of the fire and open the Foam Discharge Valve slowly (rear position).

F. Shoot the system in 5 to 10 second bursts across the base of the fire or directly
on objects that are on fire. Move the nozzle slowly to build up a layer of foam over the fire surface.

3-6. COLD WEATHER OPERATIONS

A. It is recommended that the TRI-MAX SUPER 60 SKID system be equipped with the Arctic Discharge Hose, Protective Cover and Freeze protected foam solutions when extreme cold weather conditions are anticipated.

B. There will be a degraded performance in extreme cold weather since the viscosity and density of the foam is greater.

C. The foam blanket in cold temperatures will be wetter and the discharge distances will decrease. Users should anticipate a discharge distance of 50-60 feet in sustained Sub 0 temperatures.

D. The foam will tend to skip a short distance on a frozen surface so the person employing the system should aim short of the intended target.

3-7. EMERGENCY PROCEDURES

A. LOOSE HOSE

WARNING: Do not attempt to catch a runaway hose.

(1) Move to the unit and close the Foam Charge Valve immediately (valve handle should be perpendicular to the hose).

(2) Close the Foam Discharge Nozzle (valve handle is full forward).

IF CONTINUING TO FIGHT THE FIRE:

(3) Open Foam Charge Valve slowly.

(4) Hold the hose securely and open the Foam Discharge Nozzle slowly (valve handle is full aft).

B. NO FOAM DISCHARGE

(1) Close the Foam Discharge Nozzle (move the handle full forward).

(2) Close the Foam Charge Valve.

(3) Open the backup Air Cylinder Valve.

(4) Open Foam Charge Valve slowly (valve handle should be in line with the hose).

(5) Hold the hose securely and open the Foam Discharge Nozzle (valve handle is full aft) slowly.

C. SHUT DOWN PROCEDURES

(1) Close the Foam Discharge Nozzle.

(2) Close the Foam Charge Valve.

(3) Close the Air Cylinder Valves.

(4) Open the Foam Discharge Nozzle to depressurize the hose. Close the valve when all of the foam has been expended from the hose.

(5) Open the Pressure Vent Valve slowly until all pressure is relieved.

(6) Secure the fire hose.

3-8. AVIATION REFUELING OPERATIONS

A. Helicopter hot refuel operations are by nature hazardous. An accident during refueling can result in catastrophic damage to the aircraft and possible injury or loss of life to the refuel/aircraft crew. The TRI-MAX SUPER 60 SKID provides the user a stand off capability along with the ability to prevent fires by covering up flammable liquids, sealing vapors, and cooling the surface.

B. The following techniques will help prevent catastrophic affects of accidents and reduce the overall risk of aviation refueling operations: NOTE These techniques are for informational purposes only, and are not a substitute for certified training.

(1) <u>FIREGUARDS</u>: The protective cover (if utilized) should be removed from the unit and the hose be moved to the fireguard position. Fireguards should stand just outside the rotor disc at a 45 degree angle on the side of the aircraft the refueling nozzle is located on. This position allows the fire guard the best view to monitor the refuel operation, alert the crew to any problem, and quickly react to a fire or fuel spill situation while remaining well clear of the affected area. Priorities should be given to the crew, the fuel spill, and the main fire areas.

(2) <u>IN THE EVENT A FIRE OCCURS</u>: The safety of the re-fueler and aircraft crew is the number one priority. Fuel burning in the vicinity of the aircrew should be extinguished first. Open the Foam Discharge Nozzle fully and sweep the foam stream across the base of the flames starting at the leading edge and moving slowly to the rear. Use short 5-10 second bursts checking the effectiveness of the foam between bursts. Once the fuel on the ground has been extinguished, begin foaming any remaining portion of the aircraft that is burning.

(3) IF FUEL HAS BEEN SPILLED ON THE GROUND AND THE AIRCRAFT: Foam the aircraft first by positioning the Foam Discharge Nozzle to the full open position in order to get the maximum foam possible on the aircraft. Fuel spilled in the vicinity of the engine, exhaust, or the intake should be foamed immediately to prevent ignition. Once the aircraft has been foamed, the fuel on the ground should be covered with a blanket of foam. Monitor the crew egress and reapply foam to any areas where the foam blanket has been compromised. This action can be accomplished in approximately 20 seconds by a trained fireguard. Quick action on the part of the fireguard is critical to prevent a fuel spill from becoming a fuel fire.

3-9. FUEL SPILL PROCEDURES:

A. The hazard of fuel spills can be reduced by applying a blanket of foam on top of the fuel to seal vapors and reduce the chance of combustion.

B. Cover any personnel who have been drenched with fuel with foam to prevent combustion.

WARNING

Do not hit the spilled fuel directly with an unrestricted flow of foam or with the Nozzle in the full open position. This action could spread the fuel creating a greater hazard and cause injury to refuel personnel. The operator should be positioned a minimum of 30-40 feet from the fire to maximize the effectiveness of the system. Personnel exposed to foam should follow the instructions listed in the foam manufacturer’s Material Safety Data Sheet (MSDS).

CHAPTER 4

TRAINING

4-1. TRAINING PROGRAM

A. Training on the TRI-MAX SUPER 60 SKID system should be conducted at least annually for all operators.

B. Maintainers should complete initial training and refresher training as required.

C. Trainers should be thoroughly familiar with the system, fire behavior, hazard identification and basic fire fighting skills.

D. Operator training should be conducted using a "hands-on" approach in a live fire scenario whenever possible. Live fire training can often be accomplished through coordination with a local fire department.

4-2. TRAINING AIDS:

Liquid dish soap or training foam can be mixed with water at a ratio of 1 gallon per 30 gallon tank providing the training is being conducted in non-freezing environment. The training solution should be placed in the Premix Tank when it is almost full of water in order to maximize the volume of solution available. Dish soap does not cause any damage to the system and can be mixed with AFFF without any impact on the operation.

4-3. TRAINING PROGRAM OF INSTRUCTION (POI):

A. OPERATORS & MAINTAINERS

(1) Component Identification (Pages 6-8)

(2) PMCS (Pages 10-12)

(3) Normal and Cold Weather Operating Instructions (Pages 13-14)

(4) Emergency Procedures (Pages 14-15)

(5) Aviation Refueling Operations (if applicable) (Pages 15-16)

(6) Fuel Spill Operations (Page 16)

(7) Hands-On Operation, preferably on a live fire scenario (Page 13)

B. MAINTAINERS

CHAPTER 5

MAINTENANCE

5.1. GENERAL INSTRUCTIONS

A. The TRI-MAX SUPER 60 SKID system was designed to be easy to operate and simple to maintain. The system has few moving parts; however, it is a vital lifesaving piece of equipment that requires some minimal maintenance.

B. It is recommended that the monthly PMCS be accomplished.

C. It is also very important that responsible personnel be assigned the responsibility to service and maintain the system.

D. The final important task is maintaining thorough documented records of the maintenance performed. These records should include copies of the completed PMCS Checklists, the Maintenance Log, when the Premix Tank was filled and the type/mixture of foam in each unit. A MSDS sheet should be readily available for the type of foam being utilized. Recommend a tag be affixed to each unit that lists the date and initials of the individual performing the PMCS, the foam type and mixture ratio (if any), and the location of the MSDS.

5-2. TECHNICAL ASSISTANCE:

The manufacturer is totally committed to providing technical assistance whenever required. Maintainers should contact the manufacturer whenever a problem arises that cannot be solved using the information in this manual or when unusual situations are encountered.

5-3. REPAIR PARTS

A. The TRI-MAX SUPER 60 SKID repair parts are listed in this paragraph. All repair parts can be obtained from the manufacturer by using a credit card or a purchase order. Many of the parts can also be purchased at local dive shops or hardware stores. O-rings should be purchased from the factory, an authorized TRI-MAX distributor, or from a certified scuba shop.

B. The manufacturer will replace parts that fail due to defects in workmanship during the one-year warranty period at no cost. The defective part must be returned to the manufacturer to receive credit. Users should contact the manufacturer by phone, e-mail, fax, or by completing the comment page on the website to receive replacement parts.

TRI-MAX SUPER 60 SKID REPAIR PARTS

DESCRIPTION	PART #
Reel with Spool & Guide Assembly	1TM60
Roller Guide TM60 Reel	2TM60
Bracket For TM60 Reel	3TM60
TM60 Manifold	4TM60
Tm30 Manifold	4TM60-A
Hose Barb Fitting	5TM60
1 ½" Charge Valve w/Handle & Adapter	6TM60
Pressure Relief Valve ½"	7TM60
Regulator	8TM60
Mounting Ring (2 ea.)	8TM60-A
Straight JIC	9TM60
1 ½" Hose Fittings (2 ea.)	10TM60
1 ½" Air Equip Hose (6ft.)	11TM60
1 ½" Straight JIC	12TM60
Double Male Hex Nipple Brass	13TM60
1" Hose Fittings (2 ea.)	14TM60
1" Air Equip Hose (2 ft)	20TM60
Straight JIC	15TM60
Straight Male Adapter	16TM60
Coupler	17TM60
Pipe Cross Female Branch	18TM60
Service Tee Female Branch	19TM60
FP-MP Branch Tee (2 ea.)	21TM60
Bulk Head Fitting (3 ea.)	22TM60
T-120 Industrial Air Cylinders (2 ea.)	23TM60
Standard Valve Compressed Air (2 ea.)	24TM60
Long Handle Pressure Cap	27TM60
Inside Lug Bushing Without Screen	28TM60
Poly Based Frame	29TM60
60 GAL. Tank	30TM60
1" Saberjet Nozzle Single Shutoff	67TM60
1" X 1 ½" Saberjet Adapter	68TM60
Nozzle, Smooth Bore Tip ¾"	31TM60
Hooklok	32TM60
1" Ball Valve (Discharge)	33TM60
1" Ball Shut off w/Swivel & Pistol Grip & Tip	34TM60
TM60 Manual	36TM60
Tri-Max 60 Low Profile Cover	37TM60
¾" Male Elbow	38TM60
¾" Hose Fitting	39TM60
½" Vent Hose (12 ft.)	40TM60
DESCRIPTION	PART #
Low Pressure Gauge	41TM60
High Pressure Gauge	42TM60
Check Valve	43TM60
½" 90 degree Male Elbow (4 ea.)	44TM60

¼” 90 degree Male Elbow (5 ea.)	45TM60
45 degree Male Elbow JIC-NPT	46TM60
¾” Closed Nipple (3 ea.)	47TM60
¼” JIC Straight (12 ea.)	48TM60
90 degree Pipe Elbow Male	49TM60
Pipe Reducer Bushing	50TM60
Pipe Coupling	51TM60
90 degree Female Elbow (3 ea.)	52TM60
Pipe Coupling Male	53TM60
SCBA to Scuba Fitting	54TM60
Reducer	55TM60
Male Reducer	56TM60
¾” Brass Ball Valve (2 ea.)	57TM60
Directional ½” Check Valve (2 ea.)	58TM60
Swing Valve (Flapper Valve)	59TM60
1” Booster Hose (100 ft.)	60TM60
¼” Check Valve	62TM60
¼ Hose Fitting (16 ea.)	63TM60
¼” Air Equip Hose (12 ft.)	64TM60
Tank Fill Dust Cap	65TM60
Funnel Adapter 2 QT.	66TM60
FA-Scuba Tester	101B
Scuba Regulator	101C
AFFF 3%, 6%	101D

5-4. SPECIAL TOOLS & ACCESSORIES

A. PRESSURE TESTER**:** A hand held gauge to easily determine the amount of pressure in the Air Cylinders is available from the manufacturer or local distributors. A scuba connection adapter is provided and should be installed in the industrial bottle fitting prior to connecting the pressure tester.

B. FUNNEL: A Two (2) Quart threaded funnel is provided with each unit to fill the Premix Tank.

5-5 MAINTENANCE LOG

TRI-MAX SUPER 60 SKID MAINTENANCE LOG

PREVENTATIVE MAINTENANCE CHECKS & SERVICES (PMCS)

SCHEDULED DATE	DATE COMPLETED	SIGNATURE

SCHEDULED MAINTENANCE

ACTION	DATE DUE	DATE COMPLETED	SIGNATURE
Check Air Cylinder pressures	(6 months)		
Wash unit & apply WD40 or equivalent over non-painted surfaces	(6 months)		
Lubricate and recycle pressure relief valve	(6 months)		
Air Cylinder visual inspection and certification	(12 months)		

TRI-MAX SUPER 60 SKID MAINTENANCE LOG (Continued)

SCHEDULED MAINTENANCE (Continued)

ACTION	DATE DUE	DATE COMPLETED	SIGNATURE
System Operations check	___________ (12 months)	_____________	___________________
Air Cylinder hydrostatic test	___________ (5 years)	_____________	___________________
Premix Tank & Discharge Hose hydrostatic test	___________ (5 years)	_____________	___________________

UNSCHEDULED MAINTENANCE

ACTION	DATE COMPLETED	SIGNATURE
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________
___________________________	____________	_____________________

5-6. SERVICING UNDER NORMAL CONDITIONS

A. SYSTEM PRESSURE CHECK

(1) Ensure the Pressure Vent Valve, Water/Chemical Fill Port, and the Foam Charge Valves are closed.

(2) Open one Air Cylinder and check the pressure reading on the High Pressure Air Cylinder Gauge is between 2000-2250 psi. Check the pressure on the Premix Tank gauge is between 150-175 psi. Close the Air Cylinder and open the Pressure Vent Valve to release pressure in the Premix Tank. Open the other Air Cylinder and check for an operating pressure of 2000-2250 psi. Close the Air Cylinder.

(3). Conduct a leak check if either Air Cylinder pressure is below 2000 psi or if any air noise or solution leaks are detected.

(a) Spray a light soap solution on all air lines and fittings to check for leaks.

(b) Tighten leaking fittings or replace O-rings.

(c) Contact manufacturer if regulator has an internal leak.

(d) Recharge and replace the Air Cylinder(s).

B. AIR CYLINDER PRESSURE CHECK, RECHARGE AND REPLACEMENT

CAUTION

Ensure the system is depressurized before conducting any maintenance on the system. The Air Regulator can be damaged if removal is attempted with pressure in the system. Extreme care should be used when handling and transporting the Air Cylinders. Do not fully drain the Air Cylinders as this will allow moisture to enter the cylinders. Ensure that all replacement o-rings for the Air Cylinder valve and the Air Cylinders are purchased from the factory, a TRI-MAX distributor, or a certified scuba shop

NOTE

Ensure the O-ring is secured when removing and transporting the Air Cylinder.

(1) AIR CYLINDER PRESSURE CHECK: Check the Air Cylinder pressures for normal operating pressure (2000-2250psi).

(a) Open Air cylinder Valve on One (1) Air Cylinder.

(b) Ensure pressure on Air Cylinder High Pressure gauge is within normal operating pressure range. (2000-2250 psi).
(c) Close Air cylinder Valve on Air Cylinder.
(d) Repeat procedure for Secondary Air Cylinder.

This method will result in the loss of 50-100 lbs of air per cylinder which, in turn, will require a more frequent refilling of the Air Cylinders.

Conduct a leak check if either Air Cylinder pressure is below 2000 psi:

(a) Turn on Air Cylinder(s) that showed low pressure.
(b) Spray a light soap solution on all air lines and fittings.
(c) Close Air Cylinder Valve(s).
(c) Tighten fittings, replace O-rings, or replace leaking component.

(2) AIR CYLINDER RECHARGE

Single point Air Cylinder Re-Charge Port Procedure

(a) Remove Air Cylinder Re-Charge Port cover

(b) Connect Air line from Air Compressor or Cascade System with screw on adapter.

(c) Open the Air Cylinder Valve on desired cylinder

(d) Turn Regulator knob counterclockwise to shut off low pressure air to premix tank.

NOTE:
Do not allow high pressure air to bleed into Pre-Mix tank during refill process. Air pressure will register on low pressure gauge (if pressure vent valve is closed) if pressure is allowed into Pre-Mix tank.

(e) Turn on Air Compressor or Cascade System to pump air into cylinder.

(f) Monitor High Pressure Air Cylinder Gauge and fill Air Cylinder until Gauge reads 2250 psi or just above.

(g) Close Air Cylinder Valve once pressure reaches desired pressure.

(h) Repeat steps c-f on Secondary Air Cylinder is necessary.

(i) Remove Air line from Single Point Re-Charge Port.

(j) Replace Air Cylinder Re-Charge Port cover

Cylinder Re-Charge Removal Procedure

(a) Ensure the Air Cylinder Valve is closed.

(b) Depressurize the system by opening the Pressure Vent Valve.

(c) Unscrew the Air Cylinder connector.

(d) Lift out the Air Cylinder.

(e) Have the Air Cylinder filled to 2250 psi. Either compressed air or nitrogen can be used in the Air Cylinders.

(f) Verify the Air Cylinder pressure using the pressure tester.

(g) Replace the Air Cylinders in the cradle.

(h) Re-connect airline to air cylinder and replace regulator.

(i) Turn on Air Cylinder and verify 2000-2250 psi pressure if the pressure was not verified by using a pressure tester.

C. PREMIX TANK FILLING

CAUTION

Ensure the system is depressurized before conducting any maintenance on the system. Also ensure the Water/Chemical valve is closed prior to pressuring the system to prevent a backsplash of the solution which might cause an injury to personnel.

(1) Close the Air Cylinder Valves.

(2) Close the Foam Charge Valve.

(3) Open the Pressure Vent Valve slowly and leave open.

(4) Open the Water/Chemical Fill Port

(5) Add water until the Premix Tank is approximately 75% full (Water level can be determined by placing your hand on the side of the tank to determine temperature.

(6) Add the appropriate amount of foam agent: 2 gallons for Class A (Wildfire), 4 gallons for 3% AFFF, training foam and liquid Dawn dish soap (for training only), 4 gallons for 6% AFFF, and 60 gallons for Freeze Protected Foam solutions

(7) Add water until it flows out of the Pressure Vent Valve drain line.

(8) Close the Water/Chemical Fill and Pressure Vent Valves. Remove the water hose.

CAUTION

Failure to close the Pressure Vent Valve will cause the Premix Tank drain hose to oscillate and may cause injury to personnel.

(9) Purge the solution from the Water/Chemical fill lines to prevent freezing by waiting 5 minutes for the solution to settle, opening both tank valves, and closing the valves. An alternate method is to use air to force the solution into the tank after the foam has settled.

(10) Note the type of foam and mixture ratio on a self-installed water proof label applied in a visible area on the Premix tank.

5-7. SERVICING UNDER COLD CONDITIONS

A. Fill the Premix Tank with Freeze Protected Foam solution whenever the existing temperatures are below 32 degrees F. Freeze protected foam solution provides coverage down to –40 degrees (F/C). Freeze Protected Foam solutions should be used in the concentrate form and not diluted.

5-8. SCHEDULED MAINTENANCE RECOMMENDATIONS:

A. AIR CYLINDERS

(1) Pressures to be checked at least every 6 months.
(2) An annual visual inspection be completed every 12 months
(3) A hydrostatic test to be completed every 5 years.

B. CLEANING AND LUBRICATION: (Complete at least every 6 months)

(1) Wash unit with soap and water.
(2) Apply WD40 or equivalent on all non-painted surfaces.
(3) Apply WD40 on Pressure Relief Valve and recycle.

C. PREMIX TANK:

(1) Pressurize and check for leaks every 12 months.
(2) Hydrostatic test be completed every 5 years. This test includes an internal and external visual inspection as well as pressure testing the hose and tank.

D. DISCHARGE HOSE: Hydrostatic test be completed every 5 years.

E. FOAM SOLUTION: The foam solution should be tested bi-annually per the guidance outlined in the National Fire Protection Association standards. It is recommended that only one system be tested annually providing the same brand, type of foam, and water source (if mixed) is used in all of the systems. An independent foam testing laboratory is Dyne Technologies, 2357 Ventura Dr., Suite 108, Woodbury, MN 55125, (866) 713-2299.

F. PERFORMANCE CHECK

(1) The system should be pressurized and discharged once a year.
(2) Freeze Protected Foam solutions can be reused if desired.

5-9. UNSCHEDULED MAINTENANCE

A. Unscheduled maintenance will need to be performed as required. Contact the manufacturer if a malfunction cannot be corrected after employing good troubleshooting procedures.

B. The following procedures should apply to all TRI-MAX SUPER 60 SKID systems:

(1) REPLACE AIR REGULATOR

NOTE

The Regulator is adjustable; however, the pressure is set at the factory at 150-160 psi.

REMOVAL PROCEDURE

1. Ensure air cylinder valves are closed.

2. Depressurize system by opening the pressure vent valve. Verify all pressures read 0 psi.
3. Remove both ¼” hose lines from both the low (300 psi) and the high (5000 psi) pressure gauges.
4. Remove both ¼” hose lines from the pressure out ports on the air regulator.
5. Remove adjustment knob from the regulator, slide regulator back.

6. Remove remaining hoses and fittings from the regulator and replace in the same position on the new regulator.

INSTALLATION PROCEDURE

1. Slide the regulator into position and attach both ¼” in and out lines using two wrenches to prevent damage to the hoses and regulator.
2. Reattach ¼” hoses to the low (300 psi) and the high (5000 psi) gauges. Tighten bolts in the ring to the regulator.
3. Re-install the knob.
4. Charge the system by opening air cylinder valve.
5. Check for leaks using soap and water spray.

(2) REPLACE GAUGES

CAUTION

Ensure the system is depressurized before conducting any maintenance on the system.

(a) Ensure that the Air Cylinder Valve is closed.

(b) Depressurize the system by opening the Pressure Vent Valve. Ensure all pressure gauges read 0 psi.

(c) Remove gauge using proper wrenches.

(d) Install new gauge.

(e) Charge the system by opening Air Cylinder Valve and check for leaks by squirting soap solution on connections.

(3) REPLACE PRESSURE RELIEF VALVE

(a) The **PRESSURE RELIEF VALVE** is located on top of the PREMIX TANK.

(b) Ensure the Premix Tank is fully depressurized.

(c) Remove defective Pressure Relief Valve and install new one.

(d) Pressurize the system and check for air stabilization and leaks.

(4) REPLACE CHECK VALVE:

(a) Depressurize system

(b) Remove defective check valve by removing airline

(c) Replace new check valve.

(d) Replace air lines

(e) Complete air line leak check

5-10. TROUBLESHOOTING

A. NO PRESSURE ON GAUGES

(1) Air Cylinder Valve is not turned on.
(2) Air Cylinders are empty.
(3) Pressure indicating Gauge is inoperative.
(4) Broken or blocked air line.
(5) Air Regulator has malfunctioned.

B. FOAM DOES NOT DISCHARGE FROM HOSE

(1) Premix Tank is empty.
(2) Air Cylinder is empty.
(3) Air Cylinder is not turned on.
(4) Foam Charge Valve is off.
(5) Nozzle is in the off position.
(6) Nozzle valve has malfunctioned.
(7) Blockage in the dispensing hose.
(8) Foam solution in Premix Tank is frozen.
(9) Faulty check valve

C. AIRLINE LEAK

(1) Air hose fitting is loose or broken.
(2) Air line is blocked or broken.

D. SYSTEM IS NOT FULLY DISCHARGING

(1) Insufficient volume of air in the Air Cylinder.
(2) Foam Discharge Nozzle is not fully opening.
(3) Foam Discharge Hose has a restriction.
(4) Air Regulator has malfunctioned or is not properly adjusted (Arctic Regulator only).
(5) The solution is frozen or near freezing.
(6) There is a blockage in the Premix Tank.
(7) Defective check valve

E. SOLUTION IS RUNNING OUT OF PREMIX TANK OVERFLOW

Pressure vent valve is open.

F. SOLUTION IS RUNNING OUT OF WATER/CHEMICAL FILL PORT

Water/Chemical Fill Port is open.

5-11. STORAGE AND PROTECTION

A. A PMCS should be conducted if the system has been placed in storage prior to placing the unit in an operational status.

B. It is recommended that a weatherproof protective cover be used if the unit is going to be positioned outside. Ultraviolet sun-rays can cause long term damage to the hoses and gauges if the unit is not covered. Additionally, frozen rain and snow can restrict the movement of discharge hose. A heavy duty protective cover with reflective markings and frame securing devices is available from the manufacturer.

Kingsway Industries, Inc.
6680 Lockheed Dr., Suite B, Redding, CA 96002
530.722.0272 | Fax 530.722.0450 | www.trimax.us

SPECIFICATIONS
TRI-MAX 30 WHEELED

AGENT TANK:

The agent tank shall hold 30 gallons of pre-mix foam agent and shall be manufactured in accordance with ASME standards. The tank fill shall include a fill funnel plus a garden hose adapter to facilitate easy foam and water filling. The tank shall be coated with an epoxy polyurethane red paint.

TRANSPORT FRAME:

A tubular steel framework shall support the agent tank, two (2) high pressure air vessels and discharge hose. The unit shall incorporate a "roll bar" design to protect components from accidental damage. Two (2) large semi-pneumatic tires plus two (2) swivel wheels and tow bar shall allow the unit to be horizontally towed and maneuvered at the fire scene or to be wheeled and positioned vertically. The frame and roll bar shall be coated with an epoxy polyurethane yellow paint.

AIR SUPPLY:

Two (2) 80 cu. Ft. 3,000 psi Scuba air cylinders shall be provided. One (1) air cylinder shall be capable of discharging the full agent tank at normal blend-air settings. High pressure air hose and connections shall be rated for 6,000 psi. One or two high volume air regulators (87 cfm, 155 psi) shall be provided, matched to the discharge flow rating. All low pressure air hose shall be steel braided, ¼" 300 psi, 302˚ F. All ball valves shall be rated for 400 psi. A pressure relief valve shall be provided, set at 200 psi. Pressure gauge(s) shall be provided to indicate system operating pressure(s).

DISCHARGE SYSTEM:

50 ft. of 1" rubber discharge hose shall be provided (maximum hose lay – 200 ft.). A blend-air valve shall be conveniently located to adjust the foam expansion ratio from 5:1 to 20:1 or more. The pressurization shall be a quick opening valve on the low pressure side of the regulator allowing the system to be stored and transported without pressure until needed for fire fighting (activation time 5 sec.).

PERFORMANCE:

The unit shall be capable of discharging up to 600 gpm of finished foam product. Duration time shall be from 1 ½ to 6 minutes depending on discharge rate. Foam coverage distance shall be 75 ft. or more.

SIZE AND WEIGHT:

The unit shall be compact and portable with a height of 36", width of 33" and length of 44". A fully charged 2 bottle system shall weigh approximately 577 lbs.

OPTIONAL FREEZE PROOF FOAM

Tri-Max -40F/-40C foam shall be provided in 5 gal. containers. The foam shall be bio-degradable and emulsify with flammable liquids. The foam shall contain no fluorocarbons and no ozone depleting substances.

Final

FINAL INVESTIGATION REPORT

CARIBBEAN PETROLEUM TANK TERMINAL EXPLOSION AND MULTIPLE TANK FIRES

CARIBBEAN PETROLEUM CORPORATION (CAPECO)

BAYAMÓN, PUERTO RICO

OCTOBER 23, 2009

KEY ISSUES:

TANK OVERFILL PREVENTION

COMMUNITY IMPACT

HAZARD ASSESSMENT

SAFETY MANAGEMENT SYSTEM

REGULATION GAPS:

- NO RISK ASSESSMENT CONSIDERING PROXIMITY TO COMMUNITIES
- NO ADHERENCE TO RAGAGEP
- NO REDUNDANT OR INDEPENDENT SAFEGUARDS TO PREVENT OVERFILLING A TANK

REPORT NO. 2010.02.I.PR
U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

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CONTENTS

Figures

Tables

Appendix

Acronyms and Abbreviations

ALARP	As low as reasonably practicable
AOPS	Automatic Overfill Prevention System
API	American Petroleum Institute
AST	Aboveground Storage Tank
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives
ATG	Automatic Tank Gauge
Bbls	Barrels
bbls/hr	Barrels per hour
BSTG	Buncefield Standards Task Group
CA	Competent Authority
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAPECO	Caribbean Petroleum Company
cbm/hr	Cubic meter per hour
CCPS	Center for Chemical Process Safety
CERCLA	Comprehensive Environmental Response, Compensation, and Liability
CH	Critical high level
COMAH	Control of Major Accident Hazards
CSB	U.S. Chemical Safety and Hazard Investigation Board
CWA	Clean Water Act
DFA	Direct Federal Assistance
DOH	Department of Health
DOJ	Department of Justice
EPA	Environmental Protection Agency
ESF	Emergency Support Function Annexes
FEMA	Federal Emergency Response Agency
FRP	Federal Response Plans
HAZOP	Hazard and Operability Study
HH	High-high level
HSE	Health and Safety Executive
ICC	International Codes Council
IFC	International Fire Code
IFR	Internal Floating Roof
ILTA	International Liquid Terminals Association
IOC	Indian Oil Corporation (IOC) Petroleum Oil Lubricants
IPL	Independent Protection Layer

IPAA	Independent Petroleum Association of America
ISA	International Society for Automation
JIC	Joint Incident Command
kPa	Kilopascal
LOC	Level of concern
MIIB	Major Incident Investigation Board
MOC	Management of Change
Mph	Miles per hour
MW	Maximum Working Level
NASA	National Aeronautics and Space Administration
NIMS	Incident Command System/National Incident Management
NFPA	National Fire Protection Association
OPA	Oil Pollution Act
OPP	Overfill Prevention Process
OSHA	Occupational Safety and Health Administration
PREPA	Puerto Rico Electric Power Authority
PHA	Process Hazard Analysis
PR DNR	Puerto Rico Department of Natural Resources
PR OSHA	Puerto Rico Occupation Safety Health and Administration
PREMA	Puerto Rico Emergency Management Agency
Psi	Pounds per square inch
Psia	Pounds per square inch absolute
PSM	Process Safety Management
RAGAGEP	Recognized and Generally Accepted Good Engineering Practices
RCRA	Resource Conservation and Recovery Act
RMP	Risk Management Program
SBA	Small Business Administration
SCO	State Coordinating Officer
SIF	Safety Instrumented Functions
SIL	Safety Integrity Levels
SIS	Safety Instrumented System
SOPs	Standard Operating Procedures
UCP	Unified Command Post
UK	United Kingdom
USCG	US Coast Guard
USFWS	US Fish and Wildlife Service
WWT	Wastewater treatment

1.0 EXECUTIVE SUMMARY

1.1 Incident Summary

On the night of October 23, 2009, a large explosion occurred at the Caribbean Petroleum Corporation (CAPECO) facility in Bayamón, Puerto Rico, during offloading of gasoline from a tanker ship, the *Cape Bruny*, to the CAPECO tank farm onshore. A 5-million gallon aboveground storage tank (AST) overflowed into a secondary containment dike. The gasoline spray aerosolized, forming a large vapor cloud, which ignited after reaching an ignition source in the wastewater treatment (WWT) area of the facility. The blast and fire from multiple secondary explosions resulted in significant damage to 17 of the 48 petroleum storage tanks and other equipment onsite and in neighborhoods and businesses offsite. The fires burned for almost 60 hours. Petroleum products leaked into the soil, nearby wetlands and navigable waterways in the surrounding area.

1.2 Public Impact and Emergency Response

The blast created a pressure wave registering 2.9 on the Richter scale[1] and damaging approximately 300 homes and businesses up to 1.25 miles from the site. In particular, the nearby Fort Buchanan military facility suffered over $5 million in damages; air and vehicle transportation was interrupted; and thousands of gallons of oil, fire suppression foam, and contaminated runoff were released to the environment. (Figures 9 and 10 show a map of communities neighboring the CAPECO facility and community damage.) CAPECO and the local fire department lacked the appropriate equipment or training to extinguish multiple tank fires, prolonging the environmental effects of the incident. The accident resulted in an emergency declaration for assistance from President Obama for the affected municipalities.

1.3 CSB Investigation

The CSB team arrived at the incident scene two days after the October 23, 2009, incident. The investigation team photo-documented the incident site, inventoried key evidence, interviewed witnesses, and assessed community damages. The team consulted tank experts and researched previous tank overfill incident investigations. Using several analytical tools, including timeline construction (Appendix A) and logic tree and AcciMap analysis[2] (Appendix C), the team

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[1] Puerto Rico Seismic Network. *Informe Especial, Explosión de Caribbean Petroleum en Bayamón, PR, 23 de octubre de 2009.* University of Puerto Rico Mayagüez Campus.

[2] AcciMap analysis is a causal diagram showing how factors remote from the immediate accident sequence contribute to the accident. Hopkins, A. An AcciMap of the Esso Australia Gas Plant Explosion. Australian

determined the root and systemic causes of this incident. The CSB investigators coordinated their work with the Puerto Rico Occupational Safety and Health Administration (PR OSHA) and the US Environmental Protection Agency (EPA).

1.4 CSB Findings

The CSB finds US regulations fail to consider bulk petroleum storage tank terminals similar to CAPECO as high-hazard facilities. Insufficient regulatory requirements for a hazard assessment, an unreliable level control and monitoring system, inadequate independent or redundant level alarms, and a poor safety management system led to CAPECO operating a high-hazard facility without the safeguards[3] necessary to prevent overfill. In addition, the CSB found the local Puerto Rico fire department was unprepared to address a vapor cloud explosion and multiple tank fires. This incident demonstrates that bulk aboveground tank terminals near residential populations are high-hazard facilities, and therefore regulations requiring a risk assessment and multiple layers of protection to prevent overfilling a tank, are necessary to protect workers and the public.

1.5 Key Findings

Physical Cause

1) During an operation to transfer gasoline from the vessel *Cape Bruny* tanker ship, Caribbean Petroleum Tank 409 overflowed with gasoline, resulting in a vapor cloud that encompassed 107 acres of the CAPECO tank farm.
2) The topography of the tank farm allowed the gasoline vapor cloud to migrate through open dike valves to low-lying areas of the tank farm and to the storm water retention pond in the wastewater treatment area, where it ignited.
3) Multiple physical causes likely contributed to Tank 409 overfill:
    - Malfunctioning of the tank side gauge or the float and tape apparatus during filling operations led to recording of inaccurate tank levels;
    - Normal variations in the gasoline flow rate and pressure from the *Cape Bruny* without the facility's ability to identify and incorporate the flow rate change in real time into tank fill time calculations may have contributed to the overfill;
    - Potential failure of the tank's internal floating roof due to turbulence and other factors may have contributed to the overfill.

National University. Obtained from http://www.qrc.org.au/conference/_dbase_upl/03_spk003_Hopkins.pdf (accessed January 2012).

[3] Safeguards are any device, system, or action that would likely interrupt the chain of events following an initiating event.

Control and Monitoring Failures

1) Inadequate tank filling procedures.
2) CAPECO's normal filling operations required that operators partially open the intake valve to a tank while filling another tank, because the pressure in the pipeline from the dock made manually opening a fully closed valve difficult. This inefficiency increased the potential error in fill time calculations. Refer to Section 6.9.4.
3) Unreliable tank gauging equipment.

Safety Management Systems

1) Tanks were not equipped with an independent high-level alarm system.
2) Tanks were not equipped with an independent Automatic Overfill Prevention System for terminating transfer operations.

Human Factors

1) The design of the dike valve system made it difficult to distinguish between open and closed valve positions
2) Insufficient lighting in the tank farm areas hindered operators from observing the overfilling of Tank 409 and the subsequent vapor cloud formation.

Lack of Reporting Requirements

1) An incomplete national incident database for assessing the frequency of specific types of incidents at bulk petroleum storage tank terminals inhibits the development and implementation of more tailored regulatory requirements, industry consensus standards, and best practices in this sector.

Emergency Response Findings

1) CAPECO and the local fire department lacked sufficient firefighting equipment to effectively fight and control a fire involving multiple tanks because they are not required to conduct a risk analysis where they have to consider and plan for the potential of a vapor cloud explosion involving multiple tanks.
2) CAPECO did not preplan with local emergency responders or adequately train facility personnel to deal with a fire involving multiple tanks.
3) Local fire departments lacked sufficient training and resources to respond to industrial fires and explosion.
4) A lack of coordination among the 43 federal, commonwealth and nongovernmental organizations that responded to the CAPECO incident further complicated the emergency response.

Regulatory Findings

1) The US regulatory system does not consider bulk aboveground storage tank terminals storing flammable liquid to be highly hazardous, even those near communities. Although the EPA characterizes facilities like CAPECO as substantial harm facilities, under the Facility Response Plan requirements, the risk assessment required for these facilities do not consider the potential of multiple tank releases as a worst case scenario.
2) Due to a lack of regulatory coverage under the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) standard and the Environmental Protection Agency's (EPA) Risk Management Plan (RMP), tank terminal facilities are not required to conduct risk assessments to address flammable hazards on site or to follow Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).
3) A high-level alarm system or high-integrity overfill prevention system are not required by OSHA's Flammable and Combustible Liquids standard, the EPA's Spill Prevention Control and Countermeasure (SPCC) requirements. While facilities covered under SPCC must certify a SPCC plan by a Professional Engineer, only the EPA FRP plans meeting the substantial harm criteria are approved by the EPA. Furthermore, under SPCC facilities similar to CAPECO do not have to report overfill incidents unless oil is discharged to navigable waters.

Industry Standards

1) Despite past incidents in the US and internationally, the response of US industry, trade associations, professional associations, and standard-setting organizations has been inadequate to prevent similar incidents in the US.
2) NFPA 30 only requires one layer of protection on storage tanks, at minimum consistent gauging without requirement for an independent or redundant level alarm or an automatic overfill prevention system.
3) ANSI/API 2350 only requires an automatic overfill prevention system for remotely operated facilities and does not offer substantial guidance on conducting a risk assessment that considers the complexity of site operations, the type of flammable and combustible liquids stored at the facility or proximity to nearby communities when considering the necessary safeguards to protect the public. In addition, there is a lack of one comprehensive industry standard to address tank terminal operations, including tank filling operations and overfill prevention.
4) ICC does not require an independent audible or visual alarm to indicate rising liquid levels.

To prevent a similar incident from occurring, the CSB recommends policy changes to the following regulatory agencies, consensus, and industry standard-making bodies:

- United States Environmental Protection Agency (EPA)

- United States Occupational Safety and Health Administration (OSHA)
- American Petroleum Institute (API)
- International Code Council (ICC)
- National Fire Protection Association (NFPA)

2.0 CARIBBEAN PETROLEUM CORPORATION

2.1 Company History

Petroleum refining operations first began at the CAPECO site in Bayamón, Puerto Rico in 1955. Ownership changed several times in the decades following the purchase of the refinery by Gulf Oil Corporation in 1962 and Chevron Corporation in 1984. First Oil Corporation acquired the refinery in 1987 and operated it as a 48,000 barrel-per-day petroleum refining facility until 2000,[4] when the refinery closed. After filing for bankruptcy in 2001, the company reorganized and reduced operations to the terminal and 170 Gulf service stations throughout Puerto Rico. CAPECO filed for bankruptcy in 2001 and reorganized in 2003 to operate solely as a petroleum storage terminal and distribution facility.

2.2 Status of CAPECO

In August 2010, CAPECO declared bankruptcy. (See Section 5.7.) On May 11, 2010, Puma Energy Caribe, LLC acquired the Bayamón facility and other CAPECO assets under a broader EPA settlement. The settlement required cleanup activities under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),[5] Resource Conservation and Recovery Act (RCRA),[6] and Oil Pollution Act (OPA).[7]

2.3 Site Description

The CAPECO site covered 179 acres, 115 of which were developed into four areas: a tank farm, the decommissioned refinery, an administration area, and a wastewater treatment (WWT) plant. (See Figure 1.) The facility also owned and operated a loading dock on San Juan Bay in Guaynabo, 2.5 miles northeast of the site. (See Figure 2.) At the time of the incident, CAPECO employed 65 people.

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[4] *Documentation of Environmental Indicator Determination RCRA Corrective Action Environmental Indicator (EI) RCRIS Code (CA725), Current Human Exposures Under Control* (U.S. Environmental Protection Agency, 1999).

[5] Congress enacted CERCLA, commonly known as Superfund, in 1980 to provide tax collected money to federal authorities to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. *CERCLA Overview* (Washington, DC: U.S. Environmental Protection Agency). http://www.epa.gov/superfund/policy/cercla.htm (accessed December 19, 2014).

[6] RCRA, enacted in 1976, gives EPA the authority to control hazardous waste from "cradle to grave." U.S. Environmental Protection Agency. http://www2.epa.gov/aboutepa/new-law-control-hazardous-wastes-end-open-dumping-promote-conservation-resources (accessed December 19, 2014).

[7] Signed into law in August 1990, the OPA improved the nation's ability to prevent and respond to oil spills by establishing provisions that expand the Federal government's ability and provide money and resources necessary to respond to oil spills. *Oil Pollution Act Overview* (Washington, DC: U.S. Environmental Protection Agency). http://www.epa.gov/osweroe1/content/lawsregs/opaover.htm (accessed December 19, 2014).

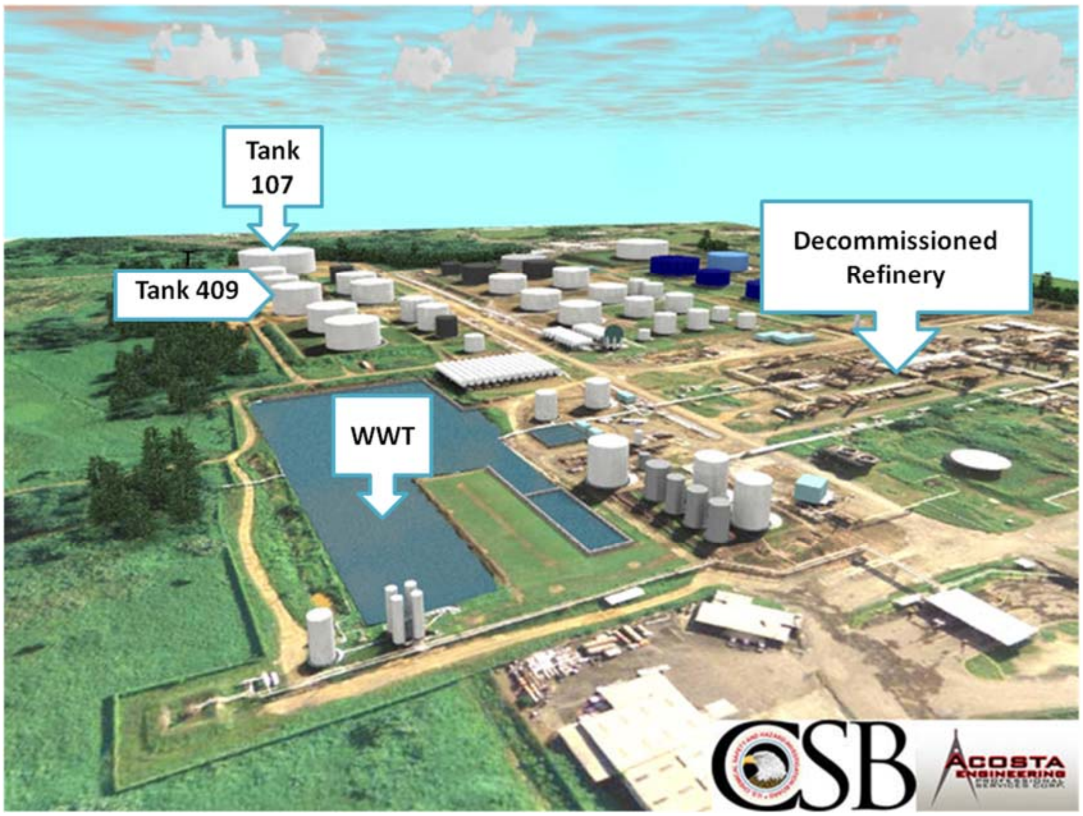

Figure 1: CAPECO tank farm, WWT, and decommissioned refinery overview

3.0 SITE OPERATIONS

CAPECO operated as a storage and distribution facility for gasoline, fuel oil, jet, and diesel fuel. The site was capable of storing approximately 90 million gallons of product.[8]

Figure 2: CAPECO Pipeline to Gulf Oil Dock where gasoline is offloaded from ships

3.1 Normal Site Operations

During normal site operations, vessels connected to the facility's pipeline at the dock in San Juan Bay and pumped petroleum products to one or more of the facility's aboveground storage tanks. Onsite, pumps transferred fuels between tanks, to the onsite truck loading facility, to the Puerto Rico Electric Power Authority (PREPA), and to the airport. Tanker trucks also received fuel onsite at the facility loading station for distribution across Puerto Rico.

3.2 Tank Farm Operations

Two tank farm operators, one WWT operator, and one shift supervisor conducted normal site operations staffing work on three 8-hour rotating shifts at the facility, from 6 a.m. to 2 p.m., 2 p.m. to 10 p.m., and 10 p.m. to 6 a.m.

Tank farm operators recorded tank levels every morning during a regular shift. Taking instructions from the facility's Planning Department, tank operators manually executed onsite

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[8] C. Jimenez, K. Glenn, G. Denning. *International Oil Spill Conference Proceedings, 2011 (1)* (Washington, DC, 1999). http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-2011-1-90 (accessed December 19, 2014).

fuel transfers, blending gasoline with methanol, pumping products to PREPA and the airport via the pipeline, and receiving shipments from the dock in San Juan Bay.

3.3 Storm Water and Oil Runoff Management

Normal operations at the tank farm required that one operator inspect the secondary containment area for accumulating storm water and oil. Operations staff managed the secondary containment valves that drained storm water through storm water pipes to the storm water retention pond in the WWT plant. The morning operator closed the dike valves after rainstorms, and the evening WWT operator (2 p.m. to 10 p.m.) verified the valves were closed. Operators then recorded the secondary containment valve position in a valve inspection log. When oil was present in secondary containment, operators used a vacuum truck to remove it. (See Section 6.9.1.)

3.4 Ship Unloading and Tank-Filling Operations

The CAPECO Planning and Economics Department (Planning Department) was integral to the operations of the tank farm and management of fuel transfer operations.[9] Its staff coordinated fuel deliveries with the company and its fuel suppliers and instructed operators on which tank to fill, specified the volume of materials, and determined the filling schedule during unloading operations.

Similar to other tank terminals, the CAPECO Planning Department directed operations in the tank farm. After obtaining tank levels from the night-shift operations staff, the Planning Department rented tank space to various petroleum vendors interested in storing gasoline, jet fuel, or fuel oil.

Prior to product delivery, the Planning Department, the petroleum vendor, and the fuel distributor, in this case the *Cape Bruny*, negotiated a fee schedule for charging CAPECO based on the length of time to complete tank-filling operations at the terminal. The purchase terms, fee schedules and delivery contracts contained credits and penalties for all parties involved in offloading operations. If CAPECO operators completed filling operations in less than the allotted time, the *Cape Bruny* would refund CAPECO fees for the unused time. If filling operations took longer, the *Cape Bruny* could charge CAPECO the negotiated rate for the additional time. The Daily Operation Report from the Planning Department contained all filling instructions,

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[9] Transfer operations for receiving a product into a tank encompasses all associated activities, including notification (verbally, electronically, or by other means) of a potential tank overfill and termination of flow into the tank (shutdown or diversion of product). American Petroleum Institute. *ANSI/API Standard 2350*. Fourth edition (Washington, DC: American Petroleum Institute, May 1, 2012).

including the level of product the tank should receive and the time it should take to fill the tank to the appropriate level. The Planning Department calculated the time based on the capacity of the pipeline and the volume discharged from the ship. CAPECO operations personnel were required to report any discrepancies in filling time to the Planning Department.

3.5 Communication

Due to the manual nature of operations, communication was essential to the success of the unloading process. During unloading operations, the operators remained in communication via radio with the WWT operator or the shift supervisor to ensure all necessary valve alignments and efficient switching between tanks occurred. Tank sizes varied at the CAPECO tank terminal, and only one tank, Tank 107 (Figure 1), was large enough to receive a full shipload of gasoline from the *Cape Bruny* tanker ship. In addition, due to storage limitations only a few designated tanks held gasoline. Because of this arrangement, CAPECO tank operators commonly switched flow among multiple tanks during unloading operations of a single shipment, requiring constant contact between tank operators and the shift supervisor.

3.6 Process Description

3.6.1 Level Measurements

CAPECO and cargo ship suppliers used multiple checks to ensure the correct amount of gasoline was unloaded and stored. Tank level measurement on a receiving tank occurred several times during filling operations. First, the tank farm operator recorded hourly readings by observing the level gauge on the side of the tank or the computer in the operator office displaying the same data. Then the tank farm operator and independent inspector placed car seals[10] on the appropriate receiving tank valves. Finally, the independent inspector[11] manually gauged the tank before and after filling operations and recorded it on gauge tickets shared with both the supplier and CAPECO. This dual verification measurement of tank levels was required for all material transfers involving a change of ownership.

[10] Car Seal: A security device consisting of a thin strip of metal cable usually attached to tank valve or hopper car closures. A broken seal indicates possible tampering or unauthorized tank entry.
[11] The independent, third-party inspector, employed by Intertek Caleb Brett, was responsible for determining the tank levels before and after filling operations to ensure that the correct amount of product was discharged to the tank. Caribbean Petroleum Corporation, Bayamón, PR. Communication, 2009.

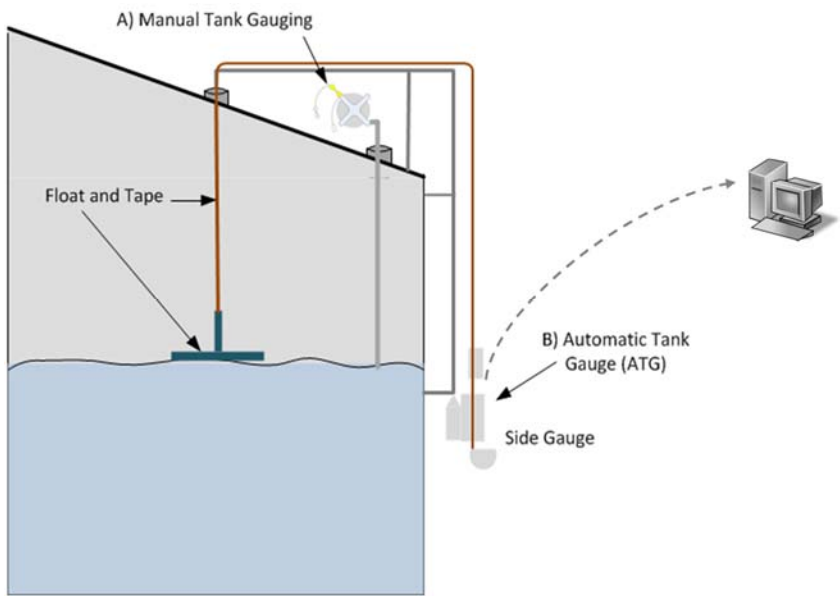

Figure 3: Manual and Automatic Tank Gauging. (A) Manual Gauging requires an operator to use a tape and measure to determine the liquid levels inside the tank. (B) Automatic Tank Gauging (ATG) requires an operator to read a level measurement from a tank gauge mounted to the side of the tank.

3.6.2 Manual Tank Gauging

Prior to the start and end of filling operations, the independent inspector manually measured the fuel tank levels by lowering a gauging tape[12] into the tank. (Figure 3.) A CAPECO operator

[12] The gauging tape used to measure tank liquid levels is similar to a common household measuring tape; it coils and has markings in feet and inches. Because gasoline and other fuels float on water, the operator coats the tape with special pastes to measure both the depth of water in the bottom of the tank and the fuel above it. Knowing the depth of the two liquids, the independent inspector and tank operators read the total liquid volume and the water volume from the strapping table. The operators subtracted the volume of water from the total volume to calculate the amount of fuel in the tank. When properly executed, this system accounted for the water volume and determined the fuel amount in a tank. Caribbean Petroleum Corporation, Bayamón, PR. Communication, 2009.

verified the measurements by comparing the tank liquid level to the strapping table[13] for that tank. The independent inspector and the operator placed car seals on various block valves of receiving tanks to prevent flow into or out of the tank before measuring the level in the tank and recording the readings on a form called a tank gauge ticket. This tracking method assured the transfer of an accurate volume of purchased product to the specified tank.

3.6.3 Manual and Automatic Tank Gauging

In addition to manual gauging by the independent inspector, operators used a float and tape gauge[14] mounted to the side of a tank, which automatically measured and displayed the tank level prior to the transfer, during transfer, and after product transfer termination.[15] *ANSI/API Standard 2350: Overfill Protection for Storage Tanks in Petroleum Facilities (2012)*[16] defines using float and tape level measurement instrumentation in this manner as an automatic tank gauging (ATG) system. (See Figure 4 and Section 6.5.)[17]

A typical float and tape gauge consists of depth-indicating dials, a motor, a long metal tape, and a sealed hollow cylinder called a float, which floats on the surface of the liquid in the tank. One end of the long metal tape attaches to the float, while at the other end, a motor winds the tape into a coil to maintain constant tension on the tape. As the liquid level in the tank falls, the weight of the float pulls the tape, and the motor allows the tape to extend farther into the tank. As the liquid level in the tank rises, the motor senses looseness in the tape and winds the tape into a coil to maintain the required tension. As the tape winds and unwinds, the mechanical dial rotates to indicate the total depth of liquid in the tank and displays the value on the side gauge (Figure 4).[18] Section 6.5 analyzes the failure of the ATG system in the incident.

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[13] Strapping table is a tabular record of a tank's volume versus height to convert measurements obtained from a tape (or strap) to liquid volumes. It is also known as a gauging table. *Access Engineering*, McGraw Hill. http://accessengineeringlibrary.com/search?q=strapping+table (accessed March 2012).

[14] The Shand and Jurs level instrument used by CAPECO is actuated by a float and stainless steel tape that measures tank levels recorded on a digital counter mounted to the side of a tank, allowing operators to read the tank liquid levels. *Automatic Tank Level Gauge Model 92021*. Product Data Sheet. Shand & Jurs: Hillside, IL.

[15] Termination refers to stopping flow of a product into a tank. American Petroleum Institute. *ANSI/API Standard 2350, Fourth edition* (Washington, DC: American Petroleum Institute, May 1, 2012).

[16] *ANSI/API Standard 2350-2012: Overfill Protection for Storage Tanks in Petroleum Facilities*. Fourth edition (Washington, DC: American Petroleum Institute, May 2012).

[17] This system is similar to the level measurement system that led to the CSB investigation of the explosion and fire at the Barton Solvents Wichita facility in Valley Center, Kansas. *CSB Barton Solvents Case Study. Static Spark Ignites Explosion Inside Flammable Liquid Storage Tank. No. 2007-06-I-KS* (Washington, DC: U.S. Chemical Safety Board, 2008). http://www.csb.gov/assets/1/19/CSB_Study_Barton_Final.pdf (accessed December 18, 2014).

[18] B. V Enraf. *The Art of Tank Gauging*. *http://enraf.ru/userfiles/File/4416650_rev4.pdf* (accessed January 2012).

3.6.4 Computer Monitoring of Tank Level

In 2004, CAPECO installed transmitter cards on the float and tape gauges that transmit the liquid depth to a computer in the operator's office, the shift supervisor's office, and the Planning Department. The computer instantaneously indicated the values for the liquid depth, the total volume based on the strapping table, and the flow rate into or out of the tank as it graphed the values over time and calculated the fill rate. When the computer data were unavailable, the shift supervisor and tank farm operator used information from the Planning Department, the start time of filling, and the strapping table, to calculate the estimated tank fill time. Refer to Section 6.5 for analysis of the automatic overfill prevention system and Section 6.7 for analysis of overfill prevention safeguards in place to prevent overfilling a tank.

Figure 4: Side gauge: mounted on the side on a tank and displaying the amount of liquid in the tank

4.0 INCIDENT DESCRIPTION

4.1 Physical Cause

On Wednesday, October 21, 2009, the *Cape Bruny* cargo ship arrived at the CAPECO dock in San Juan Bay to unload CAPECO's near-weekly shipment of more than 11.5 million gallons of unleaded gasoline. CAPECO assigned four personnel and three contract employees to assist in offloading gasoline from the *Cape Bruny* to various tanks on site.

Only Tank 107 with a capacity of 21 million gallons was large enough to hold a full shipment of gasoline, but it was already holding product. As a result, CAPECO planned to pump the gasoline shipment to four smaller storage tanks (405, 504, 409, and 411) and the balance to Tank 107, expecting the filling to take more than 24 hours (Figure 1). One CAPECO operator was overseeing transfer operations at the dock, while another was monitoring the gasoline delivery at the terminal. See Appendix A, Incident Timeline.

According to testimony and CAPECO records, shortly after noon on October 22, Tank 411 valve was fully opened but operations staff closed the valve to Tank 504 after observing the level gauge was physically stuck. Operators then fully opened the valve on Tank 409 and partially cracked the valve on Tank 411 directing more than 7,000 gallons of gasoline per minute into Tank 409 and allowing a small flow into Tank 411.

At approximately 6:30 p.m., the operator manually calculated that Tank 409 would reach maximum fill sometime between 9 p.m. and 10 p.m., during shift change. To avoid complications during shift change, the operator fully opened the valve on Tank 411 and almost completely closed the valve on Tank 409.

CAPECO operators often did not rely on the information displayed on the computer because the transmitters were frequently out of service. Therefore, under normal operation, operators manually recorded the hourly readings. On the night of the incident, the transmitter on Tank 409 was not sending level data measurements to the computer.

At 10 p.m., as Tank 411 reached maximum capacity and was closed, operators fully opened the valve on Tank 409. One operator then read the level on the Tank 409 side gauge and reported it to his supervisor, who estimated that the tank would be full at 1 a.m.

At the 11 p.m. walk-around, the tank farm operator observed the side gauge on Tank 409 during his hourly check. The operator called the level into the supervisor who calculated once again that the tank should be full at 1 a.m.; however, between the 11 p.m. and 12 a.m. check, Tank 409 began to overflow. At the 12 a.m. check, operations staff noticed a fog on the ground and on the road along Tanks 504, 411 and 409. Fuel gushed from the vents, creating a spray of gasoline that formed a vapor cloud and pooled in the secondary containment dike.

At midnight, the tank farm operator started to perform the hourly check of Tank 409, but before reaching the tank, he observed a vapor cloud and a strong smell of gasoline. He contacted the dock operator to halt the flow of gasoline to the tank and notified the WWT operator and his supervisor to meet at the western edge of the terminal. Despite the lack of illumination, they observed a white fog approximately three feet above the ground but could not hear or see gasoline overflowing from the vents on Tank 409 due to lack of lighting and the topography of the tank farm.[19] As they approached the fog, the men noticed the air cool as the fog condensed on their hands, despite the 79ºF temperature. Noting the potential danger, the supervisor sent one operator to the security gate, while the supervisor and another operator drove around the facility attempting to find the source of the leak and developing vapor cloud.

At 12:23 a.m., on October 23, 2009, security cameras at CAPECO and neighboring facilities recorded the ignition of the vapor cloud in the WWT area. About seven seconds after ignition, the vapor cloud exploded, creating a pressure wave that damaged hundreds of homes and businesses up to 1.25 miles from the site. The fire propagated through the vapor cloud and ignited multiple subsequent tank explosions registering 2.9 on the Richter scale.[20]

After the explosion, fuel in the damaged tanks burned for over two days while emergency responders fought to control the fire and prevent other tanks from igniting. The large fire demanded emergency personnel and resources from across the Commonwealth of Puerto Rico and the US mainland. Local fire departments with assistance from an industrial firefighting company took 66 hours to extinguish the fire after the explosion. As a result, 17 of the 48 tanks burned. (See Figures 5 and 6.)

[19] A CSB-commissioned topography study and visual modeling of the perspective from ground level on the night of the incident found that it would have been impossible for the operators and supervisor to observe the overflowing vents of Tank 409 because they were located a significant distance from the tank and at a lower elevation..

[20] Puerto Rico Seismic Network. *Informe Especial, Explosión de Caribbean Petroleum en Bayamón, PR, 23 de octubre de 2009.* University of Puerto Rico, Mayagüez Campus.

Figure 5: CAPECO multiple tank farm fire, October 23, 2009.

Figure 6: Impact of the explosion and multiple tank fires after the October 23, 2009 incident

4.2 Tank Overflow

Based on information from the *Cape Bruny* and CAPECO, the CSB calculated that Tank 409 overflowed for an estimated 26 minutes before the vapor cloud ignited (Table 1).

Table 1	
Estimated Volume of Gasoline Overfilling from Tank 409 during Filling Operations at CAPECO	
Tank	Estimated Volume of Gasoline into Tank
Tank 405	4,411bbls
Tank 504	62,984bbls
Tank 411	74,198 bbls
Tank 409	115,667 bbls
Total Offloaded Capacity	257,260 bbls
Total Offloaded from the Cape Bruny	261,878 bbls
Volume of Overfill	4,618 bbls
Volume of Overfill	193,974 gallons
*Overfill Duration	26 minutes
*Estimated flow rate 10,500 bbl/hr	
All calculations are approximations based on the tank gauging tickets and strapping tables from CAPECO.	

The CSB determined nearly 200,000 gallons of gasoline,[21] the equivalent of 20 fully loaded gasoline tanker trucks, rushed out of six vents in the tank. With a light breeze of about 5 mph[22] on a 79ºF night, the escaped gasoline formed a low-lying vapor cloud that encompassed an area equivalent to 107 acres.

The CSB found several possible scenarios could explain the tank overflow: malfunctions with the tank's internal floating roof, increased gasoline flow rate from the ship, and a malfunction

[21] This calculated value was obtained using the tank gauging tickets, strapping tables for each tank involved in offloading operations and the estimated flow rate based on the pump pressure from the Cape Bruny.

[22] According to the Beaufort Scale (Wind Speed), a light breeze is defined as 5-7 miles/hour. On October 22 and 23, 2009, the average wind speed in San Juan, PR (12 miles from Bayamon, PR) was 5 miles/hour. Beaufort Scales (Wind Speed). http://www.unc.edu/~rowlett/units/scales/beaufort.html (accessed June 2012). Weather Underground, http://www.wunderground.com/history/airport/TJSJ/2009/10/14/MonthlyHistory.html?MR=1 (accessed June 2012).

with the side gauge in addition to many systemic failures in CAPECO's safety management system. See Section 6.0 for incident analysis.

4.3 Vapor Cloud Formation and Migration

Tanks 409 and 410 were located within the same secondary containment dike.[23] Similar to the Buncefield incident,[24] during the overflow, gasoline sprayed from the tank vents, hitting the Tank 409 wind girder and aerosolized,[25] forming a vapor cloud.[26] A CSB topographic survey of the site shows that Tanks 409 and 411 were located at the highest point within the tank farm area, allowing the vapor cloud to spread to lower lying areas in the direction of the WWT (Figure 7). See Figure 14, Tank 409 Specifications.

[23] Federal aboveground storage tank (AST) requirements mandate that facilities storing a large amount of petroleum product construct secondary containment to hold the contents of the largest tank/container with sufficient freeboard for rain and be sufficiently impervious to contain discharged oil. Secondary containment must be impermeable to the stored materials and have a manually controlled sump pump to collect rainwater. 40 CFR 112.8(c)(2) states a facility "may empty diked areas by pumps or ejectors; however, you must manually activate these pumps or ejectors and must inspect the condition of the accumulation before starting, to ensure no oil will be discharged." Drainage must be addressed in accordance with 40 CFR 112.8(b)(1-5) and 112.8(c)(3) i-iv *Above Ground Storage Tank Requirements*, *Code of Federal Regulations, Part 112, Title 40*, 2002.

[24] The British Health and Safety Executive (HSE) performed a study to demonstrate the mechanism and rate of vapor formation after a similar gasoline tank overflow and subsequent vapor cloud explosion at the oil storage depot in Buncefield, England, in December 2005. The HSE study found that aerosolization occurs during free fall. As the gasoline splashes against the side of the tank and wind girder, the vapor formation rate increases. (A wind girder is a metal ring welded around the middle exterior circumference of a tank that reinforces its structural integrity.)

[25] Aerosolization is the production or dispersal of an aerosol from a solid or liquid.

[26] *Vapour Cloud Formation Experiments and Modelling.* RR908 (Harpur Hill, UK: Health and Safety Executive, 2012). http://www.hse.gov.uk/research/rrhtm/rr908.htm (accessed July 2012).

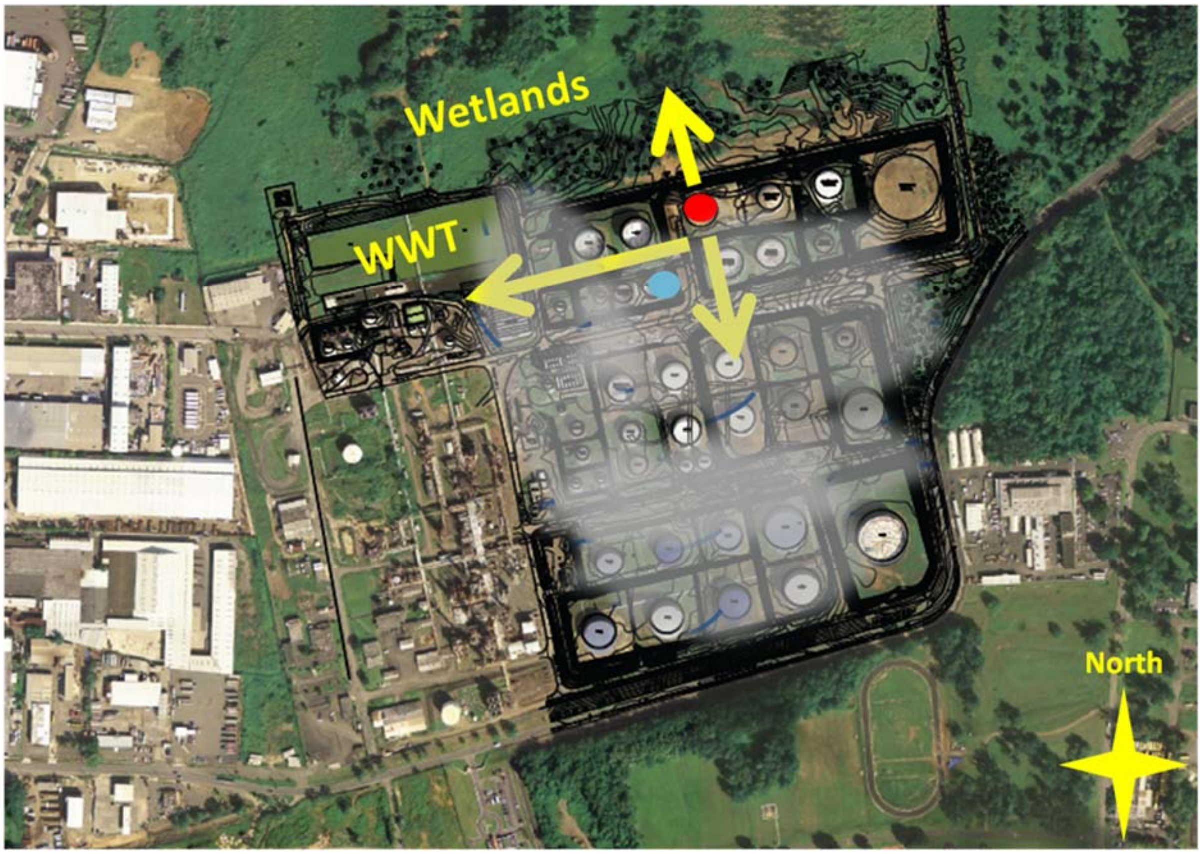

Figure 7. Topographic Survey of CAPECO Tank Farm showing the gasoline vapor cloud migration from higher elevation (Tank 409-Red and Tank 411-Blue) toward low-lying areas by the WWT plant, the south eastern end of the refinery and wetlands to the north. The cloud indicates the approximate area where the vapor cloud migrated based on surveillance footage.

4.4 Open Dike Drain Valves

Although the October 22, 2009, secondary containment valve inspection log indicated that the dike valve for Tank 409 was closed, the CSB determined that the valve was open after the incident.[27] The open dike valve directed gasoline to the storm water retention pond located in the WWT area where the large surface area pond provided a second location for gasoline to collect and vaporize. Refer to Section 6.9 for dike valve and human factors analysis.

[27] CSB investigators tested the dike valve after the incident by pouring water into the dike area of Tank 409 and observed the flow to the storm water retention pond in the WWT area through the underground storm water channel.

4.5 Ignition

The developing vapor cloud expanded from east to west toward the WWT area, north toward the wetlands area and the highway, south toward an east-west CAPECO site road, and east toward the neighboring Fort Buchanan (Figure 7). Onsite security video captured the ignition and initial flash fire in the WWT area occurring seconds before the explosion (Figure 8). The open secondary containment valves allowed the gasoline pool to extend to the storm water retention pond in the WWT area, which is not electrically classified.[28] The CSB did not determine the exact source of the ignition, but the areas where the vapor cloud traveled contained multiple potential ignition sources.

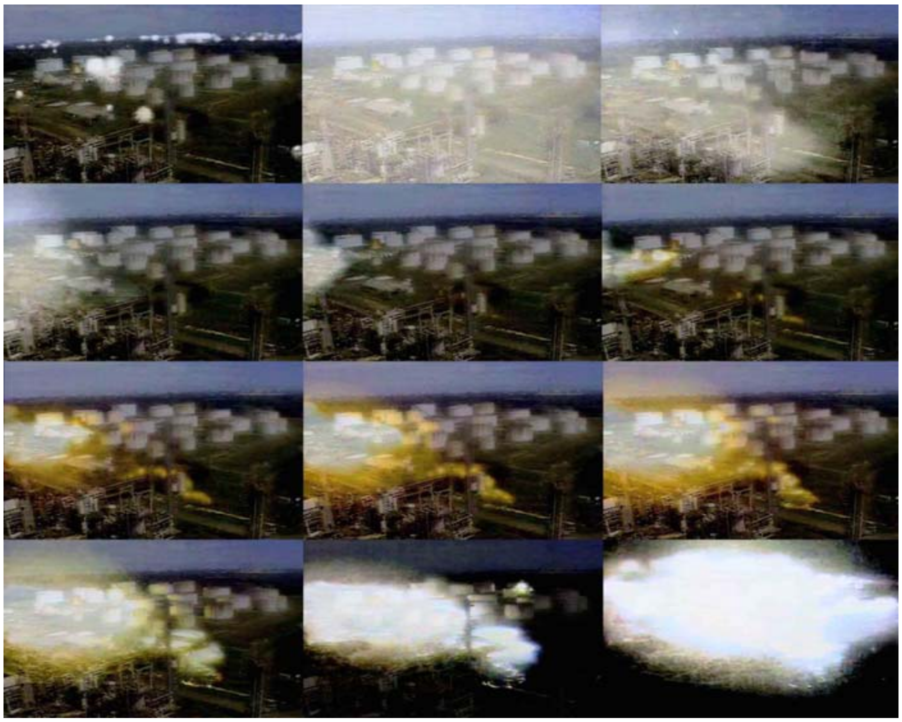

Figure 8: CAPECO surveillance footage of flame propagation during October 23, 2009 CAPECO explosion

[28] NFPA 70 defines hazardous (Electrically Classified) locations as areas where a fire or explosion hazard may exist because of the presence of flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers. *Electrical Classification: Using NFPA 70 and NFPA 499 to Classify Hazardous Locations*. http://www.oshainfo.gatech.edu/comb-dust/elec-classification.pdf (accessed December 17, 2014).

5.0 EMERGENCY RESPONSE

5.1 Response Description

Forty-three organizations responded to the incident, including federal, commonwealth, and nongovernmental organizations. The large number of responding agencies made communication difficult because the incident commander and the Unified Command Post changed frequently when different agencies claimed priority jurisdiction. The Bayamón and Cataño Fire Departments first arrived at the front gate of CAPECO at approximately 12:30 a.m. on October 23, 2009. At that time the fire had extended to approximately 103 acres (1,500 feet by 1,500 feet) of the tank farm, but firefighters were prohibited from entering the site until CAPECO safety personnel and the site fire chief arrived approximately 45 minutes later. Upon entering the facility, firefighters discovered that CAPECO lacked the necessary firefighting equipment to fight multiple tank fires at once. They found worn or missing fire hoses, stationary fire monitors without sufficient pressure to reach the tops of tanks, and insufficient equipment to provide the large quantities of foam necessary to control a fire of this magnitude.

Furthermore, CAPECO personnel and local firefighters were trained only for a worst-case scenario involving one tank on fire, rather than 11 tank fires at the same time caused by a vapor cloud explosion. Without sufficient equipment or training, local responders attempted to fight the multiple tank fires but failed as the fire encompassed more tanks.

The incident caused the governor of Puerto Rico to request federal assistance, and on October 24, 2009, the President signed an emergency declaration[29] providing assistance for the municipalities of Bayamón, Cataño, Guaynabo, San Juan, and Toa Baja (Figure 9). The federal emergency declaration activated 17 FEMA Emergency Support Function Annexes (ESF)[30] and enabled FEMA to provide logistical support, Direct Federal Assistance (DFA), and public assistance grants to state and local municipalities.[31] Logistical support included setting up a more

[29] On October 24, 2009, President Obama signed FEMA-3306-EM-PR for Category B (emergency measures) Direct Federal Assistance (DFA).

[30] During an Emergency Declaration, FEMA has jurisdiction to release funding under its 17 FEMA Emergency Support Function Annexes. The ESFs provides structure and support for coordinating a federal interagency response to an incident. *Emergency Support Function Annexes* (Washington, DC: U.S. Federal Emergency Management Agency, 2008).

[31] Through the Emergency Declaration request, Puerto Rico also requested DFA because it lacked the resources to handle the event. Under the Stafford Act, DFA states that the President can authorize 100% federal funding for emergency work: debris cleanup and/or removal; provision of food, water, ice, and other consumable commodities; and other emergency protective measures, under sections 403 and 407. The President also authorized the state and municipalities affected by the incident to be reimbursed for emergency protection measures through FEMA's Public Assistance (PA) grant programs.

than 400-person Incident Command Post to assist state and federal agencies and to circulate information to the media and respond to public inquiries. In addition to the 530 firefighters and other responding agencies, approximately 900 National Guard personnel provided support in firefighting efforts, transportation, security, and environmental assessments. These efforts continued until Sunday, October 25, 2009, at 11:30 a.m., when the fires were extinguished.[32] Ultimately, FEMA provided over $3.4 million[33] to 27 entities for response efforts during and after the incident.

5.2 Response Assessment

The CSB found the following shortcomings in the emergency response to the CAPECO incident, many of which were also identified in the FEMA After Action Report,[34] compiled after the incident.

- *Insufficient equipment*. Tank terminals like CAPECO are not considered high-hazard facilities under existing EPA and OSHA regulations;[35] therefore, they are not required to conduct a risk analysis where they consider the potential of a vapor cloud explosion and multiple tank fires. Neither CAPECO nor the fire department had the requisite amount of foam and adequate equipment to effectively fight and control a fire involving multiple tanks.

- *Insufficient preplanning with local fire departments or firefighter training at the site level*. CAPECO did not preplan with local emergency responders, set up mutual aid with other hazardous materials sites, or adequately train facility personnel to address a tank farm fire involving multiple tanks. The CSB found that after the refinery shut down in 2000, the facility curtailed investment into its firefighting operations on-site. In fact, training for CAPECO personnel was limited only to fighting a fire involving one tank, not an incident involving multiple tanks.

- *Limited emergency preparedness*. Local fire departments did not have sufficient training or resources to respond to industrial fires and explosions, which resulted in firefighting delays from insufficient foam and equipment. The limited training and resources of the local fire

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[32] The PR Fire Department extinguished the fires with assistance from a contractor that specialized in tank farm firefighting.

[33] *Summary of Declaration Report: Public Assistance Program* (Washington, DC: U.S. Federal Emergency Management Agency, June 11, 2012).

[34] *Caribbean Petroleum Corporation (CaPeCo) / Gulf Refinery Explosion After Action Report (AAR)*. FEMA 3306-EM-PR. October 23-26, 2009 (Washington, DC: U.S. Federal Emergency Management Agency, 2010).

[35] EPA considers facilities as CAPECO as a “significant and substantial harm facility” under the Facility Response Plan regulations. See Section 8.6.6 for further discussion.

departments resulted in an inefficient firefighting operation. The fires were not extinguished until an industrial firefighting company suppressed the last of the tank fires. FEMA's After Action Report identified additional training and exercises for the Incident Management Team on an all-hazards approach to improve the initial multiagency response and recovery.

- *Overlapping multi-agency, multi-jurisdictional response*. Forty-three federal, commonwealth, and nongovernmental organizations responded to the incident.[36] As new agencies arrived, the person in the Incident Commander role changed without following the Incident Command System/National Incident Management System (ICS/NIMS). For example, the Puerto Rico Emergency Management Agency (PREMA) operated using ICS/NIMS, whereas the PR National Guard conducted operations using military standards.[37] FEMA's After Action Report also identified poor integration of Unified Command with the National Guard and PREMA after the Governor's office declared the emergency. The report further emphasized the need for additional joint training and exercises to improve the integration of the ICS with the NIMS. The FEMA report also calls for the development of Mass Fatality and Mass Casualty plans to address catastrophic incidents.

5.3 Incident Impact

5.3.1 Community Impact

Despite approximately 1,600 people residing adjacent to the CAPECO facility in the Puente Blanco community[38] and about 48,500 residents living in Cataño three miles from the incident site (Figure 9), the 2009 explosion and fires did not result in any fatalities. However, shrapnel and glass from the blast caused minor injuries to three people at Fort Buchanan. Nearby residents of the surrounding communities were awakened by the blast and ensuing fire. The CSB learned, regulatory authorities in Puente Blanco issued unclear evacuation orders by bullhorn as they drove through the community. With no planned evacuation routes or shelters, residents crowded into the narrow streets. Some members of other nearby communities evacuated voluntarily to escape damaged homes and potential health effects from the smoke and vapors generated by the fire.

[36] *Caribbean Petroleum Corporation (CaPeCo) / Gulf Refinery Explosion After Action Report (AAR).* FEMA 3306-EM-PR, October 23-26 2009 (Washington, DC: U.S. Federal Emergency Management Agency, 2010): 9.9.
[37] Ibid., p.6.
[38] Ibid., p.4.

Fort Buchanan experienced the most severe damage—suffering an estimated $5 million in repair costs. Community impact assessments[39] found most of the structural damage occurred in the Puente Blanco neighborhood where PREMA and the Department of Housing (DOH) found damage to 232 of the 266 homes assessed; 139 were repaired and six were demolished by November 2009.[40] The Puente Blanco community also experienced environmental contamination to several surface water bodies, including federally protected wetlands and streams surrounding the CAPECO site. After assessing 289 homes damaged by the explosion in the Cataño community, the Small Business Administration (SBA)[41] designated 25 single-family homes as destroyed or severely damaged at or beyond 40% of their fair market value. (See Figure 10.)

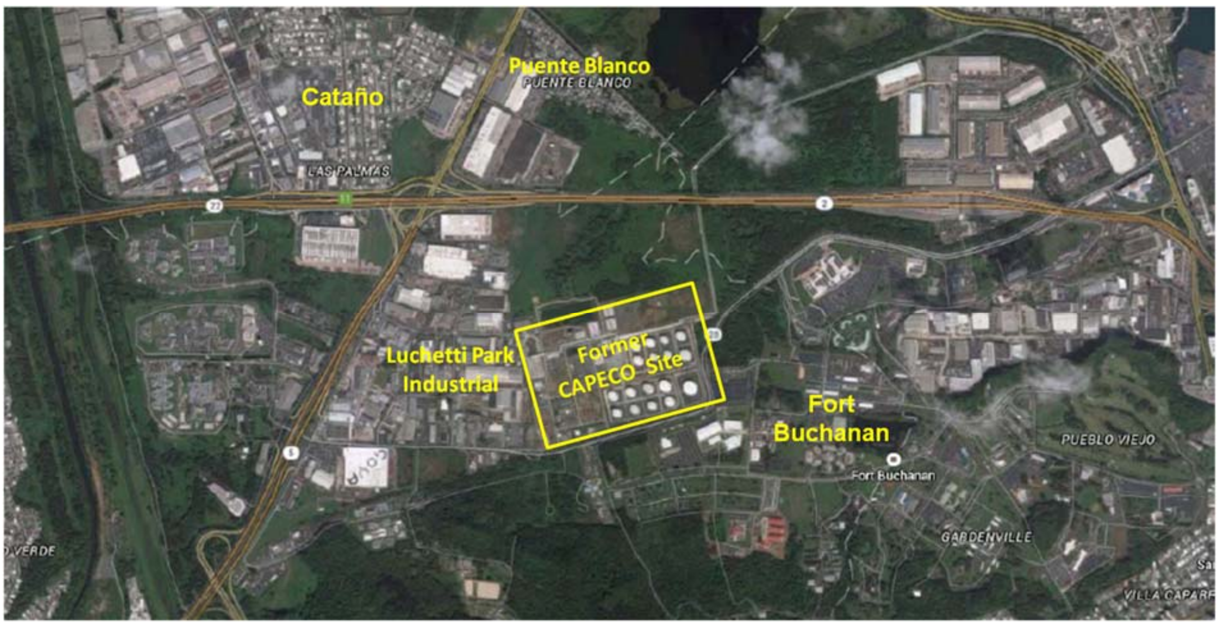

Figure 9: Communities neighboring the CAPECO facility

[39] The Small Business Administration (SBA), in conjunction with the PR Emergency Management Agency (PREMA) and the PR Department of Housing (DOH), conducted community assessments after the incident.

[40] Federal Emergency Management Agency. Caribbean Petroleum Corporation (CaPeCo) / Gulf Refinery Explosion After Action Report (AAR). FEMA 3306-EM-PR. October 23 – 26, 2009 *Incident Recovery Activities Summary: Caribbean Petroleum Corporation Fuel Explosion* (November 18, 2009).

[41] The SBA's mission is to help disaster-stricken communities through direct loans to businesses, homes, and non - profit organizations. SBA Disaster Recovery Plan. https://www.sba.gov/content/disaster-recovery-plan (accessed December 19, 2014).

Figure 10: Community damage surrounding the CAPECO facility

Figure 11: Oil Spill into nearby wetlands (photo from NOAA.gov) and in a local community drain after CAPECO explosion and tank fires

5.4 Impact to the Commonwealth

The incident forced the Commonwealth government and local officials to evacuate approximately 3,000 people in a nearby prison and other government facilities. Changing wind patterns caused the governor to prepare for the evacuation of over 30,000 individuals likely affected by particulate fallout from the smoke plume that extended miles out to sea. Overall, approximately 600 people used the shelters in Cataño, Guaynabo, and Toa Baja.[42]

5.5 Environmental Impact

The CAPECO incident released thousands of gallons of oil, fire suppression foam, and contaminated runoff to Malaria Creek, which traverses the Puente Blanco community to the San Juan Bay. CAPECO and the EPA collected and shipped offsite an estimated 171,000 gallons of oil and 22 million gallons of contact water.[43, 44] Overall, approximately 30 million gallons of petroleum was released via storm water channels, on-site and off-site surface water bodies, and neighboring wetlands to San Juan Bay.[45] Environmental assessments jointly conducted by the EPA, the US Fish and Wildlife Service (USFWS), and the Puerto Rico Department of Natural Resources (PR DNR) found dead wildlife and both aquatic and avian species, including several legally protected species, covered in oil.[46] (Figure 11.)

5.6 Impact to Transportation and Commerce

The incident also disrupted commerce and transportation corridors on the ground and in the air in the San Juan area. A main interstate, PR-22, was closed for three days, limiting access to work and shopping malls and interrupting transportation of goods to and from the main port. The smoke plume also resulted in airspace interruptions and temporary flight restrictions for the Luis Muñoz Marín International Airport. The explosion caused many tourists in the San Juan area to

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[42] *Caribbean Petroleum Corporation (CaPeCo) / Gulf Refinery Explosion After Action Report (AAR).* FEMA 3306-EM-PR. October 23-26, 2009. (Washington, DC: U.S. Federal Emergency Management Agency, 2010): 11.

[43] Contact water contains petroleum product.

[44] C. Jimenez, K. Glenn, G. Denning. *International Oil Spill Conference Proceedings*, *2011 (1).* http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-2011-1-90 (accessed December 19, 2014).

[45] Environmental Protection Agency. Securing Cleanup from ashes at the Puma Energy Caribe Site. 2014. http://www2.epa.gov/enforcement/case-study-cleanup-puma-energy-caribe-site-puerto-rico (accessed May 4, 2015).

[46] C. Jimenez, K. Glenn, G. Denning. *International Oil Spill Conference Proceedings*, *2011 (1).* http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-2011-1-90 (accessed December 19, 2014).

flee, affecting the local economy. The total economic and psychological effects of these major disruptions have not been determined.[47]

5.7 Impact of Overfill Incident on CAPECO

In May 2010, CAPECO was required to pay more than $8.2 million for environmental liabilities associated with the Bayamón petroleum distribution facility and the 170 service stations it owned and leased under a settlement agreement.[48] In the same month, the EPA issued a Notice of Federal Assumption to take responsibility for the remaining cleanup at the CAPECO site.[49]

6.0 INCIDENT ANALYSIS

6.1 Systemic Failure at CAPECO Led to Failure of the Overfill Prevention System

The CSB determined that numerous technical and systemic failures contributed to the explosion and multiple tank fires at the CAPECO tank terminal. The CSB found that multiple layers of protection failed within the level control and monitoring system at the same time. In addition a lack of independent safeguards contributed to the overfill. James Reason's Swiss Cheese Model best demonstrates these systemic failures that led to the accident.[50] Reason postulates that an accident results from the breakdown of the "interaction between latent failures[51] and a variety of local triggering events (active failures)"[52] and although rare, the "adverse conjunction of several

[47] Ibid.

[48] *United States Announces Bankruptcy Settlement with Oil Company in Wake of October 2009 Explosion and Fire.* (Washington, DC: U.S. Department of Justice, 2011) http://www.ju.tice.gov/opa/pr/2011/May/11-enrd-657.html (accessed December 19, 2014).

[49] C. Jimenez, K. Glenn, G. Denning. *International Oil Spill Conference Proceedings*, *2011 (1)* http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-2011-1-90 (accessed December 19, 2014).

[50] Reason postulated that "a multiplicity of overlapping and mutually supporting defenses" both hard and soft, allow complex systems to function despite a single technical or human failure. Hard defenses include technical devices such as automated engineered safety features, physical barriers, alarms and annunciators, interlocks, keys, personal protective equipment, non-destructive testing, and improved system design (Reason, 1997). Soft defenses rely heavily on a combination of paper and people, i.e., legislation, regulatory surveillance, rules and procedures, training, drills and briefings, administrative controls, licensing, certification, supervisory oversight, front-line operators (Reason, 1997).

[51] Latent Failures arise from strategic and other top-level decisions made by governments, regulators, manufacturers, designers, and organizational managers. They include poor design, supervisory gaps, undetected manufacturing defects, maintenance failures, unworkable procedures, poor automation, inadequate training, and insufficient or inadequate tools and equipment. These failures can lay dormant in an organization for years and, if undetected or unfixed, can contribute to active failures by creating deviation from procedures (Reason, 1997).

[52] Active failures are unsafe acts committed by those at the human-system interface or the sharp end of the system by personnel. They are immediate and have short-lived effects (Reason, 1997).

causal factors" from various layers.[53] The deficiencies or holes at each layer of protection are constantly increasing or decreasing based on management decisions and operational deviations.[54]

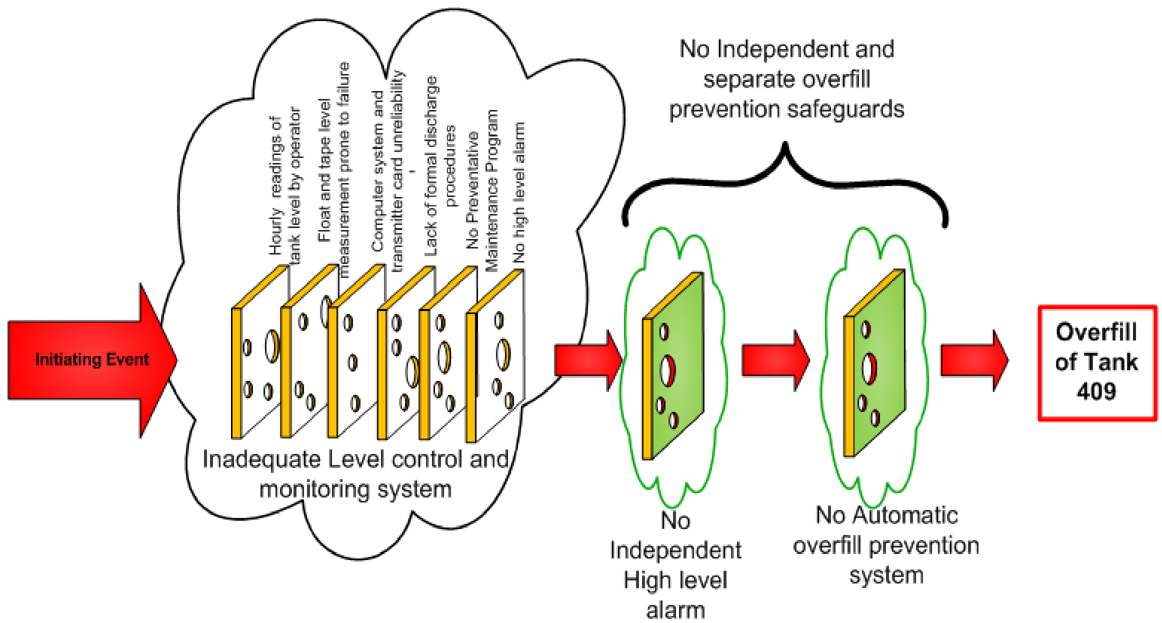

Figure 12: Contributing to the October 2009 overfill incident at CAPECO were multiple failures of the level control and monitoring system in addition to a lack of safeguards like a high level alarm, an independent level alarm and an automatic overfill prevention system that allows for automatic shutdown or diversion.

6.1.1 Inadequate Safety Management System

The CSB found that the CAPECO overfill incident resulted from a combination of multiple deficiencies in the safety management system, including the breakdown in the level control and monitoring system within an inadequate safety management system and a lack of safeguards,[55] such as an independent high-level alarm and an automatic overfill prevention system. In terminals, the level control system includes procedures and equipment used to control tank-filling operations. For many tank operations, the level control system is the operator and the alarm system, which together are able to control the fuel receiving process. In some cases, the

[53] J. Reason. *Human Error*. (United Kingdom: Cambridge University Press, 1990).
[54] J. Reason. *Managing the Risks of Organizational Accidents* (Brookfield: Ashgate, 1997).
[55] Safeguards are any device, system, or action that would likely interrupt the chain of events following an initiating event.

level control system is an automatic level controller functioning to restrict flow into the tank. The CSB finds that systemic failures at CAPECO included:

- a history of poorly maintaining terminal operations;
- an inherent financial pressure to fill the tanks within the Planning Department's stipulated time, which was at odds with safety;
- a failure to learn from previous overfill incidents at the facility;
- a lack of preventative maintenance for the malfunctioning float and tape device, automatic tank gauge transmitters;
- an unreliable computer for calculating tank fill times;
- a lack of overfill prevention safeguards as an independent alarm;
- a lack of formal procedures for tank-filling operations for operators and managers;
- an insufficient mechanical integrity program for safety critical equipment;
- poor adherence to human factors principles for safety critical equipment.

6.2 CAPECO History of Poorly Maintaining Terminal Operations

The CSB found that CAPECO had a history of poorly maintaining its terminal operations. EPA inspection records from 1992 to 2004 indicate a lack of investment in tank valves, maintenance of secondary containment around the tank farm, and appropriate level gauges and engineering controls. For the 12-year period, SPCC inspections revealed problems with leaking transfer valves, leaking product lines, insufficient secondary containment, failure to lock valves that could release content, and oil sheen present in dikes and adjacent dikes, indicating the migration of oil from a leak or spill through the dike drain valves that were unaddressed in subsequent inspections. Although these deficiencies were noted for smaller tanks holding less than 10,000 gallons of liquid and asphalt tanks not in the main tank farm, the SPCC records offer additional insight into how CAPECO management historically maintained the facility. Refer to Section 8.6.2 for CAPECO SPCC deficiencies.

6.3 Previous Spill Incidents at CAPECO

The CSB learned CAPECO had multiple overfills and spills during transfer operations. CAPECO records show a history of 15 separate incidents involving tanks of varying sizes from 1992 to 1999 and 3 others after 2005, when spills or overfills occurred during filling, draining, or transferring operations. Among the 15 incidents, 8 were overfills and 7 were spills. Incidents resulted from valves in the open position, tank gauge malfunctions, or corrosion of pipes or tank shells.

6.4 Normal Practice to Fill Tanks to Maximum Levels at Odds with Safety

The CSB found that despite the lack of computer-displayed tank levels, CAPECO operators received instructions from the Planning Department to fill the tanks to their maximum fill level during the October 21-23, 2009 filling operations, exposing the tank farm to the eventual incident. The Planning Department coordinated fuel deliveries with fuel suppliers and instructed operators on which tank to fill, specified the volume of materials, and determined the filling schedule during unloading operations. (See Section 3.4.) The contractual obligation to fill the specified tanks in the allotted time or at a faster rate was at odds with safely conducting filling operations.

6.5 Unreliable Safety Critical Equipment

The CSB found that CAPECO purchased the least effective level-measurement system and employed an inadequate maintenance program to care for that system. These shortfalls in safety critical equipment in the level control and monitoring system, including the transmitters on the side gauge and the float and tape device in the tank, prevented operators from determining tank levels during filling operations. Figure 10 illustrates the issues with the level control system at CAPECO.

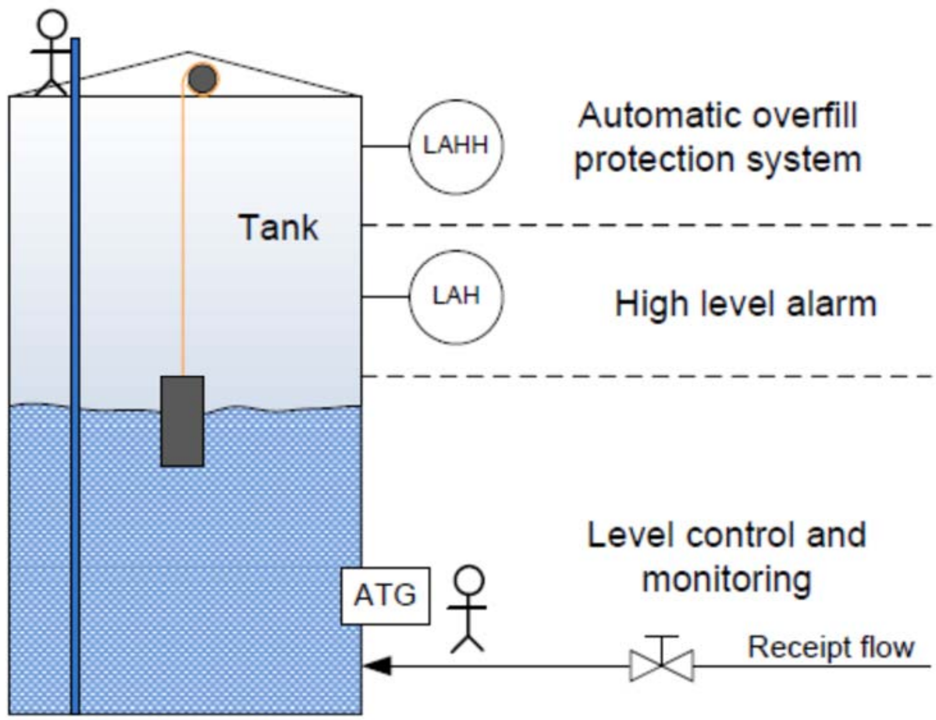

Figure 13: A comprehensive overfill prevention system includes the ATG, high-level alarm (LAH), and automatic overfill protection system (LAHH), in addition to the operator and facility procedures that govern, monitor, and control the flow of fuel into a tank.

6.5.1 Unreliable Level Control and Monitoring Systems

CAPECO lacked a reliable automatic level control and monitoring system for measuring tank levels. (See Figure 13.) The automatic gauging system at CAPECO, described in Section 3.6.3, had a history of repeated failures and prolonged out-of-service periods. On the night of the incident, the float and tape device inside Tank 504 became stuck and the transmitters for Tanks 107 and 409 were not receiving data from the side gauge on Tank 409; therefore, data on the tank liquid level and a calculated fill rate into 409 were not available in real time on the computer. The computer monitoring system was often compromised by outages from lightning strikes and accidental breakage of the computer cables after maintenance activities in the tank farm area. In addition, the transmitters[56] that sent the data to the computer were also susceptible to electromagnetic interference and frequently needed replacing after lightning storms.

Records show, CAPECO took weeks to replace the faulty transmitters. Therefore, CAPECO operators found the computer monitoring system to be unreliable. After completing hourly rounds, the operator reported the tank level back to the shift supervisor, who then manually calculated the time it would take to fill the tank. The CSB learned that CAPECO operators had been calculating the tank levels by hand for decades. This method of monitoring the level in the tanks was unreliable given the 15 prior tank spill incidents at the facility and the extended time that the level detection equipment remained out of service due to failure.

6.5.2 Float and Tape Gauges Prone to Failure

Float and tape gauges, which the aboveground storage tank industry has used for many years, are also prone to failure due to historically well-known design flaws.[57] Mechanical friction in pulleys, spring motors, and indicators degrade measurement reliability, causing the system to indicate the liquid depth inaccurately.[58] In addition, the gear mechanism attached to the indicator and transmitter can disengage, resulting in inaccurate readings, and can disrupt synchronization of the transmitter.[59] The float tape gauge is also subject to "excessive wear and tear,"[60] resulting from continuous and sudden movement from turbulence generated by the fuel in the tank.[61]

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[56] In accordance with *ANSI/API Overfill Protection for Storage Tanks in Petroleum Facilities (ANSI/ANSI/API 2350)*, operators recalibrate the level transmitter when they note more than a 3-inch discrepancy in tank levels between the physical gauge reading and the float and tape reading recorded at the side gauge. (See section 8.10 for API discussion.)

[57] B. V. Enraf. *The Art* of *Tank Gauging*. http://enraf.ru/userfiles/File/4416650_rev4.pdf (accessed January 2012).

[58] Ibid.

[59] Ibid.

[60] Ibid.

[61] Ibid.

6.5.3 Poor Float and Tape Gauge Maintenance

The CSB found the float and tape gauges installed on CAPECO tanks were poorly maintained. Installed in February 2004, the float and tape gauges were frequently out of service for multiple tanks at the same time. The CSB learned that just nine months after initial installation, CAPECO hired L&J Engineering to service the level transmitter due to "volume discrepancies," and one month prior to the 2009 explosion, CAPECO hired contractors to calibrate the side gauge on numerous tanks in the tank terminal.

The CSB found CAPECO's lack of preventative maintenance[62] resulted in the failure to repair the tank gauging system. A review of CAPECO maintenance logs found no status update on maintenance activities addressing a broken float tension on Tank 411 in July 2009, or on fixing strapping problems with Tanks 405 or 411 in early October 2009. During October 2009, the level transmitter for Tank 409 was out of service from the week prior, and maintenance personnel were waiting for repair parts. Despite frequent outages, CAPECO management did not replace the level transmitter on any of the tanks and relied only on the float and tape gauge located on the side of the tank to obtain tank levels.

The CSB found many of CAPECO's tank gauging practices were contrary to the recommended practices in API Manual of Petroleum Measurement Standards (MPMS) Chapter 3.1A,[63, 64] which might have contributed to inaccurately calculating liquid levels in Tank 409. Volume discrepancies in a tank could also arise from using a specific tank gauge, relying on a strapping table to calculate tank levels, and using unslotted still pipes.

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[62] CCPS Guidelines for Safe Process Operations and Maintenance: "Preventative maintenance seeks to reduce the frequency and severity of unplanned outages by establishing a fixed schedule of routine inspection and service. The chief advantage of a preventative maintenance program is that it gives maintenance management the flexibility to plan and execute required equipment service with a minimum disruption of essential plant operations. The importance of preventative maintenance to process safety management cannot be overemphasized." American Institute of Chemical Engineers, Center for Chemical Process Safety. *Guidelines for Safe Process Operations and Maintenance* (New York: Wiley & Sons, 1995).

[63] American Petroleum Institute. *Manual of Petroleum Measurement Standards*, Chapter 3.1A, Standard Practice for the Manual Gauging of Petroleum and Petroleum Products, 3rd edition (August 2013).

[64] *The Manual of Petroleum Measurement Standards*, Chapter 3.1A applies to liquids with a Reid vapor pressure. Reid vapor pressure is the property of a liquid fuel that defines its evaporation characteristics and a common measure of and generic term for gasoline volatility. http://www.epa.gov/otaq/fuels/gasolinefuels/volatility/index.htm.) of less than 103 kPa. A Pascal is the SI-derived unit of pressure, internal pressure, stress, Young's modulus, and tensile strength. 1 Kilopascals (kPa) ≡ 1000 Pa. or 15 psia.

- *Type of gauge:* CAPECO did not use an innage gauge, as recommended by the MPMS Chapter 3.1A, but relied on an outage gauge[65] to obtain tank levels. The MPMS Chapter 3.1A recommends the use of innage gauges over outage gauges due to movement of the tank gauge reference point, but recognizes circumstances when outage gauges are more applicable. The MPMS Chapter 3.1A also recommends that facilities inspect both manual tape-and-bob assembly and portable electronic gauging devices daily for inconsistencies that may introduce error, and that they verify for accuracy at least annually. It also requires operations personnel to check the detection signal from the sensor/probe annually. The CSB did not find any inspection records demonstrating daily or annual float and tape checks at CAPECO.

- *Strapping table inaccuracies*: API MPMS Ch. 3.1A advises that a volume discrepancy can arise from the inherent inaccuracies in strapping tables, which can lead to overestimating or underestimating of tank quantity, among other problems.

- *Calculating tank volume in the critical zone*: According to API MPMS Ch. 3.1A, "computing tank volume in the critical zone[66] is subject to considerable error." Inaccuracies can also arise from strapping tape calibration or thermal expansion, tension of the strapping tape, correction of shell expansion due to liquid head (static head), measurement of shell plate thickness and calculation of deadwood.[67]

- *Using still pipes without slots*: The independent inspector used a gauge hatch on the fixed roof and a gauging funnel on the floating roof to obtain liquid levels in Tank 409 but used an 8-inch still pipe[68] to physically gauge Tank 107. According to API MPMS Ch. 3.1A, still pipes without slots can lead to "serious liquid height measurement, temperature determination, and sampling errors."

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[65] An innage gauge is a direct measurement of the linear distance along a vertical path from the datum plate or tank bottom to the surface of the liquid being gauged. An outage gauge is an indirect measurement of the linear distance along a vertical path from the surface of the liquid being gauged to the tank reference gauge point.

[66] The critical zone is the area where liquid is partially displaced by the roof between the point where the liquid just touches the lowest section of the roof and the point where the roof floats freely.

[67] Deadwood refers to the ducted weight of all parts of a floating roof, including the swing joint, the drain and other items attached to the tank shell or bottom that are resting on the roof supports when the floating roof is immersed in liquid.

[68] Still pipe is used to gauge liquid levels inside a tank. The reference gauge point is located on the upper lip, and the datum plate is located at the lower lip. Still pipes may have slots or be solid.

6.6 Lack of Formal Procedures for Tank Terminal Operations

The CSB learned that CAPECO's standard operating procedures only addressed activities requiring a permit to work and did not cover terminal operations. When CAPECO became a fuel storage depot, it was no longer required to follow standards that would require regularly updated standard operating procedures (SOPs), such as OSHA PSM or EPA RMP. CAPECO last updated refinery SOPs to comply with PSM in 1999. In August 2009, CAPECO updated procedures that resulted in work permits (hot work, cold work, confined space, and lockout/tagout) but failed to update or write terminal operating procedures. The terminal often had activity outlines and checklists, but it did not have SOPs to instruct employees how to perform daily activities, such as discharging from a vessel or barge, gauging tanks, or operating dike drain valves. For example, CAPECO had a two-page document listing the activities to discharge from a vessel or barge, but the document did not provide details on how to perform the activities, who would be in charge, or what to do in an emergency. In addition, CAPECO lacked procedures dictating how to load multiple tanks at the same time. The normal practice of partially opening the tank valves of the next tank in line to be filled (See Section 6.9.4) directly influenced the tank fill rate, but the facility lacked procedures addressing the influence of valve cracking on calculating the tank fill time. As a result of the incident, the Puerto Rico Occupational Safety and Health Administration (PR OSHA) issued a serious violation to CAPECO for lacking tank filling procedures during transfer operations. See PR OSHA Section 8.8.

6.7 Lack of Additional Safeguards such as High-Level Alarms and an Automatic Overfill Prevention System

The CSB found that CAPECO tanks lacked effective safeguards to prevent a tank overfill. In addition to an accurate automatic tank gauging system with a reliable computer monitoring system, potential safeguards include independent high-level alarms, which give a visual or auditory indication when material in the tanks reach a specific high level, and an automated overfill prevention system,[69] which allows for shutoff or flow diversion to prevent overfill. Tank 409 lacked an independent high level alarm.[70] Without safety alarms and associated critical response procedures, CAPECO tank farm operators were left with a faulty level control and monitoring system to detect an overfill in Tank 409.

[69] *ANSI/ANSI/API 2350* defines an automated overfill prevention system (AOPS) as an overfill prevention system not requiring the intervention of operating personnel to function.

[70] High-high level alarm: An alarm generated when the product level reaches the high tank level. American Petroleum Institute. *ANSI/API Standard 2350-2012: Overfill Protection for Storage Tanks in Petroleum Facilities*, fourth edition (Washington, DC: American Petroleum Institute, May 2012).

6.8 Other Potential Contributing Factors

The CSB found that other factors might have contributed to the accident, such as the construction and limitations of the Tank 409 internal floating roof and the variable flow rates and line pressures into Tank 409.

6.8.1 Internal Floating Roof Construction and Limitations

The destruction of the Tank 409 internal floating roof in the explosion prevented the CSB from determining if it failed during filling operations. Therefore, internal floating roof failure might have contributed to the overfilling of Tank 409. The roof construction of Tank 409 was subject to numerous operational limitations. Tank 409 had a fixed cone roof with an aluminum internal floating roof (IFR), and a freeboard[71] of 12 feet (24,157 bbls). (See Figure 14 for Tank 409 specifications.) Aluminum IFRs are prone to corrosion when exposed to caustic liquids but sufficient for petroleum and organic materials. An internal floating roof can fail by means of turbulence,[72] roof submersion,[73] seal issues, and fatigue.[74]

API MPMS Ch. 3.1A discusses the impact of the floating roof on tank volume. On the night of the incident, the final reading likely occurred when the floating roof was floating freely. When floating roofs are in the free-floating position, they displace the amount of liquid equal to the weight of the roof and attached deadwood. The only accurate way to obtain volume in the critical zone is by a liquid calibration procedure. API MPMS Ch. 3.1A advises that facilities calculate roof displacement by considering the roof weight, temperature, and density of the liquid of tank contents in the critical zone. CAPECO did not calculate the roof displacement of Tank 409.

[71] Freeboard is the vertical distance between the maximum liquid level and the top of the tank.
[72] Turbulence: high velocity of receipt fluid sufficient to generate waves at the surface of the liquid causing floating roofs to shake, move, and vibrate. Turbulence usually results from excessive receipt rates when the liquid level is low in the tank.
[73] Roof Submersion: Part or the entire roof becomes covered with the stored tank product.
[74] Fatigue is the creation of initiating cracks at discontinuities in steel structures resulting from stresses magnified by "stress risers" or discontinuities from corrosion.

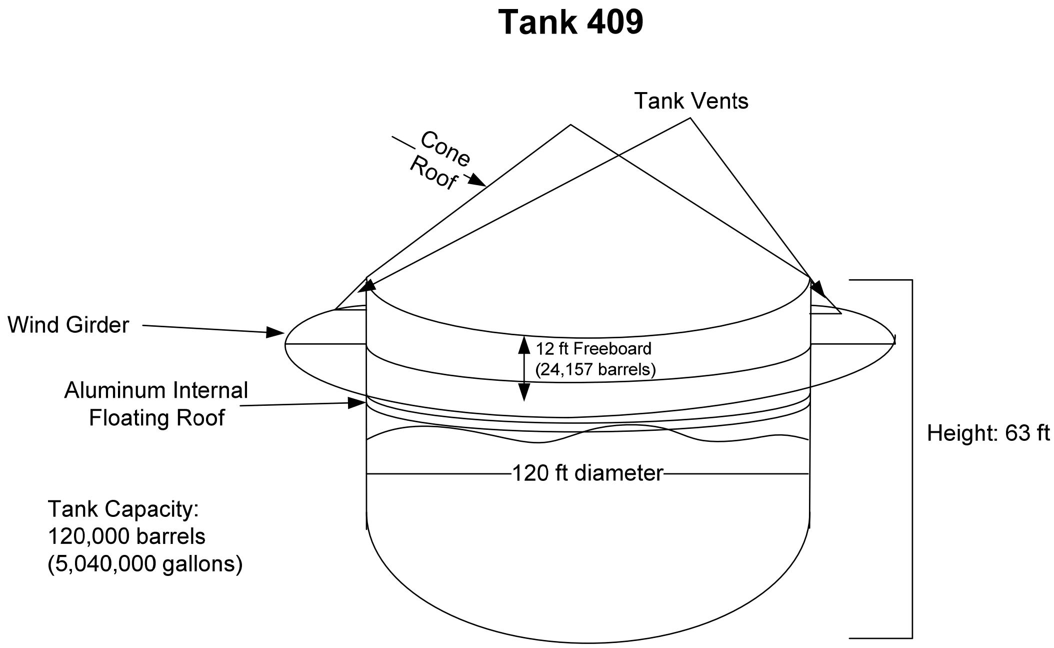

Figure 14: Tank 409 Specifications

6.8.2 Variable Flow Rates and Line Pressure into Tank

The CSB found that the fuel discharge flow rate to the terminal was controlled only by personnel from the *Cape Bruny*. CAPECO and the *Cape Bruny* had to complete filling operations in the allotted time negotiated by the Planning Department or face a financial penalty. (See section 3.4).

The CSB found it was normal for flow rates to vary from the barge to the tanks during filling operations. However, CAPECO lacked the ability to obtain product line flow rate information from the *Cape Bruny* to the CAPECO tank terminal via real time flow monitors, thus preventing CAPECO staff from accurately calculating the tank fill time and likely contributing to the overfill of Tank 409. The gasoline flow rate from the *Cape Bruny* to the terminal was determined before filling operations started in a pre-transfer meeting on the ship. Both CAPECO and *Cape Bruny* personnel determined the initial transfer limit to be 4,400 bbls/hr and a bulk transfer rate of 12,000 bbls/hr. Normal transfer operations from the *Cape Bruny* established a minimum allowable backpressure at 100 psig with a maximum discharge rate of 18,870 bbls/hr during transfer operations. However, CAPECO requested the discharge pressure to be 125 psig. At the time of the incident, CAPECO's manifest showed gasoline was pumped at a rate of 10,000-11,000 bbl/hr at a pressure of 100-110 psi, corresponding to about 7000-7700 gallons per minute. Despite the predetermined transfer rate and backpressure, CAPECO operators lacked information on the flow rate into the tanks during filling operations.

To change the ship pumping pressure during filling operations, CAPECO tank farm operators communicated with the dock operator via radio. The dock operator then contacted the ship to increase or reduce the pressure of fuel pumped from the ship to the terminal. However, CAPECO personnel testified that stopping pumping from the ship was rare and only occurred if the tank farm lacked sufficient tank space onsite. Ship discharge records show the line pressure at the dock started at 50 psig on October 21, 2009, at 1 a.m. and increased by approximately 5-10 psig every three hours. At 11 p.m., approximately one hour before the incident, on October 22, 2009, the dock pressure was 115 psig, within the agreed-upon pump pressure. As the line pressure increased, the tank operator manually switched from Tank 405 (line displacement) to Tank 504 then to Tank 411, and cracked the valve on Tank 409 to contain the gasoline. However, it was difficult for operators to determine the exact flow rate into the tanks after cracking the valves because gasoline flow rate was also dependent on the pipe diameter. Operators often went to the tank 10-30 minutes prior to the calculated filling time to switch the lines and address any discrepancy in flow rates. The lack of flow indicators coupled with various pipe diameters, the tank-switching process, and an unreliable gauging system all contributed to the overfilling of Tank 409.

6.9 Human Factors

Human factors-related deficiencies[75] also contributed to the breakdown in the safety management system, including issues with dike valve designs, insufficient staffing, facility lighting, and valve cracking.

6.9.1 Lack of Consistent Dike Valve Design

A major contributor to the migration and dispersion of the vapor cloud was the open dike valves that enabled fuel to accumulate in the storm water retention pond in the WWT area. In addition, the use of multiple types of manual valves coupled with poor lighting made it impossible for operators to visually observe whether the dike valves were open or closed on the night of the incident. CAPECO operators failed to determine whether the dike drain valve for Tank 409 was properly shut.

The CSB verified that the dike drain valve for Tank 409 was open at the time of the incident. EPA SPCC regulations require that dike drain valves be closed to prevent discharging oil.

[75] "Human factors refer to environmental, organizational and job factors, and human and individual characteristics which influence behavior at work in a way which can affect health and safety. A simple way to view human factors is to think about three aspects: the job, the individual and the organization and how they impact people's health and safety-related behavior." U.K. Health and Safety Executive. *Introduction to Human Factors*. http://www.hse.gov.uk/humanfactors/introduction.htm (accessed December 20, 2014).

CAPECO's normal practices required operators to open and close valves during the day shifts. Operators customarily inspected whether the dike drain valves were open or closed from their vehicles as they drove by. The tank farm used both rising stem and fixed stem valves on the dike drains leading to the storm water retention pond in the WWT area. Rising stem valves allowed operators to easily observe the open or closed position while fixed stem valves do not provide a visual indication of the position. The fixed stem valve on the dike drain for Tank 409 made it difficult for tank farm operators to observe its position without physically turning it. (See Figure 15.) In some cases, the valve position could not be determined with a visual inspection because the rising stem valve position was hidden in the sump. (See Figure 15, center photo.) Furthermore, none of the dike valves shown in Figure 15 were consistent with RAGAGEP. Regulatory coverage under the EPA Risk Management Plan (RMP) or OSHA's Process Safety Management (PSM) Standard requires that CAPECO use the best available engineering practices to assess valve open/close status.

Figure 15: Various dike drain valves at CAPECO. Tank 409 fixed stem dike drain valve (left): position of the valve is undeterminable without physically turning the valve. Rising stem valves (center, right). In some cases, the valve position is hidden in the sump (center).

6.9.2 Lack of Facility Lighting

On the night of the incident, operators could not see the tank overflowing or the vapor cloud forming because the lighting was insufficient. Lighting in the tank farm area was limited; therefore, operators used flashlights to monitor tank farm activity and read liquid levels from the tank side gauges. A 1999 EPA inspection found insufficient lighting at the CAPECO tank farm to "detect spills and prevent vandalism." Operators used flashlights, which were insufficient to monitor for unusual activity, such as a tank overflowing or a vapor cloud forming. In a 2010 post-incident inspection report, the EPA again noted inadequate facility lighting for discovering unusual activity, such as vandalism and oil discharges in darkness.[76]

6.9.3 Lack of Sufficient Staffing during Offloading Operations

The management decision to staff each fuel offloading shift with two operators at the tank farm and one operator at the dock provided insufficient staffing resources during filling operations. CAPECO often offloaded inventory into multiple tanks, which required manually switching fuel flow between tanks. This task often required two people due to the increased pressure of the fuel on the valve. Operators addressed this lack of staffing by cracking the valves of the next tank in line to fill. For example, Tank 409 and Tank 411 shared the same line connected to the pipeline. When the operator needed to change the line from the pipeline to fill another tank, he had to call the WWT operator for help, leaving the WWT area unattended.

6.9.4 Valve Cracking

The lack of motor-operated valves compromised the accuracy of tank-filling time estimates. The valves for unloading gasoline were manually operated and as large as 16 to 20 inches. The pressure in the line from the dock was as high as 125 psig, which made opening the valves difficult. To easily change gasoline flow between tanks, operators fully opened the inlet valve to one tank and cracked open the inlet valve on the next tank to be filled. Cracking the inlet valve facilitated opening the valve for the next tank after the previous tank reached the target level. With both valves opened, the flow rate into the individual tanks varied, making it difficult to determine the exact filling time required.

Installing motor-operated valves can eliminate the difficulty of manually opening large valves.

6.10 Using a Risk-based Approach to Design an Overfill Prevention System

Bulk petroleum storage and distribution facilities, like CAPECO's Bayamón facility, are not considered highly hazardous under the U.S. regulatory system, despite often storing flammable liquids near highly populated areas. CAPECO was not required to use a risk-based approach to determine the level of risk posed by facility operations to the nearby community and to mitigate those risks accordingly.

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[76] General requirements for Spill Prevention, Control, and Countermeasure Plans. *Code of Federal Regulations*, Part 112, Section 7, Title 40, 2008.

A Safety Instrumented System (SIS)[77] approach allows tank terminal operators to design an overfill prevention system for controlling the risk of an overfill incident to various safety integrity levels using multiple layers of protection. Following the promulgation of the US Occupational Health and Safety (OSHA) Process Safety Management (PSM) standard (1910.119), the International Society for Automation (ISA) created ISA 84.01-1996, the Safety Instrumented Systems (SIS) standard. Its intent was to augment the PSM standard for implementing instrumentation and controls necessary for safe operation.[78] OSHA recognizes ISA-84 as Recognized and Generally Accepted Good Engineering Practice (RAGAGEP). See Section 8.9 for a discussion of RAGAGEP.

Under this standard, a safety system requires robust design and rigorous management to achieve the required integrity.[79] In applying SIS for process industries, ISA-84 uses two concepts to reduce the risk of facility-based hazards: a safety lifecycle and safety integrity levels (SIL).[80] A safety lifecycle model uses a disciplined systemic approach to design, build, operate, and maintain a facility throughout its lifetime;[81] a safety integrity level (SIL) is a probability-of-failure measurement of safety system performance.[82] There are four SILs,[83] where a higher SIL means that an installed system has a lower potential to fail.

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[77] SIS is an instrumented system used to implement one or more safety-instrumented functions (SIF). This software implements a safety-instrumented function by programming a single instrumented loop or multiple instrumented loops to a single electronic system. SIS removes the human element from a process when the expected human error rate increases because of automated controls with too many repeated and continuous control changes or when the complexity of work activity increases. A Safety Instrumented Function (SIF) is a safety function associated with a specific safety integrity level that is necessary to achieve functional safety. It can be a safety instrumented protection function or a safety instrumented control function. *International Standard IEC 61511-1: Functional safety – Safety instrumented systems.*

[78] A. Summers. *Difference between IEC 8111 and ISA 84.01-1996* (Instrumentation, Systems and Automation Society, 2003).

[79] Buncefield Major Incident Investigation Board. *The Buncefield Incident 11 December 2005 Volume 1*. 2008. http://www.buncefieldinvestigation.gov.uk/reports/volume1.pdf.

[80] International Society for Automation. Technology ISA-84. http://www.isa-95.com/subpages/technology/isa-84.php (accessed December 20, 2014).

[81] S. Gillespie. *Safety Instrumented Systems*. http://www.idc-online.com/technical_references/pdfs/instrumentation/Safety_Instrumented_Systems.pdf (accessed December 20, 2014).
http://www.idc-online.com/technical_references/pdfs/instrumentation/Safety_Instrumented_Systems.pdf

[82] Buncefield Major Incident Investigation Board. *The Buncefield Incident 11 December 2005 Volume 1* (2008). http://www.buncefieldinvestigation.gov.uk/reports/volume1.pdf (accessed December 20, 2014).

[83] SIL 0 = none is the lowest risk; SIL 1 = 95% of the safety instrumented function (ALARP); SIL 2 =5% SIF; SIL 3 = <1% SIF; SIL 4 =highest risk (nuclear industry)
Process Engineering Associates. http://www.processengr.com/ppt_presentations/safety_instrumented_systems.pdf

Facilities such as CAPECO are not covered under OSHA PSM Standard or the EPA RMP Program. They are not required to conduct risk assessments to address flammable hazards on site, or to follow RAGAGEP. Therefore, the CAPECO facility was not required to conduct a hazard assessment that would determine the necessary safeguards needed to prevent a catastrophic incident. This precaution would have alerted management to the need for RAGAGEP, including instrumentation and controls necessary for safe operations. Had CAPECO been covered by these standards, it likely would have installed an independent or redundant level alarm and an automatic overfill protection system with several independent safeguards to prevent a catastrophic overfill incident.

7.0 TANK LOCATIONS, PREVALENCE OF INCIDENTS AND LESSONS LEARNED FROM PREVIOUS CATASTROPHIC INCIDENTS

According to the US Census Bureau, there were 4,810 petroleum bulk stations and terminals in the US in 2007.[84,85] The terminals include commercial facilities, proprietary terminals owned by refineries, chemical manufacturers, and Department of Defense facilities.[86]

Tank terminals are located throughout the US in both rural and urban areas. Figure 16 illustrates the location of bulk petroleum tank terminals in all 50 states in 2012. In 2009, 3,807 bulk liquid storage facilities registered a release with the EPA Toxic Release Inventory (TRI).[87,88] The CSB mapped 3,847 bulk petroleum storage tank terminal locations obtained from the EPA TRI database for 2012 and found 2,959 bulk petroleum storage terminals within one mile of communities with over 300,000 residents (Figure 16).

[84] *Geographic Distribution*: *Petroleum Bulk Stations* and *Terminals* (Washington, DC: U.S. Census Bureau, 2007). http://www.census.gov/econ/industry/geo/g424710.htm (accessed December 20, 2014).

[85] NAICS code 424710 – bulk petroleum stations and terminals includes industry establishments with bulk liquid storage facilities primarily engaged in the merchant wholesale distribution of crude petroleum and petroleum products, including liquefied petroleum gas.

[86] Advanced Resources International. *Assessment of the Potential Costs and Energy Impacts of Spill Prevention, Control, and Countermeasure Requirements for Petroleum Bulk Storage and Distribution Terminals* (Washington, DC: US Department of Energy Office of Fossil Energy, August 22, 2006).

[87] The EPA Toxic Release Inventory is a database containing self-reported information on the disposal or release of 650 chemicals from facilities in the US.

[88] *Toxic Release Inventory: 2009* (Washington, DC: U.S. Environmental Protection Agency, 2010).

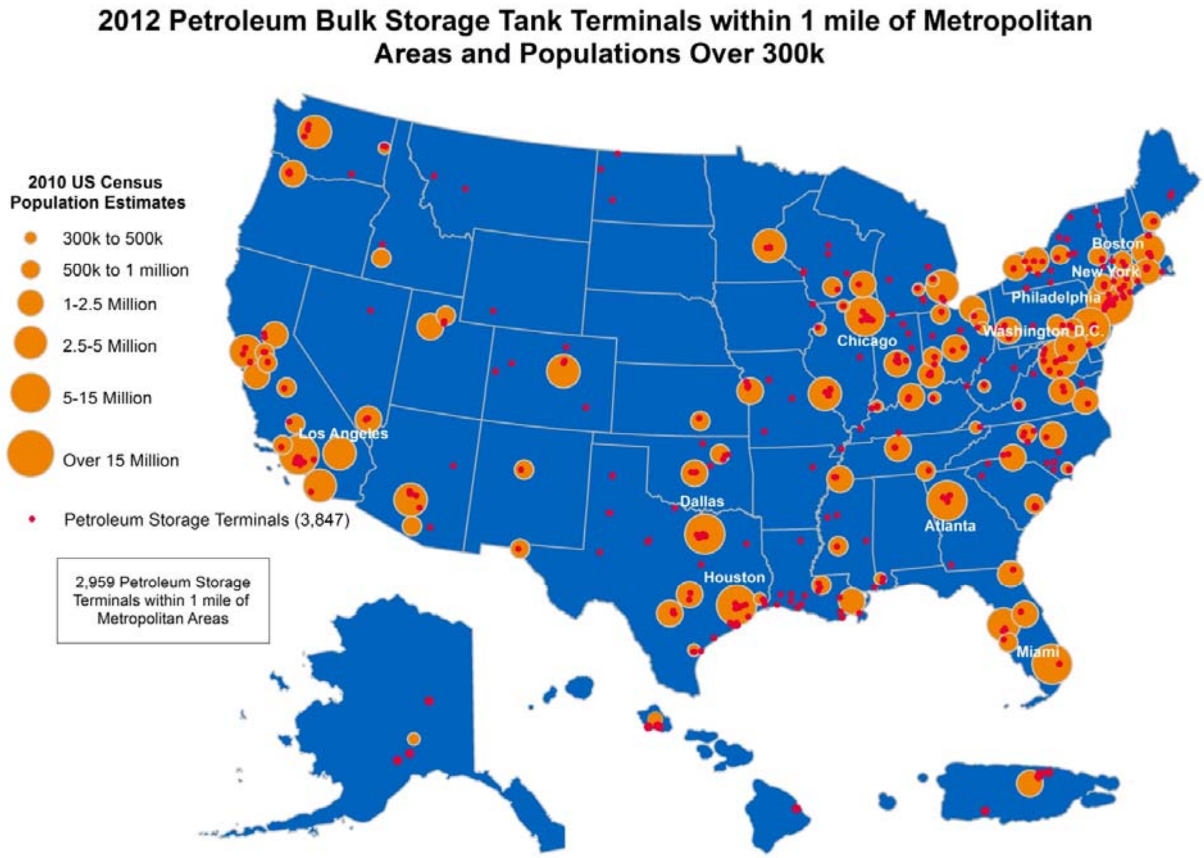

Figure 16: Tank terminals distributed across the US in 2012 in proximity to 2010 population data. (EPA TRI Database, 2012)

7.1 Prevalence of Tank Incidents

The lack of a comprehensive database of publicly available accident data makes it difficult to analyze for trends in overfill incidents. A 2006 study using published reports from various sources analyzed 242 storage tank accidents, finding that fires and explosions accounted for 85% of the accidents on six continents over 40 years (1960-2003).[89] The study also found 105 accidents that occurred in the US. Moreover, terminals and pumping stations accounted for 25%, or 64, of the accidents—the second most frequent sites for accidents after refineries (47.9% or

[89] J. I. Chang, et al. "A Study of Storage Tank Accidents." *Journal of Loss Prevention in the Process Industries*. 2006.19: 56.

116 cases).[90] In addition, overfilling was cited as the most frequent cause of an accident during operation; among the 15 overfill incidents found, 87% led to a fire and explosion. Since 2005, three low-frequency, high-consequence incidents involving a vapor cloud formation from a gasoline storage tank resulted in catastrophic explosions and fires.

The cost of overflow prevention systems is nominal in contrast with the societal and economic costs of incidents such as Buncefield and CAPECO. A 2006 US Department of Energy Office of Fossil Energy assessment found fully automated liquid level sensing alarms and shutoffs range from $12,000 to $18,000 per tank installation, and liquid level sensing devices with alarms cost $4,000 to $5,000.[91]

7.2 Lessons Learned from Previous Incidents

Similar overflow incidents have occurred in the US and internationally. The CSB found 22 incidents of overfills and vapor cloud explosions at bulk petroleum tank terminals, 16 of which occurred in the US. The three incidents discussed below and in Appendix B demonstrate the catastrophic potential and high-hazard nature of storing flammable liquids in aboveground storage tanks. Yet US regulations and industry practices do not adequately reflect the lessons learned from such catastrophic incidents and fail to classify terminals storing flammable materials as high-hazard facilities.

7.3 Buncefield (Hertfordshire, UK)

One of the most notable recent incidents—resulting in a number of technical and regulatory recommendations in the United Kingdom—is an explosion and fire that occurred at the Buncefield Oil Storage Depot in Hemel Hempstead, Hertfordshire, UK, on December 11, 2005. Similar to the CAPECO incident, the vapor cloud explosion and multiple tank fires occurred after a tank was overfilled with gasoline. The overfilling tank was equipped with a gauge that allowed operators to monitor filling operations and an independent high-level switch that allowed for automatic shutdown of filling operations if the tank overfilled. But both were inoperable at the time of the incident.[92] The explosion generated significant blast pressure,

[90] J. I. Chang, et al. "A Study of Storage Tank Accidents." *Journal of Loss Prevention in the Process Industries*. 2006.19: 56.

[91] Advanced Resources International. *Assessment of the Potential Costs and Energy Impacts of Spill Prevention, Control, and Countermeasure Requirements for Petroleum Bulk Storage and Distribution Terminals* (Washington, DC: U.S. Department of Energy, Office of Fossil Energy, August 22, 2006).

[92] The Competent Authority. Control of Major Accident Hazards. *Buncefield: Why Did It Happen?* (U.K. Health and Safety Executive (HSE) and Environment Agency). http://www.hse.gov.uk/comah/buncefield/buncefield-report.pdf (accessed December 21, 2014).

resulting in additional loss of containment that led to fire and other damage involving 22 tanks. There were no fatalities, but 43 people were injured and the damage to nearby commercial and residential property totaled $1.5 billion.[93] The fire burned for four days.

Following Buncefield, the UK Health and Safety Executive (HSE) established a Major Incident Investigation Board (MIIB),[94] which made recommendations to the industry and regulators concerning the incident. The MIIB recommendations overhauled both the UK legal compliance standards and industry practices governing petroleum storage facilities similar in size to the Buncefield Storage Depot. Differing from the US viewpoint, the United Kingdom considers petroleum storage facilities to be high-hazard facilities, subjecting them to the regulations similar to the US OSHA Process Safety Management (PSM) standard. The UK view allows for additional oversight from the Competent Authority (CA) or the Control of Major Accident Hazards (COMAH). Therefore, covered facilities must demonstrate a major accident prevention policy and a safety management system.[95]

The MIIB report emphasizes that controlling the risks associated with a major incident like Buncefield requires an integration of safety integrity levels at high-hazard sites, specifically addressing containment of dangerous substances and process safety with mitigation planning against offsite impact, preparedness of emergency response, land use planning for controlling societal risk, and regulatory system enforcement at high-hazard facilities.[96]

Many of the MIIB recommendations are pertinent to CAPECO. The most salient MIIB recommendations address preventing primary loss of containment,[97] conducting a risk assessment, maintaining sector leadership, cultivating a safety culture, and conforming petroleum storage facilities to high-reliability organization principles. Table 2 summarizes and

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[93] D. M. Johnson, et al. "The Potential for Vapour Cloud Explosions: Lessons from Buncefield." *Journal of Loss Prevention in the Process Industries*. (2010.23): 921-927.

[94] The Buncefield incident caused the MIIB to conduct a comprehensive review of the design and operation of storage sites, emergency preparedness for and response to incidents, and land use planning. In addition, the MIIB analyzed the regulatory system, including the HSE and UK Environmental Agency requirements governing petroleum storage depots and examined the explosion mechanism of the Buncefield incident. The MIIB produced nine reports published from 2006 to 2009. Follow-up reports resulting from recommendations issued by the MIIB address layer-of-protection analysis while other working groups issued subsequent analysis of the implementation of the HSE recommendations.

[95] Buncefield Standards Task Group. 2007. Safety and *Environmental Standards* for *Fuel Storage Sites*. http://www.hse.gov.uk/comah/buncefield/bstgfinalreport.pdf. (accessed January 2012)

[96] Buncefield Major Incident Investigation Board. 2008. *The Buncefield Incident 11 December 2005 Volume 1*. http://www.buncefieldinvestigation.gov.uk/reports/volume1.pdf. (accessed January 2012).

[97] Primary means of containment are the tanks, pipes, and vessels that hold liquids and the devices fitted to them to allow safe operation. (Buncefield MIIB, 2008).

compares both incidents. Because of the Buncefield incident, the API made changes to the Tank Overfill Prevention Standard (ANSI/API 2350) addressing risk assessment. This report issues additional recommendations to the API to enhance its guidance on conducting a risk assessment. (See Section 8.10.1.)

Table 2: Comparison of CAPECO and Buncefield Incidents

	CAPECO	**Buncefield**
Incident Date	October 23, 2009	December 11, 2005
Number employee injuries	0	0
Number of public injuries	3	40
Number of tanks at facility	47	39
Product being filled	Unleaded Gasoline	Unleaded Gasoline
Time of explosion	12:23 am	6:00 am
Storage capacity of site	283,233 tons (90 million gallons)	194,000 tons (61.6 gallons)
Tank storage capacity	18.9 million liters (5 million gallons)	6 million liters (1.58 million gallons)
Vapor cloud explosion	Yes	Yes
Richter Scale	2.9	2.4
Estimated area of vapor cloud	107.2 acres (4,669,632 ft^2)	32 acres (1,393,920ft^2))
Number of tanks engulfed in fire	17	20
Number of days to contain fire	2.5	5
Tank involved in overfill	Tank # 409	Tank # 912
Estimated overfill volume	757,082 liters (200,000 gallons) of gasoline	250,000 liters (66,043 gallons) of gasoline
Volume of contaminated water released to environment	647,305 liters (171,000 gallons) of collected oil; 83,279,059 liters (22,000,000 gallons) of contact water	800,000 liters (211,338 gallons)
Type of tank gauging system	Manual tank gauging system	Fully automated level control system under remote supervision
Functionality of gauging system at incident	Failed	Failed
Independent high level alarm	Not present	Present but not functioning
Redundant alarms	Not present	Not functioning
Root cause	Deficient Management System	Deficient Management System
	Production Pressure	Production Pressure
	Lack of reliable instruments: Level control failure due to inaccurate available volume calculation; no high-level alarm to notify ship to stop transfer or divert flow; no AOPS with ability to shut down or divert flow into tank	Lack of reliable instruments: Level control failure due to level sensor failure; failure of high level alarm; failure of the independent AOPS
Contributing cause	Failure of Safety Management System	Failure of Safety Management System
Regulatory consideration	Not considered high-hazard facility	Considered high-hazard facility

7.4 Texaco Oil Company (Newark, NJ)

On January 7, 1983, a similar incident occurred at the Texaco Oil Company tank terminal in Newark, New Jersey. A gasoline vapor cloud exploded when a 1.76-million gallon capacity tank overflowed, resulting in one fatality and 24 injuries. Inadequate monitoring of the rising gasoline levels in the storage tank during filling operations contributed to the overflow, explosion, and subsequent fire. An NFPA report on the incident also attributed the root cause to errors in calculating the available space and pumping rates.[98] Equipment damage was observed up to 1,500 feet away from the exploding tank. The overflowing tank had manual level controls. The facility also had no documentation of previous liquid level monitoring in the hours leading up to the explosion. The last "check" on the tank level occurred approximately 24 hours prior to filling operations.[99]

Following the incident, the Newark Fire Department made recommendations to the NFPA to strengthen its guidance on overfill prevention under the *Flammable and Combustible Liquids Code*. (See Section 8.10.9.1 for further discussion on NFPA 30.)

7.5 Indian Oil Company (Jaipur, India)

Another recent incident occurred in Jaipur, India, at the Indian Oil Corporation (IOC) Petroleum Oil Lubricants terminal 16 miles south of Jaipur, India. On October 29, 2009, one week after the CAPECO explosion and fire, four operators were transferring gasoline to a tank when the delivery line developed a large leak, which continued unabated for 75 minutes after fumes overcame two operators. The pooling fuel migrated through an open dike drain valve to a storm drain, producing a large vapor cloud. The cloud was ignited by either non-intrinsically safe electrical equipment or a vehicle startup. The resulting explosion and fireball engulfed the entire site. Fire affected 11 tanks and persisted for 11 days. The incident resulted in 11 fatalities, 6 of them IOC employees, and the others from neighboring organizations. Among the 39 recommendations issued, one was for an independent Hazard Operability study (HAZOP) or risk assessment, and another addressing automated operations and improving instrumentation and alarms.[100] Appendix B contains a list of other similar incidents.

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[98] *Summary Investigation Report: Gasoline Storage Tank Explosion and Fire. Newark, NJ, 7 January 1983* (Quincy, MA: National Fire Protection Agency, 1983).

[99] *Summary Investigation Report: Gasoline Storage Tank Explosion and Fire. Newark, NJ, 7 January 1983* (Quincy, MA: National Fire Protection Agency, 1983).

[100] T. Fishwick. "The Fire and Explosion at Indian Oil Corporation, Jaipur: A Summary of Events and Outcomes." *Loss Prevention Bulletin* (2011. 222): 9.

8.0 REGULATORY ANALYSIS

The CSB analysis of the relevant regulatory, industry, and consensus standards for safety and management of bulk petroleum aboveground storage facilities found that the accident at CAPECO might have been prevented had OSHA and EPA considered the facility to pose a high hazard and required the facility to:

1) Conduct a hazard assessment;
2) Implement more than one layer of protection as an independent level alarm system; and
3) Incorporate changes based on lessons learned from previous similar incidents.

The CSB determined that existing regulatory, industry, and consensus standards do not adequately protect workers and the public from the dangers posed by bulk petroleum storage tank terminals. The following section discusses shortcomings of the regulatory, standard and recommended practice framework governing this industry. (See Figure 17.)

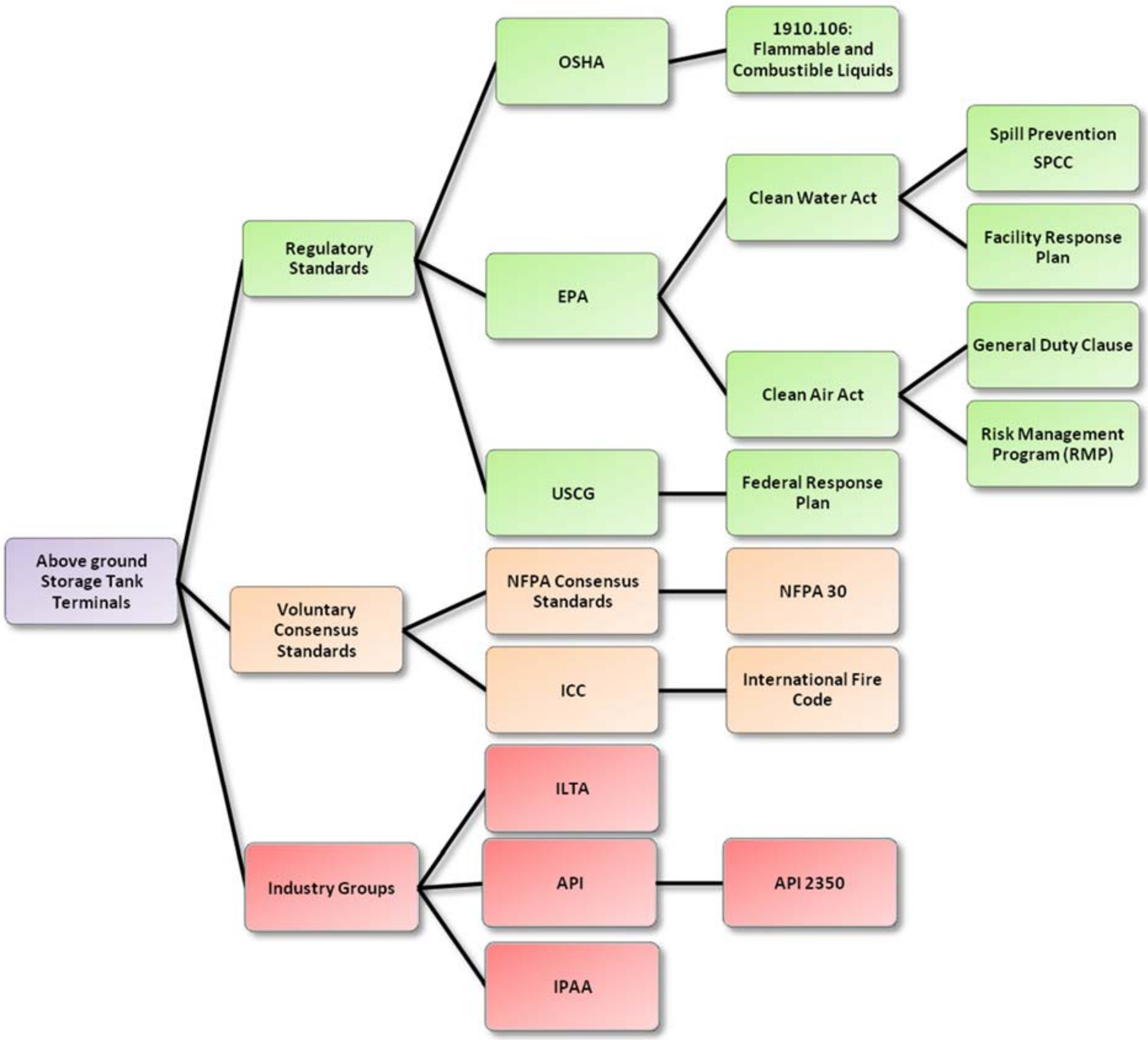

Figure 17: Many regulatory policies, voluntary and consensus standards contain safety requirements or recommendations for bulk petroleum aboveground storage tanks, but not all are required, and storage tank facilities are not generally covered by the RAGAGEP provisions of the OSHA PSM and EPA RMP programs. The voluntary industry and consensus standards could be considered RAGAGEP, if the process or facility were covered under these programs.

8.1 Environmental Protection Agency (EPA)

Although certain environmental statutes and EPA regulations apply to bulk petroleum aboveground storage tank terminals such as CAPECO, the CSB finds these regulations do not adequately protect the public from catastrophic incidents at bulk petroleum storage tank terminals storing NFPA 704, Class 3 flammable liquids:

- The EPA Clean Air Act General Duty Clause (CAA Section 112(r)(1)) lacks specific guidance for preventing accidental releases, while other regulations, such as the Risk Management Program (RMP), the Spill Prevention, Control and Countermeasure (SPCC), and the Facility Response Plan (FRP), do not require an overfill prevention program and a robust hazard assessment.
- The Clean Air Act (CAA) General Duty Clause protects the public living near facilities. Due to a gasoline exemption and the flammable mixture provision[101] under the List Rule (see Section 8.3), bulk petroleum storage tank terminals are not subject to the EPA risk management program regulations because they store NFPA Class 3 flammable liquids not regulated by the standard.
- The Clean Water Act (CWA) SPCC regulations, which protect navigable waterways and shorelines from oil spills, require only one layer of protection for overfill prevention and do not require that bulk petroleum tank terminals implement a second layer of protection, such as an independent high level alarm.

8.2 Clean Air Act: The General Duty Clause

Section 112(r)(1) of the CAA, the General Duty Clause, 42 U.S.C. § 7412(r)(1), requires owners and operators of stationary sources[102] who produce, store and handle extremely hazardous substances to identify hazards, design, and maintain a safe facility to prevent their release and protect the public.[103] The EPA issues chemical safety alerts advising industry on the types of issues covered by the General Duty Clause and publishes alerts on reactive hazards, lightning,

[101] Flammable mixtures containing more than 1% of a regulated substance and the overall mixture meets the NFPA 4 flammability criteria are covered and must submit a Risk Management Plan to the EPA. *General Duty Clause of the Clean Air Act* (Washington, DC: U.S. Environmental Protection Agency, March 2009). http://www.epa.gov/oem/docs/chem/gdc-fact.pdf (accessed December 21, 2014).

[102] *Stationary source* means any buildings, structures, equipment, installations, or substance-emitting stationary activities that belong to the same industrial group, which are located on one or more contiguous properties and under the control of the same person (or persons under common control), and from which an accidental release may occur (63 FR 645).

[103] *Guidance for Implementation of the General Duty Clause Clean Air Act, Section 112(r)(1)* (Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response Office of Enforcement and Compliance Assurance, May 2000). http://www2.epa.gov/sites/production/files/2013-10/documents/gdcregionalguidance.pdf (accessed December 21, 2014).

and other catastrophic hazards. In 2009, the EPA issued a Chemical Safety Alert for Rupture Hazard from Liquid Storage Tanks to address catastrophic hazards posed by fertilizer storage tanks.[104]

However, to date, the EPA has not issued any alerts for overflow hazards from flammable liquids in storage tanks, despite the occurrence of high-consequence incidents such as Texaco Oil Company and Buncefield incidents prior to CAPECO. In addition, the performance-based[105] nature of the general duty clause leaves the responsibility of protecting the public up to each covered facility, without any specific requirements from the EPA. The CSB found that further guidance under the General Duty Clause may be necessary to encourage more than one layer of overfill protection for bulk aboveground petroleum storage tank terminals near communities.

8.3 EPA: The List Rule

After a number of chemical accidents in the US and overseas, Congress enacted the Clean Air Act Amendments (CAAA) of 1990. Sections 301 and 112 of the CAAA require that the EPA issue regulations preventing accidental releases that could harm the public.[106] Section 112(r) of the CAAA, 42 U.S.C. § 7412 (r), requires owners and operators of stationary sources to identify hazards and to prevent and minimize the effect of accidental releases when extremely hazardous substances are present.[107] The EPA promulgated the Risk Management Program rule in 1996 to address accidental releases.[108] The CAAA required EPA to promulgate an initial list of 100 substances "known to cause or may [reasonably] be anticipated to cause death, injury, or serious adverse effects to human health or the environment"[109] in the event of an accidental release.[110]

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[104] *Chemical Safety Alert: Rupture Hazard from Liquid Storage Tanks*. U.S. Environmental Protection Agency: Washington, DC, September 2009. http://www.epa.gov/osweroe1/docs/chem/tanks7.pdf (accessed December 21, 2014).

[105] A performance-based standard, also referred to as a functional approach, allows facilities to define their own methods to achieve the regulatory goal or standard. Examples of performance-based standards are the OSHA PSM standard and a numeric limit on emissions that does not prescribe how it is achieved.

[106] CONSAD Research Corporation. *Analytical Support and Data Gathering for an Economic Analysis of the Addition of Selected Reactive Chemicals within the Scope of the OSHA Process Safety Management Standard* (Washington, DC: U.S. Occupational Safety and Health Administration, 1998).

[107] *Guidance for the Implementation of the General Duty Clause of the Clean Air Act, Section 112(r)(1).* 550-B00-002 (Washington, DC: U.S. Environmental Protection Agency, May 2000): 2.

[108] *EPA Can Improve Implementation of the Risk Management Program for Airborne Chemical Releases*. 09-P-0092 (Washington, DC: U.S. Environmental Protection Agency, February 10, 2009).

[109] *Guidance for Implementation of the General Duty Clause Clean Air Act, Section 112(r)(1)* (Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response Office of Enforcement and Compliance Assurance, May 2000). http://www2.epa.gov/sites/production/files/2013-10/documents/gdcregionalguidance.pdf (accessed December 21, 2014).

[110] The Public Health and Welfare. *U.S. Code,* Section 7412(r)(3), Title 42, 2009.

Known as the List Rule, this requirement obliged covered facilities, in addition to other requirements, to submit a Risk Management Plan (RMP) to the EPA when they exceeded the threshold quantity of a regulated substance on the list. The initial list included 77 acutely toxic substances, 63 flammable gases and volatile flammable liquids, and Division 1.1 high-explosive substances as designated by the Department of Transportation (DOT).

The List Rule has been amended several times since its promulgation. Shortly after enactment,[111] the API and the Institute of Makers of Explosives (IME) filed petitions requesting a judicial review of the List Rule. In settlement of these petitions, the EPA specifically exempted regulated substances in gasoline[112] from determining whether a threshold quantity was present in a process.[113] The EPA stated, "risks associated with the storage and handling of flammable substances are a function of the properties of the materials, not their end use."[114] The agency argued for "exempting gasoline because it does not meet the NFPA 4 flammability criteria,"[115] and "the EPA believes it does not represent a significant threat to the public of vapor cloud explosions."[116]

The EPA also exempted flammable mixtures including blendstocks[117] and natural gasoline that do not meet the NFPA flammability rating of 4.[118] However, flammable mixtures and

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[111] Petitions were filed within the standard 60-day period under CAA 307(b), around March 1994. The settlement of the petitions occurred in early 1996.

[112] Gasoline is exempt from the EPA List Rule because it does not meet the boiling point criterion for listing (NFPA 4 criteria, flammability hazard rating of 4); therefore, this substance is not assigned a threshold level. Approval of Colorado's Petition To Relax the Federal Gasoline Reid Vapor Pressure Volatility Standard for 1996 and 1997. *Federal Register* (1996): 61, 73.

[113] Regulated Substances for Accidental Release Prevention – Threshold Determination. *Code of Federal Regulations,* Part 68.115(b)(2)(ii), Title 40, 1998.

[114] 40 CFR Part 68, List of Regulated Substances and Thresholds for Accidental Release Prevention; Final Rule. Rules and Regulations, January 6, 1998. *Federal Register* (1998): 63 (3),

[115] NFPA 704 defines NFPA 4 flammability criteria to include materials that rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air and burn readily. This may include flammable gases, flammable cryogenic materials, any liquid or gaseous material that is liquid while under pressure and has a flash point below 22.8°C (73°F) and a boiling point below 37.8°C (100°F) (i.e., Class IA liquids), and materials that ignite spontaneously when exposed to air. Solids containing greater than 0.5 percent by weight of a flammable or combustible solvent are rated by the closed cup flash point of the solvent. NFPA 704. http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=704 (accessed December 21, 2014).

[116] 40 CFR Part 68 List of Regulated Substances and Thresholds for Accidental Release Prevention; Final Rule. Rules and Regulations, January 6, 1998. *Federal Register* (1998): 63 (3).

[117] Blendstocks are motor gasoline blending components intended for blending with oxygenates to produce finished reformulated motor gasoline. (Energy Information Administration, Definitions, Sources and Explanatory Notes http://www.eia.gov/dnav/pet/tbldefs/pet_move_wkly_tbldef2.asp (accessed December 21, 2014).

[118] 40 CFR Part 68, List of Regulated Substances and Thresholds for Accidental Release Prevention. Final Rule. Rules and Regulations, 6 January 1998. *Federal Register* (1998): 63 (3).

blendstocks meeting the NFPA 4 flammability are subject to threshold determinations[119] irrespective of their end use. If a mixture consists of 1% or greater concentration of a regulated flammable substance and the mixture meets the NFPA 4 flammability criteria, the EPA considers the entire weight of a flammable mixture as the regulated flammable substance.[120] The EPA recognizes specific circumstances in which a facility not covered under the List Rule has the potential for a vapor cloud explosion, and it asserts that the General Duty Clause protects against site-specific factors that "make an unlisted chemical extremely hazardous."[121]

The unleaded gasoline involved in the CAPECO incident had an NFPA 704 flammability rating of 3, falling outside the RMP criteria. The flammable mixture also had an API gravity[122] of 63.7, characterizing it as highly flammable. Although the components of unleaded gasoline—benzene, toluene, xylene, cyclohexane, trimethyl benzene, and alcohol additives—are not regulated substances under the List Rule, they contribute to its high flammability. In the CAPECO incident, these components resulted in a vapor cloud formation and explosion.[123] The magnitude of the CAPECO incident warrants that the EPA reassess its criteria for exempting blendstocks and flammable mixtures that do not meet NFPA 4 flammability criteria.

Furthermore, the EPA did not consider the previous incidents when it granted the gasoline and flammable mixture exemption.[124] These incidents and the CAPECO explosion demonstrate that a vapor cloud formation from a flammable mixture such as unleaded gasoline can result in catastrophic impact to local communities and workers. In addition, despite a requirement to protect the public under the General Duty Clause, CAPECO did not implement an adequate safety management system to prevent the catastrophic explosion and fire.

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[119] A threshold determination is the method by which a source calculates whether a threshold quantity is present in a process. Exemptions and exclusions of regulated substances from threshold determination allow a source not to include regulated substances in a mixture in specified instances.

[120] 40 CFR Part 68, List of Regulated Substances and Thresholds for Accidental Release Prevention. Final Rule. Rules and Regulations, January 6, 1998. *Federal Register* (1998): 63 (3).

[121] Ibid.

[122] The American Petroleum Institute (API) characterizes flammability of crude oil and condensate by gravity level. The higher the gravity, the lighter and more flammable the compound; materials below an API gravity value of 35 are characterized as crude oil, while those above 45 are considered condensate.

[123] Gasoline with blends that include more than 1% of pentane is subject to coverage under the RMP.

[124] See Section 7.2 and Appendix B for incidents excluded from EPA consideration in its gasoline and flammable mixture exemption.

8.4 Risk Management Program

Under 40 CFR §68, covered facilities fall into three Program Levels (Program 1, 2, or 3) based on a process unit's potential to affect the public and the requirements to prevent accidents.[125] Consistent with OSHA's PSM requirements, facilities that fall under Program 3 must implement a prevention program that includes process safety information, process hazard analysis, standard operating procedures, training, mechanical integrity, compliance audits, incident investigations, management of change (MOC), pre-startup reviews, employee participation, and hot work permits. Tank terminals similar to CAPECO that store gasoline do not fall under Program 1, 2 or 3 requirements. In addition, under the Risk Management Program, covered facilities are subject to the same recognized and generally accepted good engineering practices (RAGAGEP) requirements for mechanical integrity and process hazard analyses (PHAs) as the OSHA PSM standard.

8.5 Chemical Accident Provisions, Risk Management Plan (RMP)

The EPA's Chemical Accident Provisions (40 CFR §68) require facilities that have more than a threshold quantity of a List Rule-regulated substance to submit a Risk Management Plan (RMP) identifying the quantity of flammable or toxic material and to report on their accident prevention program, accident history, and planning.[126] Every five years, covered facilities must conduct a hazard assessment that considers worst-case scenarios, certify to the EPA their compliance with prevention program requirements,[127] and coordinate their emergency response preparedness with local responders. Had CAPECO been required to conduct a hazard assessment that evaluated the quantity of flammable products stored at the terminal and their proximity to the neighboring community, the facility may have had to address the risk of a vapor cloud explosion and resulting multiple tank fires. Under RMP, CAPECO would have had to develop accident prevention programs and coordinate response planning with local emergency responders, actions that might have mitigated the incident.

The EPA requested more information from the public and regulated community on amending the RMP rule to include more specific siting requirements as part of the PHA in a July 31, 2014, Request for Information (RFI).[128] The CSB issued comments under the RFI encouraging the

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[125] 40 CFR §68.10. Applicability. http://www.law.cornell.edu/cfr/text/40/68.10 (accessed December 21, 2014).

[126] Regulated Substances for Accidental Release Prevention. *Code of Federal Regulations,* Part 68.115(b)(2), Title 40, 1998.

[127] Ibid.

[128] The RFI was issued under 40 CFR §68, Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act, Section 112(r)(7).

EPA to provide more guidance on facility siting.[129] Examples of siting requirements provided by the EPA include buffer or setback zones for newly covered stationary sources, or establishing safety criteria for siting of structures that house people inside a facility.[130]

8.6 The Clean Water Act (CWA)

The Federal Water Pollution Act of 1972, or Clean Water Act (CWA), as amended, gives the EPA jurisdiction[131] to protect navigable waters from pollution. Section 311 authorizes a program to prevent, prepare for, and respond to discharges of oil and hazardous substances. Section §311(j)(1)(C) provides that the President shall issue regulations establishing procedures, methods, equipment, and other requirements to prevent and contain discharges of oil[132] from facilities and vessels, and to contain such discharges. CAPECO was subject to various EPA regulations promulgated under the CWA.

8.6.1 Spill Prevention, Control and Countermeasure (SPCC) Regulations

The Spill Prevention, Control, and Countermeasure (SPCC) requirements govern oil discharge at aboveground storage tank sites. The EPA promulgated the SPCC regulation (40 CFR §112) on January 10, 1974 (See 38 FR 34164). The SPCC regulation requires a facility to prepare and certify by a Professional Engineer, a plan detailing the equipment, workforce, procedures, and steps to prevent and control an oil discharge to navigable waters and shorelines. The regulation at 40 CFR §112.8(c)(8) requires SPCC-subject facilities to provide for overfill protection for each container in accordance with good engineering practice including applicable industry standards.[133] The regulation allows the owner/operator of a container to select only one suggested method of overfill controls. The options include, high liquid level alarms at a constantly attended location or surveillance station, high liquid level pump cut off devices to stop

[129] Docket No. EPA-HQ-OEM-2014-0328 http://www.csb.gov/assets/1/7/EPA_RFI.pdf. (accessed January 7, 2015)

[130] Environmental Protection Agency. 40 CFR Part 68. Accidental Release Prevention Requirement: Risk Management Programs Under the Clean Air Act, Section 11(r)(7). Proposed Rule. *Federal Register*. (2014): 79 (147), 44604-44633.

[131] CWA jurisdiction includes navigable waters of the United States and adjoining shorelines, the waters of the contiguous zone, and the high seas beyond the contiguous zone in connection with activities under the Outer Continental Shelf Lands Act. It covers activities under the Deepwater Port Act of 1974 or activities that may affect natural resources belonging to, appertaining to, or under the exclusive management authority of the United States, including resources under the Magnuson Fishery Conservation and Management Act of 1976.

[132] Under CWA §311(a)(1), "oil" means "oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil." Clean Water Act Section 311 – Oil and Hazardous Substances Liability. http://www.epa.gov/region7/public_notices/CWA/section311.htm (accessed December 21, 2014).

[133] Environmental Protection Agency. 40 CFR Part 112.8(c)(8). Spill Prevention, Control, and Countermeasure Plan requirements for onshore facilities (excluding production facilities). Section 112.8(c)(8). (2002).

the liquid flow into a tank at a previously established level, direct audible or code signal communication between the container gauger and the pumping station, and a fast response system such as a digital computer, telepulse or direct vision gauges to determine liquid levels in a tank or container. [134] The regulation also requires regular testing of level sensors for the selected overfill prevention option.[135]

8.6.2 CAPECO's SPCC History

The CAPECO facility had a history of noncompliance with SPCC regulations. In 1993, EPA inspections noted poor housekeeping, including oil in tank berm areas and inadequate control of vegetation in the secondary containment areas. In 1996, the EPA cited CAPECO for deficiencies in their SPCC plan that include not adequately explaining the engineering controls in place to prevent a spill. The facility also experienced an overfill incident in 1999, when fuel spilled from an asphalt tank outside the tank farm area. Oil flowed out of a vent located at the top of the tank into the secondary containment. Although this incident occurred in a separate process from the tank farm, the EPA findings are relevant to the 2009 overfill incident. The EPA cited the facility for not updating the bulk storage tank installations and for not incorporating fail-safe engineering to prevent the overfill incident.[136] After this incident, the EPA recommended that CAPECO consider installing one or more of the following safeguards:

- High-level alarms with an audible or visual signal at a constantly manned operation or surveillance station;
- High-liquid-level pump cutoff devices set to stop flow at a predetermined tank content level;
- Direct audible or code signal communication between the tank gauger and the pumping station; or
- A fast response system for determining the liquid of each bulk storage tank, including digital computers, telepulse, or direct vision gauges or their equivalent.

According to EPA records, CAPECO was compliant with recommendations by 2001. The facility installed two levels of protection, the computer system, equipped with a high-liquid level

[134] Spill Prevention, Control, and Countermeasure Plan requirements for onshore facilities (excluding production facilities). *Code of Federal Regulations*, Part 112.8, Title 40 (2002). http://www.ecfr.gov/cgi-bin/text-idx?SID=67da1ecbd5068d7f144a92e0e59ef956&mc=true&node=pt40.22.112&rgn=div5#se40.22.112_18 (accessed June 2015).
[135] Ibid.
[136] US Environmental Protection Agency Region 2. *Review of Revised SPCC Plan for the Caribbean Petroleum Refining Facility*, Bayamón, Puerto Rico (Washington, DC: U.S. Environmental Protection Agency, September 20, 1999).

audible/visual alarm, and established direct communication between the gauger and the pump station, but was not required to conduct a hazard assessment to determine if the two safeguards adequately prevented an overfill. See Section 6.5.1 for discussion on the computer system.

After the October 23, 2009, incident, the EPA cited CAPECO again for not having "fail safe engineering"[137] on any of its bulk storage tanks at the time of the incident. CAPECO contended that the facility did employ "fail safe engineering," as evidenced by its gauging system, which included reading the tank side gauge and using the Digital Electric Level Transmitter. The EPA deferred to guidance on fail-safe engineering, referring CAPECO to industry standards. However, the CSB found, both the consensus standards (NFPA 30, Section 8.10.2.1) and industry standard (ANSI/API 2350, Section 8.10.1.1) offer little guidance on fail-safe engineering practices at tank terminals. Furthermore, the 2009 incident breached secondary containment and spilled into navigable waterways. Although the secondary containment captured the gasoline from Tank 409, the open dike valves allowed oil, fire suppression foam, and an oily-water mixture to migrate to the storm water retention pond in the WWT area. The fuel mixture discharged into Las Lajas Creek, which feeds 100 acres of wetlands and nearby Malaria Creek flowing into the Bay of San Juan. (See Section 5.3.1 for a discussion of community impact.) The pooling gasoline in the containment dike also contributed to the formation of the flammable vapor cloud. (See Section 4.3 on flammable vapor cloud development.) The CSB further concludes that a high-level alarm system as part of an automatic overfill prevention system equipped with one additional layer of protection under SPCC could have alerted operators to the high liquid levels, or automatically shut down transfer operations, or diverted the flow operations to another tank.

The CSB learned that tank terminal facilities do not have to register or report overfill incidents unless those discharges are in violation of CWA section 311(b)(3), as per 40 CFR §110.6. A 2008 Government Accountability Office (GAO) report found that the EPA did not have a clear understanding of the universe of facilities regulated under SPCC. This limited knowledge hinders the agency's ability to effectively identify regulated facilities, establish inspection priorities, and evaluate whether the program is achieving its goals."138 These findings were again reiterated in a 2012 report that found the EPA lacked sufficient data on the facilities covered in the Oil Prevention Program, which includes both the SPCC and Facility Response

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[137] Fail Safe Engineering refers to the design of a product to fail in a predictable manner, to a "safe state." P. Herena. *The Principle of Fail Safe* (American Institute of Chemical Engineers, February 23, 2011). http://chenected.aiche.org/process-safety/the-principle-of-fail-safe/ (accessed December 21, 2014).

[138] Government Accountability Office. *Aboveground Oil Storage Tanks: More Complete Facility Data Could Improve Implementation of EPA's Spill Prevention Program,* GAO-08-482 (Washington, DC: U.S. Government Accountability Office, April 30, 2008).

Plan (FRP). The 2012 report stated, "the Agency [EPA] remains largely unaware of the identity and compliance status of the vast majority of CWA Section 311 regulated facilities."139 Furthermore, the 2012 report calls attention to the inadequacy of data collection for OPP-covered facilities: "Agency data systems cannot exchange data with each other, and lack consistent and sufficient codes to categorize deficiencies and noncompliance. These data systems limitations prevent EPA from capturing the full details of a violator's history and identifying trends in compliance and enforcement."140 A registry of incidents occurring at tank terminal facilities, such as CAPECO, would allow the EPA to tailor overfill protection requirements more effectively.

8.6.3 Facility Response Plans (FRP)

Section 311(j)(5) of the CWA, amended by the 1990 Oil Pollution Act (OPA), calls for facilities that could cause substantial harm[141] from an oil discharge to submit a Facility Response Plan (FRP). The FRP requires contingency measures for oil discharged from an incident.[142] Designed in accordance with Sections 112.20, 112.21 and Appendices C-F of the CWA FRP regulation, FRPs demonstrate a facility's response to a worst-case discharge of oil. Because CAPECO had vessel loading and unloading capabilities, the terminal was also subject to USCG's FRP regulation at 33 CFR §154. Both the EPA and USCG conducted multiple inspections at the CAPECO facility prior to the incident. The EPA and USCG have separate regulatory jurisdiction for this facility. EPA's jurisdiction begins at the first valve inside secondary containment whereas the USCG's jurisdiction begins at this first valve inside secondary containment for the EPA regulated tank and extends to the vessel. The USCG inspects marine operations at the dock and the pipeline carrying fuel to the first valve inside secondary containment.

The FRP rule at 40 CFR §112.20(f)(1) outlines the substantial harm criteria that allows for owner/operators to self-identify whether their facilities are subject to the FRP regulation. A facility can be classified for the potential to cause substantial harm if they meet the following

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[139] Environmental Protection Agency, Office of Inspector General. *EPA Needs to Further Improve How It Manages Its Oil Pollution Prevention Program*. Report No. 12-P-0253 (Washington, DC: U.S. Environmental Protection Agency, February 6, 2012).

[140] Ibid., p.9.

[141] A facility could reasonably be expected to cause substantial harm to the environment if it has 42,000 gallons or more in oil storage capacity and transfers of oil over water to or from vessels, or if it has 1 million gallons or more in oil storage capacity, and if one of the following is true: 1) it has inadequate secondary containment and freeboard; 2) a discharge could cause injury to fish and wildlife and sensitive environments; 3) a discharge could shut down a public drinking water intake; or 4) it has had a reportable oil discharge of 10,000 gallons or more within the last 5 years.

[142] Subpart D-Response Requirements: Facility Response Plans, *Code of Federal Regulations,* Part 112.20, Title 40 (2000).

criteria: 1) The facility transfers oil over water to or from vessels and has a total oil storage capacity greater than or equal to 42,000 gallons; or 2) The facility's oil storage capacity is greater than or equal to 1 million gallons and one of the following is true:

- The facility does not have adequate sized secondary containment for each aboveground storage area;
- The facility is located at a distance such that a discharge from the facility could cause injury to fish and wildlife and sensitive environments;[143]
- The facility is located at a distance (i.e., planning distance) such that a discharge from the facility would shut down a public drinking water intake; or
- The facility has experienced a reportable oil discharge greater than or equal to 10,000 gallons within the last 5 years.[144]

In accordance with 40 CFR §112.20(f)(3), all FRPs submitted to EPA are reviewed by EPA to determine whether an oil discharge from the facility could cause significant and substantial harm. Facilities with this harm designation require the EPA approval of their FRP. CAPECO met the substantial harm criteria, had submitted an FRP to EPA Region 2, was designated as a "significant and substantial harm" facility, and was inspected multiple times by EPA inspectors for SPCC and FRP compliance.

8.6.4 EPA FRP Inspection History

Similar to its SPCC record, CAPECO had a history of non-compliance related to FRP requirements. CAPECO submitted its first FRP to the EPA in 1997. However, a 1998 EPA field inspection identified violations, which the facility failed to correct when reapplying for approval in 1999 and 2001. The EPA denied approval of CAPECO's FRP in 1999 and March 2001.[145] CAPECO received approval for its FRP in July 2001; however, another EPA FRP inspection in 2005 revealed deficiencies in maintaining discharge prevention meetings or logs.[146]

8.6.5 USCG FRP Inspection History

The USCG conducted annual FRP inspections of the CAPECO facility from 2004 to 2011 to evaluate communications, pollution prevention/response, operations/management, firefighting, documentation, and other emergency response elements. However, the FRP inspection failed to

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[143] This distance is referred to as the "planning distance." Calculation instructions are outlined in Appendix C of 40 CFR §112.

[144] 40 CFR §112.20 Facility response plans. (f)(1)

[145] Caribbean Petroleum Refining LP. *US EPA Region 2 Facility Response Plan (FRP)*; FRP ID 20027. Caribbean Petroleum Refining LP: Bayamon, PR (2001).

[146]Ibid., p.1.

document CAPECO's ability to fight a catastrophic loss of containment that could result in multiple tank fires. CAPECO received a satisfactory inspection from 2004 to March 2008. Seven months prior to the October explosion and fires CAPECO submitted an updated FRP and received a satisfactory inspection.[147]

8.6.6 Lack of Robust FRP Inspections

Despite receiving a satisfactory rating on the various components of emergency response, CAPECO experienced the 2009 overfill incident that spilled into nearby wetlands. The CSB found the FRP inspection process does not require FRP inspectors to conduct a thorough evaluation of an emergency response plan that encompasses catastrophic failure of multiple tanks at once. Under the EPA's jurisdiction, Appendix F of 40 CFR §112.20(h) and Appendix F, Section 1.5.1.2 requires a facility to address chain reactions[148] of a tank failure leading to contaminating navigable waters, while the USCG FRP inspection report assesses oil spill preparedness by evaluating a terminal's pollution prevention and response, firefighting, communications, deck, and cargo, among other factors. However, both FRP inspections lack substantive evaluation of a covered facility's mitigation efforts to prevent a catastrophic incident like an explosion and multiple tank fires that can contaminate navigable waters.

Had the EPA and USCG FRP inspectors been required to fully assess the functioning of the containment dike, dike drain valves, and the full scope of CAPECO's emergency discharge plan, CAPECO might not have received a satisfactory inspection and would have had to evaluate its inadequate dike drainage system, which led to the spread of the gasoline vapor cloud. See Section 6.9.1 for discussion on dike drain valves.

8.6.7 EPA RMP and SPCC Programs Lack Resources to Inspect Tank Facilities

The CSB has identified significant gaps in the RMP and SPCC programs that warrant the EPA to extend coverage to bulk petroleum terminals storing NFPA 704 Class 3 flammable liquids and above. However, both programs lack the resources to sufficiently inspect all covered facilities. The CSB Chevron investigation report discusses how the EPA's Risk Management Program lacks the ability to inspect all covered facilities and made recommendations to the Governor of California to "Ensure that a means of sustained funding is established to support an independent,

[147] United States Coast Guard. *Activity Summary Report. Annual Exam*, Activity ID 1985003, 2521895, 3093795, 3162359, 3428543 (Washington, DC: U.S. Department of Homeland Security, 2009).

[148] A chain reaction of a failure requires a covered facility to consider the impact of the failure on the environment. Facility response training and drills/exercises. *Code of Federal Regulations*, Part 112.20(h) and Appendix F, Section 1.5.1.2, Title 40 (2000).

well funded, well staffed, technically competent regulator."[149] Federal EPA RMP and SPCC programs lack the capacity to undertake inspection of such tank terminals.
A 2009 report of the EPA Risk Management Program found that EPA inspected only 197 of the 493 high-risk facilities identified by the EPA's Office of Emergency Management. Among the 296 uninspected facilities, 151 had the potential to affect 100,000 people or more in a worst-case accident.[150] The report identified a lack of full-time inspectors as one of the main factors limiting the EPA's ability to conduct on-site audits or inspections of facilities covered under the Risk Management Program. In fiscal year 2009, the EPA had 24 full-time inspectors to cover 11,529 facilities covered in the program.[151] For the EPA to sufficiently inspect tank terminals like CAPECO, the Risk Management Program will require additional resources.

8.6.8 The OPP Program Lacks Resources

EPA lacks sufficient staff to inspect all its SPCC- and FRP-covered facilities and lacks a comprehensive understanding of the facilities it regulates. EPA has an estimated 30 to 40 full-time employees to inspect all SPCC- and FRP-covered facilities. From 2008 to 2012, the EPA inspected only 3,700 of the 640,000 facilities covered under SPCC.[152] In addition, a 2008 report found "Without more comprehensive data on the universe of facilities that are subject to the SPCC rule, EPA cannot employ a risk-based approach to target its SPCC inspections to those facilities that pose the greatest risks of oil spills into or upon U.S. navigable waters and adjoining shorelines."[153] The same report found that the "incomplete information on the universe of SPCC facilities prevents EPA from determining whether and to what extent the SPCC program is achieving its goals."[154]

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[149] U.S. CSB. *Regulatory Report: Chevron Richmond Refinery Pipe Rupture and Fire*, *Chevron Richmond Refinery #4 Crude Unit, Richmond, CA. August 6, 2012*. 2012-03-I-CA (Washington, DC: U.S. Chemical Safety Board, October 2014). http://www.csb.gov/assets/1/19/Chevron_Regulatory_Report_11102014_FINAL_-_post.pdf (accessed December 21, 2014).

[150] Environmental Protection Agency. Office of Inspector General. *EPA Can Improve Implementation of the Risk Management Program for Airborne Chemical Releases*. 09-P-0092 (Washington, DC: U.S. Environmental Protection Agency, February 10, 2009).

[151] Ibid.

[152] Environmental Protection Agency, Office of Inspector General. *EPA Needs to Further Improve How It Manages Its Oil Pollution Prevention Program*. 12-P-0253 (Washington, DC: U.S. Environmental Protection Agency, February 6, 2012).

[153] Government Accountability Office, *Aboveground Oil Storage Tanks: More Complete Facility Data Could Improve Implementation of EPA's Spill Prevention Program,* GAO-08-482, April 30, 2008.

[154] Ibid.

8.7 Occupational Safety and Health Administration (OSHA)

A CSB analysis found deficiencies in various OSHA standards addressing tank terminals in protecting workers from the flammable hazards. In addition, similar to the EPA's policies, OSHA's exemption of atmospheric storage tanks from the Process Safety Management (PSM) standard undermines the development of hazard assessments and management of change (MOC) reviews that would have required CAPECO personnel to analyze the hazards posed by terminal operations. Furthermore, specific requirements for robust overfill prevention and risk management are lacking because OSHA regulations do not consider tank terminals as PSM-covered or high-hazard facilities.[155]

8.7.1 Flammable and Combustible Liquids (1910.106)

OSHA's Flammable and Combustible Liquids standard (1910.106), which covers tank terminals containing flammable materials, does not require overfill protections for aboveground storage tanks.[156] Based on the 1968 version of NFPA 30: Flammable and Combustible Liquids Code, the standard offers no guidance on overfill prevention at terminal facilities during the transfer of flammable or combustible fluids. While recent versions require limited overfill protection, OSHA has not updated 1910.106 to include newer versions of NFPA 30 or other updated good engineering practices. (See Section 8.10.2.1.)

The Puerto Rico Occupational Safety and Health Administration (PR OSHA)[157] cited CAPECO for endangering the lives of tank farm workers following the incident. Although the October 23, 2009, explosion did not result in any worker injuries, tank farm operators escaped the initial vapor cloud ignition by a few minutes. PR OSHA cited CAPECO under 1910.106, stating:

> *"At Caribbean Petroleum Refining in Bayamón employees that worked performing routine tasks such as tank operator, waste treatment operator, loading rack operator, among others were exposed or could be exposed to flammable and combustible release, fire and or explosion during the performance of their duties. At the tank farm area the employer stored gasoline, jet fuel, fuel oil and diesel, in above ground tanks, ranging*

[155] A PSM-covered facility or high-hazard facility, as defined by OSHA PSM, has the potential for a *catastrophic release* (major uncontrolled emission, fire, or explosion, involving one or more highly hazardous chemicals that present serious danger to employees in the workplace). A *facility* is defined as the buildings, containers, or equipment which contain a process. *Highly hazardous chemical* is defined as a substance possessing toxic, reactive, flammable, or explosive properties. Process safety management of highly hazardous chemicals. *Code of Federal Regulations*, Part 1910.119, Title 29, 2012.

[156] 1910.106 contains some overfill provisions for tank trucks and tank cars.

[157] Puerto Rico OSHA operates as a state plan. Established by the 1975 Occupational Safety and Health Act of Puerto Rico, the Puerto Rico Occupational Safety and Health Administration (PR OSHA) oversees 29 CFR 1910.106 – Flammable and Combustible Liquids, 29 CFR 1910.119 – Process Safety Management of Highly Hazardous Chemicals, 29 CFR 1910.120 – Hazardous Waste Operations and Emergency Response.

> *from 500 to 500,000 barrels. The employer did not review the Operational hazard of a large Hydrocarbon release from on-site piping entering the process sewer and storm water sewer systems. Equipment hazards like the additional hazards created by the use of expansion joints on the gasoline transfer lines at the Cummins pump station area. Human factors analysis related to what could occur if operators did not follow instructions for conducting rounds or gauging tanks. Level reading erroneous at the tank gauge and at the operators console. Additional hazards created when operators had to read tank sight gauge levels during the night in low light conditions. Lack of formal written operating procedures for determining the level of storage tanks during filling operations."*

The CSB found OSHA's Flammable and Combustible Liquids standard to be outdated, concluding that requiring terminal facilities to implement more than one safeguard and good engineering practice would have spared endangering the lives of CAPECO tank farm operators, and they would have likely been notified of the overfill before the vapor cloud developed.

8.7.2 Incorporating Elements of Process Safety Management (PSM) into 1910.106

OSHA's PSM Standard (29 CFR §1910.119) is a performance-based standard that requires covered entities, such as refineries and chemical plants, to implement a safety management system to prevent accidental releases from highly hazardous processes. PSM requires periodic audits, process hazard analysis (PHA),[158] and a management of change (MOC) process. Although the standard needs strengthening,[159] these tools indoctrinate additional safety measures into a covered entity's procedures. OSHA requires employers to use appropriate methods, such as hazard and operability studies (HAZOP), failure mode and effects analyses (FMEA), or fault tree analyses, among other safeguards, to identify and control hazards when conducting a PHA.

[158] "The process hazard analysis is a thorough, orderly, systematic approach for identifying, evaluating, and controlling the hazards of processes involving highly hazardous chemicals. The employer must perform an initial process hazard analysis (hazard evaluation) on all processes covered by the [PSM] standard. The process hazard analysis methodology selected must be appropriate to the complexity of the process and must identify, evaluate, and control the hazards involved in the process." U.S. Department of Labor OSHA. *Process Safety Management*. OSHA 3132 (Washington, DC: U.S. Department of Labor Occupational Safety and Health Administration, 2000).

[159] The CSB made recommendations to amend the PSM regulations in the following investigations: BP Texas City, Motiva, Universal Form Clamp, Chevron and Tesoro. OSHA is undertaking measures to strengthen the standard. The CSB submitted comments to OSHA's request for information addressing PSM in January 2014. These comments are located on the CSB website: http://www.csb.gov/assets/1/16/CSB_RFIcomments.pdf (accessed December 21, 2014).

This performance-based standard requires the PHA methodology to address factors[160] such as engineering and administrative controls and appropriate detection methods, including process monitoring and control instrumentation with alarms.[161] Additionally, the standard requires covered facilities to update or revalidate their PHA every five years. PR OSHA adopted the Federal PSM standard as written.

The CSB found that the CAPECO incident was attributable to a lack of controls, enforcement, and adherence to these best engineering practices:

(1) A PHA, which might have identified additional engineering controls to prevent the vapor cloud formation.

(2) Engineering controls, such as automatic tank overflow protection system with a separate independent high-level alarm, which could have prevented the overflow.

(3) Facility design and tank spacing in a hazard analysis under aspects of PSM, likely increasing the number of safeguards to prevent an overfill.

Following the shutdown of the CAPECO refinery in 2000, the tank farm facility was no longer covered under PSM due to standard Section (a)(ii)(B) of the PSM standard, which expressly exempts flammable liquid stored in atmospheric storage tanks not connected to a covered process that are below normal boiling point. Under PSM, the facility was required to conduct periodic PHAs and MOCs of its process equipment. Facing fewer regulatory requirements for the tank farm, CAPECO management was not required to maintain the safety management system an MOC, and a periodic hazard assessment mandated under the PSM standard. Any of these requirements might have identified the lack of independent or redundant level alarm, overfill prevention safeguards and poor preventive maintenance. Including elements of PSM like the process hazard methodology into 1910.106 would compel tank terminals storing flammable liquids to reduce the risk posed to the workers and the public.

[160] Other PHA factors include the hazards of the process, previous incidents, consequences of failure of engineering and administrative controls, facility siting, human factors, and a qualitative evaluation of possible safety and health effects on employees in the workplace.

[161] U.S. Department of Labor OSHA. *Process Safety Management*. OSHA 3132 (Washington, DC: U.S. Department of Labor Occupational Safety and Health Administration, 2000).

8.8 Puerto Rico Occupational Safety and Health Administration (PR OSHA)

The Puerto Rico Occupational Safety and Health Administration (PR OSHA) visited the CAPECO facility nine times between 1988 and 2000. None of the visits occurred after the refinery shutdown in 2000 when the facility operated solely as a tank farm.

In 1988, PR OSHA fined CAPECO for serious violations under the General Duty Clause and the Flammable, Combustible Liquids standard (1910.106) after an employee was fatally injured, and another hospitalized while removing a blind from the pipeline when gasoline spilled and ignited. PR OSHA inspected CAPECO after the October 23, 2009 incident, issuing general duty citations for inadequate overfill prevention consistent with the recommended practice of ANSI/ANSI/API 2350, *Recommended Practice, Overfill Protection for Storage Tanks in Petroleum Facilities*, and NFPA 30, *Flammable and Combustible Liquids C*ode. Unable to issue citations under the PSM standard due to the atmospheric storage tank exemption, PR OSHA issued multiple serious violations and fines for lacking written procedures and not providing a safe workplace, and it referred to consensus and industry standards to address the flammable hazards onsite. The PHA, MOC, and procedural components of the PSM standard address most of the deficiencies cited by PR OSHA, but CAPECO was not compelled to follow them. If the OSHA PSM standard covered tank terminals, not only would terminals like CAPECO have to conduct a periodic analysis of their hazards, but also PR OSHA would be empowered to issue appropriate citations aimed at preventing similar incidents. The CSB issued a similar recommendation to remove the storage tank exemption in its Motiva investigation.[162]

8.9 Recognized and Generally Accepted Good Engineering Practices (RAGAGEP)

CFR §1910.119(d)(3)(ii) of the PSM and RMP standards require covered facilities and high-hazard facilities to ensure their equipment complies with recognized and generally accepted good engineering practices (RAGAGEP). These may include the Center for Chemical Process Safety (CCPS) research and publications; ASTM standards; piping, mechanical, and electrical codes; professional society standards; fire codes; and lessons learned from previous incidents.[163] OSHA and the EPA can cite facilities covered under PSM and RMP for noncompliance with

[162] The CSB Motiva Enterprises LLC investigation called for OSHA to extend PSM coverage to atmospheric storage tanks that could be involved in a catastrophic release interconnected to a covered process with 10,000 pounds of a flammable substance. This recommendation came after one worker was fatally injured and eight were injured when hot work on an aboveground storage tank holding sulfuric acid ignited the flammable vapors inside the tank, releasing contents into the Delaware River on July 17, 2001.

[163] A. S. Blair. "RAGAGEP Beyond Regulation: Good Engineering Practices for the Design and Operation of Plants." *Process Safety Progress* 26.4: 330–332.

RAGAGEP. Covering tank terminal facilities like CAPECO under PSM and RMP would ensure that they use the best available engineering practices**.**

8.10 Industry and Consensus Standards

Industry and consensus standards serve as industry best practices and fire codes for tank terminal facilities. In some cases, specific versions of industry standards and fire codes are incorporated by reference into different regulations. The API and the National Fire Protection Association (NFPA) have a number of standards and codes that apply to overfilling a petroleum storage tank.

8.10.1 American Petroleum Institute

The American Petroleum Institute (API), a national trade association representing the oil and natural gas industry, develops voluntary industry standards and recommended practices widely used in industry. Updated periodically, API standards and recommended practices use the term "shall" to communicate requirements and "should" to indicate a recommendations. The American National Standards Institute, ANSI/API Standard 2350 and API Manual of Petroleum Measurement Standards (MPMS) Ch. 3.1A are the most relevant to overfilling of tanks at storage terminals.

8.10.2 ANSI/API Standard 2350 and the Overfill Prevention Process

ANSI/ANSI/API 2350, *Overfill Protection for Storage Tanks in Petroleum Facilities*, offers guidance on preventing overfills in petroleum storage tanks. The current, fourth edition, released in 2012, recommends that heavier oils including gasoline be included in the scope of a facility-specific overfill prevention program. The standard recognizes that prevention provides the most basic level of protection; thus, while using both the terms "protection" and "prevention," the document emphasizes prevention. The standard covers minimum overfill (and damage) prevention practices for aboveground storage tanks in petroleum facilities, including refineries, marketing terminals, bulk plants, and pipeline terminals that receive flammable and combustible liquids.

8.10.3 Overfill Prevention Process

To prevent tank overfills, ANSI/API Standard 2350 (2012) calls for implementing an overfill prevention process (OPP) and an automatic overfill prevention system (AOPS) supported by a risk assessment or risk analysis. The standard recommends that an OPP contain a management system, a risk assessment system, defined operational parameters, and other procedures, including those for receipt termination.[164] Incorporating a management system into the overfill prevention process is a significant revision to the standard from previous editions. The standard recommends that facilities implement a safety management system that includes, among other safeguards:

- Formal documented operating procedures;
- Competent operating personnel;
- Scheduled inspections;
- A management of change process for personnel and equipment changes; and
- Systems for investigating and communicating overfill near misses and lessons learned.

The standard asserts overfill prevention is best achieved through awareness of available tank capacity and inventory, careful monitoring, product movement control, reliable instrumentation and sensors and systems, and automatic overfill prevention systems when recommended by a risk assessment or risk analysis.[165] Although this standard did not exist in its current form at the time of the incident, CAPECO lacked formal procedures, sufficient operations personnel, and an effective safety management system.

8.10.4 Inadequate Guidance on Conducting a Risk Assessment

The CAPECO facility was not required to conduct a risk assessment. However, if the facility looked to API for guidance, neither the 2008 nor the current 2012 edition of the ANSI/ANSI/API 2350 standard offers guidance on how to conduct a thorough risk assessment. The risk assessment component of ANSI/ANSI/API 2350 asks the owner and operator of facilities to "categorize risks associated with potential tank overfills as either meeting or not meeting the criteria of the stakeholders."[166] It offers a conceptual framework for conducting an overall risk assessment, without significant details on what is necessary.

While this standard provides a level of autonomy to tank terminal owners and operators, it should offer clear guidance on minimum criteria. The standard says tank terminals "shall consider" incorporating regulatory requirements when conducting a risk analysis, but facilities are not limited to using regulatory requirements to define the parameters of their risk analysis. Since the basis for the AOPS is contingent on results from a risk assessment, API should provide more guidance on the risk assessment process or provide authoritative resources for this purpose.

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[164] Receipt termination refers to stopping or completing tank-filling operations.
[165] *ANSI/API Standard 2350-2012. Overfill Protection for Storage Tanks in Petroleum Facilities.* Fourth edition. (Washington, DC: American Petroleum Institute, May 2012).
[166] *Ibid*.

8.10.5 Insufficient Requirement for Alarm Levels

Another deficiency of the ANSI/ANSI/API 2350 standard is the levels of concern (LOC) required for necessary level alarms. The standard recommends terminal owners and operators consider a number of parameters[167] when establishing LOC for all tanks and at minimum establish three levels: critical-high (CH) levels, high-high level (HH), and maximum-working level (MW).[168] ANSI/ANSI/API 2350 recommends using the LOC to set level alarms. The standard also recommends a minimum of three inches separating the CH and HH tank levels to account for potential errors in data and measurement.[169] Each level should be set sufficiently below the other to allow appropriate response time to terminate the process if necessary. ANSI/ANSI/API 2350 also stipulates that an AOPS level for emergency action be set below the critical-high level to allow for automatic termination of a receipt before the critical level is reached.

The aboveground storage tank industry should implement either a high-level alarm, an automatic overfill prevention system, or both, but the current edition of ANSI/API 2350ANSI/ANSI/API 2350 recommends only a high-level alarm. ANSI/API 2350 neither specifies using a highly reliable alarm nor provides guidance on when a high-level alarm is sufficient to reduce the overfill risk. In the case of CAPECO, the level alarms were prone to failure because the transmitter signal did not transmit the level signal to the computer, forcing operators to work with no automatic fill rate or time to fill estimate. The lack of guidance on when to use high-level alarms may encourage owners and operators of tank terminals to use only one level of alarm when two may be necessary. The UK Government and industry response to Buncefield included comprehensive new guidance on Safety and Environmental Standards for Fuel Storage Sites. *Process Safety Leadership Group, Final*, (PSLG) report sets minimum standards of overfill protection for gasoline storage tanks.[170] The UK Regulator (COMAH Competent

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[167] ANSI/API 2350 recommends tank terminals consider the product stored, operating practices in the field and for each tank, operating limits for valves and manifolds, tank capacities and physical conditions, the amount of product transferred, delivered or received and the rate of flow into each tank.

[168] The critical-high level of concern delineates the highest level that product in the tank can reach without detrimental impacts. The high-high level alarm is set below the critical-high level to enable termination of product receipt before reaching the critical-high level. Maximum-working level is an operational level and the highest product level to fill the tank during normal operations. No alarm is required at this level, but alerts are recommended.

[169] *ANSI/API Standard 2350-2012: Overfill Protection for Storage Tanks in Petroleum Facilities*. Fourth edition (Washington, DC: American Petroleum Institute, May 2012).

[170] *The Process Safety Leadership Group Report*: *Safety and Environmental Standards for Fuel Storage Sites*, *Final Report* (Kew, Richmond, UK: U.K. Health and Safety Executive, The Office of Public Sector Information, Information Policy Team, 2009): 25-37. www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf (accessed December 21, 2014).

Authority) treats these as the minimum standard to meet UK legal requirements for major hazard sites.

8.10.6 Categories

ANSI/API 2350 also establishes the level of overfill protection based on three categories of onsite or remote monitoring:

- Category 1 includes fully attended and continuously monitored storage facilities, which have the option to install level instrumentation. Operations staff may terminate receipt of product if emergencies arise.
- Category 2 includes semi-attended facilities and requires personnel to be present during the start of receipt and transfer operations and to attend the operations for 30 minutes. This category requires a storage facility to have an automatic tank gauging system with an independent high-level alarm transmitted to a local or remote control center.
- Category 3 is for unattended facilities. It requires both an automatic tank gauging system and an independent high-level alarm.

Overall, these categories are arbitrary—API does not explain its rationale—despite increasing layers of protection with each category. CAPECO, for example, was a fully attended facility that would have fallen under Category 1. Because the level instrument did not function appropriately, operators were unable to terminate receipt because they were unable to recognize they had an overfill developing. Had CAPECO been required to use a functioning independent high-level alarm and automatic overfill prevention system, surpassing the Category 3 requirements, notification of the overflow would have sounded, and automatic termination of the transfer would have occurred prior to the tank overfill.

Additionally, ANSI/API 2350 does not discuss the risk reduction achieved in each of these categories compared to an automatic overfill prevention system. It also does not consider that increased flow rates or flammability of various products may require more layers of protection. At CAPECO, the tank farm stored unleaded gasoline (NFPA flammability 3), jet fuel (NFPA Flammability 2), diesel fuel (NFPA flammability 2), and fuel oil (NFPA flammability 2), all with different NFPA ratings requiring varying layers of protection.

The current ANSI/API 2350 does not go far enough to require implementing an automatic overflow prevention system for all tank terminals but acknowledges it may be necessary based on risk level. It leaves the decision to the owner/operator of the facility. Finally, the standard does not provide sufficient guidance to facilities on how to fully assess their hazards and make decisions based on the best overfill prevention plan.

To further streamline the hazard assessment process and facilitate safety audits on new or existing tank farms, ANSI/API 2350 should provide guidance on creating a risk-based system to assign all tanks a risk level.

8.10.7 Lack of One Industry Standard for Operations at Tank Farms

The CSB found that while multiple standard practices govern tank farm operations, a single industry standard for tank terminal operations does not exist, including for filling operations. For example, to avert hydrocarbon ignition in the petroleum industry, API 2003, "Protection against Ignitions Arising out of Static, Lightning, and Stay Currents" (2008), provides best practices for preventing static and stray electrical currents.[171] While the standard provides charts that compare pipe diameter, flow velocities, and flow rates that minimize static and stray currents, it is not specific to tank filling operations.

Similarly, API MPMS, Chapter 3.1A, *Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*, 3rd edition (August 2013), discussed in Section 6.5, offers useful information on manual gauging and floating roof displacement, but it is unlikely that the standard practice is accessible to the aboveground tank industry. Furthermore, in addition to ANSI/ANSI/API 2350, these standard practices are not mandatory but considered RAGAGEP under PSM and RMP. Creating one standard practice, or publicizing the existence of all standard and recommended practices governing aboveground storage tank operations including references to international standards[172] and best practices at tank terminals, would enable facilities to readily access these good engineering practices.

8.10.8 International Fire Code (IFC)

The International Code Council (ICC) is a consensus organization that develops the International Fire Code (IFC) in addition to other I-Codes. I-Codes are "minimum safeguards for people at

[171] ANSI/API Standard API 2003-2008. *Protection against Ignitions Arising out of Static, Lightning, and Stay Currents.* Seventh edition (Washington, DC: American Petroleum Institute, January 2008),

[172] The UK Government response to Buncefield published guidance on 'Identification of Instrumental level detection systems used with Buncefield in-scope substances.

Health and Safety Laboratory. *Identification of Instrumented Level Detection and Measurement Systems Used with Buncefield In-scope Substances* (Buxton, Derbyshire, UK: U.K. Health and Safety Executive, 2011). www.hse.gov.uk/research/rrpdf/rr872.pdf (accessed December 21, 2014).

home, at school and in the workplace." [173] The I-Codes are building safety and fire prevention codes. Puerto Rico adopted the International Fire Code (IFC); therefore, all municipalities on the island are required to follow the IFC guidance to prevent fires.

At the time of the incident, the 2009 edition of IFC was in place. The 2009 IFC Section 3404.2.7.5.8, "Overfill Prevention," requires the use of an overfill prevention system for each tank over 1,320 gallons of flammable liquids falling within Class I, II and IIIA.[174] Same as the NFPA, the IFC defines gasoline as a class 1B liquid. Similar to the NFPA recommendations and the SPCC requirements for filling operations, the IFC requires that in no case should the tank fill in excess of 95% of its capacity. IFC provides two options to achieve this requirement:

1. Install an audible or visual alarm system that signals the tank has reached 90% of the capacity, and automatically shut off flow after a tank reaches 95% of its capacity.
2. Reduce the flow rate to not more than 15 gallons per minute (0.95 L/sec) in the system so that at the reduced flow rate, the tank will not overfill for 30 minutes and automatically shut off flow into the tank so that none of the fittings on the top of the tank are exposed to product because of overfilling.[175]

Although CAPECO had audible alarms that were not functioning, they were not required to have an independent audible or visual alarm to indicate rising liquid levels in Tank 409.

The ICC modified the overfill prevention text above in the 2015 edition IFC by requiring terminal owners and operators to provide an independent means of notifying the person filling the tank that the fluid level has reached 90% of tank capacity. The code then provides options that include an audible or visual alarm signal, a level gauge marked at 90% of tank capacity or other approved means. The CSB recognizes the ICC for requiring the independent level notification in addition to automatic shutdown as one viable option to prevent an overfill incident. However, the ICC did not go far enough to require:

1) A visual or audible alarm physically separate and independent from the level control and monitoring system;
2) A hazard assessment to determine the necessary safeguards and operations, as well as the reliability of the gauging system and operator monitoring, to prevent an overfill, especially for terminals near a community or sensitive environment, or

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[173] International Code Council. http://www.iccsafe.org/AboutICC/Pages/default.aspx (accessed December 21, 2014).
[174] ICC defines flammable liquids as a liquid having a closed cup flash point below 100ºF (38ºC). Class 1 liquids include Class 1A liquids having a flash point below 73ºF (23ºC) and a boiling point below 100ºF (38ºC); Class IB liquids having a flash point below 73ºF (23ºC) and a boiling point at or above 100ºF (38ºC); and Class IC liquids having a flash point at or above 73F (23ºC) and below 100F (38ºC).
[175] International Fire Code 2009. http://publicecodes.cyberregs.com/icod/ifc/2009/ (accessed December 21, 2014).

3) Proof testing to ensure the overfill prevention system is tested regularly.

Including these safety parameters into the IFC and extending it to both existing and new tank terminals will further ensure an incident like CAPECO does not occur.

8.10.9 National Fire Protection Association (NFPA)

The NFPA, a nonprofit organization, develops consensus codes and standards for fire protection and prevention. The standards are voluntary but can be adopted by reference into law. Various groups, including insurance companies, engineers, and safety professionals, use the codes and standards. Approximately 250 panels and committees within the NFPA develop and revise NFPA codes and standards. Although Puerto Rico adopted the International Fire Code (IFC) issued by the International Code Council (ICC), many states have adopted NFPA codes. NFPA 30, *Flammable and Combustible Liquids Code* (2003), had overfill provisions that applied to tank terminals like CAPECO at the time of the 2009 incident.

8.10.9.1 NFPA 30: Code for Storage of Flammable and Combustible Liquids

NFPA 30 provides guidance on storing and transporting flammable and combustible liquids from mainline pipelines and marine vessels. The NFPA defines flammable liquids having an NFPA 704 flammability rating of 3 as class 1B liquids.[176] Section 21.7.1 of the NFPA 30 code, "Prevention of Overfilling of Storage Tanks," addresses overfill hazards for tanks containing flammable liquids, such as those at CAPECO, but lists an automatic overfill prevention system as only one of three options. The code also references ANSI/API 2350, *Overfill Protection for Storage Tanks in Petroleum Facilities*, for additional guidance. The 2008, 2012, and 2015 editions of NFPA 30 require terminal facilities storing gasoline to follow formal written procedures or to provide equipment or both to prevent overfilling of tanks by choosing one of the following options:

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[176] NFPA 30 defines flammable liquids as any liquid that has a closed-cup flash point below 100ºF (37.8ºC). Flammable liquids are further classified into Class I, II, and III liquids. Class I liquids include Class IA, which is any liquid with a flash point below 73ºF (22.8ºC) and a boiling point below 100ºF (37.8ºC); Class IB, which is any liquid with a flash point below 73ºF (22.8ºC) and a boiling point of or above 100ºF (37.8Cº); and Class IC, which is any liquid with a flash point at or above 73ºF (22.8ºC), but below 100ºF (37.8ºC). Class II and Class III liquids are considered combustible liquids because they have a flash point at or above 100ºF (37.8ºC) and at or above 140ºF (93ºC). *NFPA 30: Flammable and Combustible Liquids Code* (Quincy, MA: National Fire Protection Association, 2014). http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=30 (accessed December 21, 2014).

1) Gauge tanks at intervals in accordance with established procedures by deploying personnel continuously on the premises during product receipt. Maintain communication with the supplier so flow can be shut down or diverted in accordance with established procedures.
2) Equip tanks with a high-level detection device that is either independent of any gauging equipment or incorporates a gauging and alarm system with electronic self-checking to indicate when the gauging and alarm system has failed. Locate alarms where on-duty personnel throughout product transfer can arrange for flow stoppage or diversion in accordance with established procedures.
3) Equip tanks with an independent high-level detection system that will automatically shut down or divert flow in accordance with established procedures.

CAPECO was fully compliant with the NFPA 30 since the facility implemented option 1, but it had neither a high-level alarm nor an automatic overfill prevention system that allowed for automatic shutdown. The only overfill protection was the hourly gauging performed as part of the level control and monitoring system. This was insufficient given the fill rate of Tank 409.

The NFPA first amended the overfill prevention guidance in 1981 to require overfill prevention for tanks located near a residence or community.[177] Then after the Texaco Tank Farm incident in Newark, New Jersey, occurred during the 1984 revision cycle (see Section 7.4 and Appendix B), the Newark Fire Department issued a comment, asking the NFPA 30 committee to require:

1) Gauging tanks at frequent intervals during transfer of product;
2) Increasing communication with pipeline or marine personnel;
3) Equipping terminals with the ability to rapidly shut down or divert flow; and
4) Installing independent high-level alarms that automatically shut down or divert flow during filling operations.

The NFPA 30 committee amended the standard to require one of the four recommendations,[178] stating, "It would be inappropriate and unjustifiably burdensome to require cumulative provisions." The technical committee of NFPA 30 stated that any one of the methods would

[177] R. Benedetti. *Flammable and Combustible Liquids Code Handbook*. Third edition (Quincy, MA: National Fire Protection Association, 1987).

[178] In 1984, the NFPA 30 committee required overfill protection whenever Class 1 liquids were transferred from mainline pipelines or marine vessels, formal written procedures, a continuous presence of personnel during the transfer operation at manned facilities, and two-way communication with the supply source. The committee also required a high-level detection device independent of any gauging equipment and allowed alternatives to the three options if approved by the local authority with jurisdiction.

provide an acceptable degree of safety.[179] It asserted that one of the four options would also protect unmanned, fully automated receiving terminals that have a good safety record. These remote terminals would have been required to implement all four level control recommendations, had the Newark Fire Department recommendations been adopted by the NFPA 30 committee.[180]

The four options taken together improve the reliability of the level control and monitoring system and ensure that an automatic overfill prevention system is used to detect and prevent an overflow incident. Recent findings from Buncefield and now CAPECO further enhance the need for more robust overfill prevention guidance beyond one of the four options presented by the NFPA 30 committee in 1984.

The CSB finds it necessary to further strengthen the overfill protection language in NFPA 30 to require all four options within an automatic overfill prevention system. In addition, a hazard assessment should be completed considering a facility's proximity to neighboring communities and sensitive environments, the complexity of terminal operations, the reliability of tank gauging system and operator monitoring, and periodic proof testing.[181] This assessment should ensure 1) the overfill system continues to function appropriately and 2) a facility implements and maintains an overfill prevention system that addresses the site-specific hazards. These requirements should extend to both old and new tanks.

The OSHA Flammable and Combustible Liquids standard (1910.106), incorporates by reference the 1968 version of NFPA 30. (See Section 8.7.1.) However, the current 2015 version of NFPA 30 does not require an automatic overfill prevention system and an independent high-level alarm or automatic shutdown to prevent a similar incident like CAPECO from occurring—despite prior recommendations to do so following the Texaco Oil Company tank overfill incident in 1983 discussed in Section 7.4.

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[179] R. Benedetti. *Flammable and Combustible Liquids Code Handbook*. Third edition. (Quincy, MA: National Fire Protection Association, 1987).

[180] Ibid.

[181] ANSI/ANSI/API 2350 defines proof testing as a complete overfill prevention system instrumentation loop test through the primary sensing element verifying appropriate response all the way from sensors to the final control element including alarms. The standard identifies proof testing as an essential element in maintaining the reliability of overfill prevention systems. Section 4.5.5.4 of the ANSI/ANSI/API 2350 standard recommends the testing procedures be in sequential format to ensure safe, consistent practices and the testing procedures be accessible to personnel responsible for testing, inspection, and maintenance of the overfill prevention system. American Petroleum Institute. *ANSI/API Standard 2350-2012. Overfill Protection for Storage Tanks in Petroleum Facilities*. Fourth edition (Washington, DC: American Petroleum Institute, May 2012).

To prevent another overfill incident like CAPECO's, OSHA should incorporate the most updated version of NFPA 30 with the CSB recommendation to incorporate more than one safeguard.

8.11 Trade Associations

Both the International Liquid Terminals Association (ILTA) and the Independent Petroleum Association of America (IPAA) represent small independent producers and storage terminals in the US. They can advocate for safer operations at their member facilities by endorsing and publicizing best industry practices.

9.0 ROOT AND SYSTEMIC CAUSES

The CSB's investigation identified the following key findings:

Physical Cause

1) During an operation to transfer gasoline from the vessel *Cape Bruny* tanker ship, gasoline overflowed from CAPECO Tank 409, resulting in a vapor cloud formation encompassing approximately 107 acres of the CAPECO tank farm.
2) The gasoline vapor cloud migrated to low-lying areas of the tank farm and to the storm water retention pond in the wastewater treatment (WWT) area through open dike valves.
3) The vapor cloud ignited in the WWT area, which was not electrically classified for use in a flammable atmosphere.
4) Multiple proximate causes likely contributed to Tank 409 overfill:
    - Malfunctioning tank side gauge during filling operations that led to inaccurate tank levels being recorded;
    - Normal variations in the gasoline flow rate and pressure from the *Cape Bruny* without the facility's ability to identify and incorporate the flow rate change in real time into tank fill time calculations may have contributed to the overfill;
    - Potential failure of the tank's internal floating roof due to turbulence and other factors may have contributed to the overfill.

Control Failures

1) An unreliable level control and monitoring system did not provide accurate and timely information for the operator to prevent overfilling Tank 409.
2) The failure-prone float and tape gauges and the unreliable level transmitters proved ineffectual. The level transmitters were frequently out of service due to lightning damage.
3) Insufficient independent and separate safeguards to prevent overfill, such as a high-level alarm and an automatic overfill prevention system (AOPS) compromised facility safety.

Safety Management Systems

1) Inadequate formal tank filling procedures were restricted to a list of equipment to be manipulated. In addition, the outdated procedures were often applicable to the tank farm when the refinery was in operation.

2) The automatic tank gauging system, the only level control and monitoring system to support the operator in preventing overfill, was often out of service.
3) The defective level transmitter was not sending data for Tank 409 or 107 to the computer in the operator shack or to the supervisor’s office on the day of the incident.
4) A nonexistent automatic overfill prevention system and the inability to rapidly stop transfer operations or divert flow before an overfill weakened CAPECO’s safety program.
5) Ill-equipped CAPECO tanks were left with an unreliable level monitoring and control system or a high-level alarm system.

Safety Management Systems

1) Tanks were not equipped with an independent high-level alarm system.
2) Tanks were not equipped with an independent Automatic Overfill Prevention System (AOPS) for terminating transfer operations.

Human Factors

1) The design of the dike valve system made it difficult to distinguish between open and closed valve positions
2) Insufficient lighting in the tank farm areas hindered operators from observing the overfilling of Tank 409 and the subsequent vapor cloud formation.

Lack of Reporting Requirements

1) The CSB analysis of the EPA’s Toxic Release Inventory data for 2012 found that 2,959 bulk petroleum tank terminals are within one mile of communities with over 300,000 residents.
2) An incomplete national incident database for assessing the frequency of specific types of incidents at bulk petroleum storage tank terminals inhibits the development and implementation of more tailored regulatory requirements, industry consensus standards, and best practices in this sector.

Emergency Response Findings

1) CAPECO and the local fire department lacked sufficient firefighting equipment to effectively fight and control a fire involving multiple tanks because they are not required to conduct a risk analysis where they have to consider and plan for the potential of a vapor cloud explosion involving multiple tanks.
2) CAPECO did not preplan with local emergency responders or adequately train facility personnel to deal with a fire involving multiple tanks.
3) Local fire departments lacked sufficient training and resources to respond to industrial fires and explosion.
4) There was a lack of coordination among the 43 federal, commonwealth and nongovernmental organizations that responded to the CAPECO incident.

Regulatory Findings

1) The US regulatory system does not consider bulk aboveground storage tank terminals storing flammable liquid to be highly hazardous, even those near communities. Although the EPA characterizes facilities like CAPECO as substantial harm facilities, under the Facility Response Plan requirements, the risk assessment required for these facilities do not consider the potential of multiple tank releases as a worst case scenario.
2) Due to a lack of regulatory coverage under the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) standard and the Environmental Protection Agency's (EPA) Risk Management Plan (RMP), tank terminal facilities are not required to conduct risk assessments to address flammable hazards on site or to follow Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).
3) A high-level alarm system or high-integrity overfill prevention system are not required by OSHA's Flammable and Combustible Liquids standard, the EPA's Spill Prevention Control and Countermeasure (SPCC) requirements. While facilities covered under SPCC must certify an SPCC plan by a Professional Engineer, only the EPA FRP plans meeting the substantial harm criteria are approved by the EPA. Furthermore, under SPCC facilities similar to CAPECO do not have to report overfill incidents unless oil is discharged to navigable waters.

Industry Standards

1) Despite past incidents in the US and internationally, the response of US industry, trade associations, professional associations, and standard-setting organizations has been inadequate to prevent similar incidents in the US.
2) NFPA 30 only requires one layer of protection on storage tanks, at minimum consistent gauging without requirement for an independent or redundant level alarm or an automatic overfill prevention system.
3) ANSI/API 2350 only requires an automatic overfill prevention system for remotely operated facilities and does not offer substantial guidance on conducting a risk assessment that considers the complexity of site operations, the type of flammable and combustible liquids stored at the facility or proximity to nearby communities when considering the necessary safeguards to protect the public. In addition, there is a lack of one comprehensive industry standard to address tank terminal operations, including tank-filling operations and overfill prevention.
4) ICC does not require an independent audible or visual alarm to indicate rising liquid levels.

10.0 RECOMMENDATIONS

Environmental Protection Agency (EPA)

2010-02-PR R1

Revise where necessary the Spill Prevention, Control and Countermeasure (SPCC); Facility Response Plan (FRP); and/or Accidental Release Prevention Program (40 CFR Part 68) rules to prevent impacts to the environment and/or public from spills, releases, fires, and explosions that can occur at bulk aboveground storage facilities storing gasoline, jet fuels, blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher.

At a minimum, these revisions shall incorporate the following provisions:

a) Ensure bulk above ground storage facilities conduct and document a risk assessment that takes into account the following factors:
   1. The existence of nearby populations and sensitive environments;
   2. The nature and intensity of facility operations;
   3. Realistic reliability of the tank gauging system; and
   4. The extent/rigor of operator monitoring
b) Equip bulk aboveground storage containers/tanks with automatic overfill prevention systems that are physically separate and independent from the tank level control systems.
c) Ensure these automatic overfill prevention systems follow good engineering practices.
d) Engineer, operate, and maintain automatic overfill prevention systems to achieve appropriate safety integrity levels in accordance with good engineering practices, such as Part 1 of International Electro-technical Commission (IEC) 61511-SER ed1.0B-2004, *Functional Safety – Safety Instrumented Systems for the Process Industry Sector*.
e) Regularly inspect and test automatic overfill prevention systems to ensure their proper operation in accordance with good engineering practice.

2010-02-PR R2

Conduct a survey of randomly selected bulk aboveground storage containers storing gasoline or other NFPA 704 flammability rating of 3 or higher at terminals in high risk locations (such as near population centers or sensitive environments) that are already subject to the Spill Prevention, Control and Countermeasure (SPCC) and/or Facility Response Plan (FRP) rules to determine:

a) The nature of the safety management systems in place to prevent overfilling a storage tank during loading operations. Analysis of the safety management systems should include equipment, training, staffing, operating procedures and preventative maintenance programs.
b) The extent to which terminals use independent high level alarms, automated shutoff/diversion systems, redundant level alarms or other technical means to prevent overfilling a tank

c) The history of overfilling incidents at the facilities, with or without consequence
d) Whether additional reporting requirements are needed to understand the types of incidents leading to overfilling spills that breach secondary containment and have the potential to impact the environment and/or the public, as well as the number of safeguards needed to prevent them.

2010-02-PR R3

As an interim measure, until the rule changes in CSB Recommendation No. 2010-02-I-PR-R1are adopted and go into effect: issue appropriate guidance or an alert, similar to EPA's previously issued Chemical Safety Alert addressing *Rupture Hazard from Liquid Storage Tanks*, to illustrate the hazards posed by spills, releases, fires and explosions due to overfilling bulk aboveground storage containers storing gasoline, jet fuel, blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher.

Occupational Safety and Health Administration (OSHA)

2010-02-PR R4

a) Revise the Flammable and Combustible Liquids standard (29 CFR§ 1910.106) to require installing, using, and maintaining a high-integrity automatic overfill prevention system with a means of level detection, logic/control equipment, and independent means of flow control for bulk aboveground storage tanks containing gasoline, jet fuel, other fuel mixtures or blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher, to protect against loss of containment. At a minimum, this system shall meet the following requirements:
   1. Separated physically and electronically and independent from the tank gauging system.
   2. Engineered, operated, and maintained to achieve an appropriate level of safety integrity in accordance with the requirements of Part 1 of International Electrotechnical Commission (IEC) 61511-SER ed1.0B-2004, *Functional Safety – Safety Instrumented Systems for the Process Industry Sector*. Such a system would employ a safety integrity level (SIL) documented in accordance with the principles in Part 3 of IEC 61511-SER ed1.0B-2004, accounting for the following factors:
      i. The existence of nearby populations and sensitive environments;
      ii. The nature and intensity of facility operations;
      iii. Realistic reliability for the tank gauging system; and
      iv. The extent/rigor of operator monitoring.
   3. Proof tested in accordance with the validated arrangements and procedures with sufficient frequency to ensure the specified safety integrity level is maintained.

b) Establish hazard analysis, management of change and mechanical integrity management system elements for bulk above ground storage tanks in the revised 1910.106 standard that are similar to those in the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR §1910.119) and ensure these facilities are subject to Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).

International Code Council (ICC)

2010-02-PR R5

Revise the Section 5704.2.7.5.8 (2015), Overfill Prevention of the International Fire Code (IFC) to require an automatic overfill prevention system (AOPS) for bulk aboveground storage tank terminals storing gasoline, jet fuel, other fuel mixtures or blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher, or equivalent designation. These safeguards shall meet the following requirements:

a) Engineered, operated, and maintained to achieve an appropriate safety integrity level in accordance with the requirements of Part 1 of International Electrotechnical Commission (IEC) 61511-SER ed1-2004, *Functional Safety – Safety Instrumented Systems for the Process Industry Sector*.
b) Specified to achieve the necessary risk reduction as determined by a documented risk assessment methodology in accordance with Center for Chemical Process Safety *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, accounting for the following factors:
    i. The existence of nearby populations and sensitive environments;
    ii. The nature and intensity of facility operations;
    iii. Realistic reliability for the tank gauging system; and
    iv. The extent/rigor of operator monitoring.
c) Proof tested in accordance with the validated arrangements and procedures with sufficient frequency to maintain the specified safety integrity level.
d) Ensure that the above changes are not subject to grandfathering provisions in the codes.

National Fire Protection Association (NFPA)

2010-02-PR R6

Revise NFPA 30, Flammable and Combustible Liquids Code, Section 21.7.1.1 (2015) for bulk aboveground storage tank terminals storing gasoline, jet fuel, other fuel mixtures or blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or greater. This modification shall meet the following requirements:

a) More than one safeguard to prevent a tank overfill, all within an automatic overfill prevention system as described in ANSI/API Standard 2350 (2015) *Overfill Protection for Storage Tanks in Petroleum Facilities* with an independent level alarm as one of the safeguards. The safeguards should meet the following standards:
    1. Separated physically and electronically and independent from the tank gauging system;

2. Engineered, operated, and maintained for an appropriate level of safety based on the predetermined risk level after considering part b of this recommendation; and
3. Proof tested with sufficient frequency in accordance with the validated arrangements and procedures.

b) Specified to achieve the necessary risk reduction as determined by a documented risk assessment methodology conducted in accordance with Center for Chemical Process Safety *Guidelines for Hazard Evaluation Procedures, 3rd Edition*, accounting for the following factors:
1. The existence of nearby populations and contamination of nearby environmental resources;
2. The nature and intensity of facility operations;
3. Realistic reliability for the tank gauging system; and
4. The extent/rigor of operator monitoring.

c) Ensure that the above changes not subject to grandfathering provisions in the code.

American Petroleum Institute (API)

2010-02-PR R7

Revise ANSI/API 2350, Overfill Protection for Storage Tanks in Petroleum Facilities (2015), to require the installation of an automatic overfill prevention systems for existing and new facilities at bulk aboveground storage tanks storing gasoline, jet fuel, other fuel mixtures or blendstocks, and other flammable liquids having an NFPA 704 flammability rating of 3 or higher. At a minimum, this system shall meet the following requirements:

a) Separated physically and independent from the level control and monitoring system.

b) Engineered, operated, and maintained to achieve an appropriate safety integrity level in accordance with the requirements of Part 1 of International Electrotechnical Commission (IEC) 61511-SER ed1-2004, *Functional Safety – Safety Instrumented Systems for the Process Industry Sector*.

c) Specified to achieve the necessary risk reduction as determined by a documented risk assessment methodology set in accordance with Center for Chemical Process Safety *Guidelines for Hazard Evaluation Procedures, 3rd Edition*, accounting for the following factors:
1. The existence of nearby populations and contamination of nearby environmental resources;
2. The nature and intensity of facility operations;
3. Realistic reliability for the tank gauging system; and
4. The extent/rigor of operator monitoring.

d) Proof tested with sufficient frequency in accordance with the validated arrangements and procedures to maintain the required safety integrity level.

e) Ensure that the above changes are not subject to grandfathering provisions in the standard.

2010-02-PR R8

Develop detailed guidance on conducting a risk assessment for onsite and offsite impacts of a potential tank overfill during transfer operations involving one and multiple tanks and for determining the Safety Integrity Level of the required overfill prevention safeguard to replace Annex E of ANSI/API 2350, *Overfill Protection for Storage Tanks in Petroleum Facilities (2015)*.

2010-02-PR R9

Develop a single publication or resource describing all API standards and other relevant codes, standards, guidance, and information for filling operations of aboveground storage tanks in petroleum facilities that describes:

a) The required design and management practices for control of filling operations;
b) The minimum set of independent overfill prevention safeguards if the control fails; and
c) Operational challenges (e.g., monitoring/calculating flow rates, ability to maintain constant line pressures, and influences of valve cracking) related to loading multiple tanks concurrently from a single product source.

Appendix A INCIDENT TIMELINE

Timeline of events leading to explosion and fire

Date	Time	Events
10/21/09	**8:47 p.m.**	Pumping starts. Verification pumping is sent to Tank 405.
10/21/09	**9:43 p.m.**	Pumping verification ends. Valves lined to fill tank 504.
10/22/09	**12:20 a.m.**	Product movement begins into Tank 504.
10/22/09	**1:18 a.m.**	Line displacement into Tank 504 ends.
10/22/09	**1:40 a.m.**	Bulk pumping begins into 504, 409 and 411.
10/22/09	**4:00 a.m.**	Tank levels, posted in the daily log, read as follows: 504 @ 14'6.5" (from 5' 24 hours prior) *Increase* 409 @ 8'4" (from 3'2.8" 24 hours prior) *Increase* 411 @ 4'7" (from 8'8.8" 24 hours prior) *Decrease*
10/22/09	**~11:00 a.m.**	The tank farm operator notes the level of Tank 504 before going to lunch (level unknown) and calculates that the tank would be full around 1 p.m.
10/22/09	**11:20 a.m.**	411 @ 2'5.7" *Decrease (contractor gauge)*
10/22/09	**~12:15 p.m.**	The operator returns to see that the same numbers on Tank 504 that he noted before lunch are still on display. The level instrument is physically stuck inside of the tank. He climbs to the top of Tank 504 to visually inspect the level and finds that it is well below the fill level – 42.75' (out of ~54').
10/22/09	**~12:15 p.m.**	The operator and supervisor decide to close Tank 504 early. Tank 409 is fully opened, and Tank 411 is cracked open.
10/22/09	**~1:00 p.m.**	Tank 409 is fully opened, and Tank 411 is cracked open. 2 p.m. is shift change (8-hour shifts: 2 p.m.-10 p.m., 10 pm-6 a.m., 6 a.m.-2 p.m.).
10/22/09	**1:25 p.m.**	Tank 504 is gauged by the contractors and CAPECO personnel: Level 42' 2$^3/_4$".
10/22/09	**~6:00-6:30 p.m.**	The tank farm operator calculates that Tank 409 will be full at shift change (9-10 p.m.). Since Tank 409 does not display properly on the computers and to avoid complications at shift change, the operator fully opens the valve to Tank 411 and cracks down the valve to 409 (cracked open). 409 @ ~44' 411 @ ~20'-27'
10/22/09	**~9:00-9:30 p.m.**	Shift Change. Relief for the wastewater and tank farm operators arrive. The tank farm operator rotates to the dock (working a double shift).
10/22/09	**10:10 p.m.**	The tank farm operator determines that Tank 411 is full; with help from the other operator, he closes 411 and fully opens 409. He asks the assistant to briefly close Tank 409, while he observes the full flow rate into Tank 411; then they perform the switch. The tank operator estimates that 409 will be full around 1 a.m.
10/22/09	**11:20 p.m.**	Tank 411 is gauged by the outside inspectors and CAPECO personnel: Level 46' 7$^3/_4$". Nothing abnormal is observed.
10/22/09	**~11:25 p.m.-12:00 a.m.**	Tank 409 begins to overflow. The CSB calculates that the overflow lasted approximately 26 minutes. See Appendix E.
10/23/09	**~12:00 a.m.**	The tank farm operator notices a fog on the ground and on the road along Tanks 504, 411, and 409. He notifies the supervisor, who then instructs the ship to stop pumping and for the WWT operator to assist the guards at the gate. The supervisor and the tank farm operator attempt to drive around to the other side of the fog to determine its origin.
10/23/09	**12:23 a.m.**	Explosion occurs.

Appendix B TANK INCIDENTS IN THE PAST 50 YEARS

	Facility Name / Location	Incident Date	Injured	Fatality	Cost	Product	Incident Type	Description
1	Houston, TX, USA [4]	4/1962	0	0		Gasoline	Leak, Vapor Cloud Explosion	A 12,700 M gasoline tank leaked and vapors accumulated. A car driving on a nearby highway ignited the vapor cloud.
2	Collegedale, TN, USA [8]	9/25/1972	0	0		Gasoline	Overfill	An overfill of a 55 ft diameter gasoline tank ignite while emergency responders were preparing to foam the spill surface. Multiple tank explosion involving five tanks followed. A dike fire burned for over 24 hours due to leaking flanges and manways and lack of firefighting foam.
3	Gulf Oil Co., Philadelphia, PA, USA [1]	8/17/1975	8	14		Gasoline	Overfill, Vapor Cloud Explosion	Flammable vapors were released from an overfilled. Crude oil tank, which exploded. A second explosion occurred in the crude tank during the incident response, killing 8 firefighters and injuring 14.
4	Baytown, TX, USA [5]	1/27/1977	0	0		Gasoline	Ship Hold Overfill, Vapor Cloud Explosion	In a ship overfilling incident, a tugboat ignited as it was tied up alongside a dock on the opposite side of the ship. The explosion overturned the tug, which sank. Little other explosion damage occurred.

5	Rialto, CA, USA [8]	2/21/1978	0	0		Gasoline	Overfill, Vapor Cloud Explosion	Gasoline vapors ignited after an overfill of a 50 ft gasoline tank. A valve was mistakenly opened causing fuel to spill out of the tank vents into the secondary containment dike at approximately 30,300 L/min(8000 gpm).
6	Chevron Tank Terminal, HI, USA [8]	1980	4	2		Gasoline	Overfill, vapor cloud ignition	At 10:30 am, an overfilling gasoline tank created a vapor cloud that ignited after reaching a switch-room at an adjacent Shell facility.
7	Texaco Oil Company, Newark, NJ, USA [1]	1/7/1983	1	24		Gasoline	Overfill, Vapor Cloud Explosion	A gasoline vapor cloud exploded when a 1.76-million gallon capacity tank overflowed, resulting in one fatality and 24 injuries. Lack of monitoring of the rising gasoline levels in the storage tank during filling operations contributed to the overflow, explosion, and subsequent fire.
8	Naples Harbour, Italy [4]	12/21/1985	0	4	$50.9M	Gasoline	Overfill, Vapor Cloud Explosion	A gasoline storage tank overflowed and spilled nearly 800 tons into a diked area. A vapor cloud formed and ignited. The explosion killed 2 employees and 2 members of the public, destroyed 24 of the 32 tanks onsite, caused serious structural damage within 100 meters, and broke glass out to 1 kilometer. Fire covered 3.7 acres, caused severe damage to nearby industrial and residential areas, and took 3.5 days to extinguish. The estimated loss was $50.9 million.
9	Saint Herblain, France [3]	1991	0	0		Gasoline	Pipe leak, Vapor Cloud Explosion	A release of gasoline from a section of pipe inside a bund produced a vapor cloud. Ignition of the vapor cloud produced extensive damage.

10	Brenham, TX, USA	4/7/1992	0	0		Gasoline	Vapor Cloud Explosion	The ignition of a vapor cloud comprising a mixture of hydrocarbons in a rural area resulted in significant damage to nearby buildings. No pipework congestion was present but the cloud engulfed wooded areas.
11	Steuart Petroleum, Jacksonville, FL USA[8]	1/2/1993	0	1		Gasoline	Overfill, Vapor Cloud Explosion	Gasoline vapors ignited after an overfill of a 2.3 million gallon gasoline tank fatally injuring one terminal operator who was driving into the spill. A large ground fire persisted impinging two additional tanks located approximately 50 feet away. Gasoline flowed from the tank's eyebrow vents, complicating firefighting activities. The fire covered about one acre and exposed unprotected aboveground pipelines, manifolds and a number of flange connections.
12	Nanjing, China	10/21/1993	0	2		Gasoline	Overfill, Vapor Cloud Explosion	A gasoline storage tank (10,000 m^3 tank) overflowed resulting in a gasoline spill and vapor cloud. The vapor cloud ignited by passing tractor and killed 2 employees. Fire involved at least 100 tons of gasoline. The fire took 17 hours to control.
13	IOCL Baroda, Gujarat, India	8/4/1995	N/A	N/A	N/A	Gasoline	Overfill, Vapor Cloud Ignition	An overfill of a tank created a vapor cloud which ignited. The fire encompassed two tanks in the same secondary containment area. Nearby tanks were cooled to prevent further fire impact.

14	Thai Oil Company, Laem Chabang, Thailand [2]	12/2/1999	0	7	$22.3M	Gasoline	Overfill, Vapor Cloud Explosion	A gasoline storage tank overflowed forming a vapor cloud. It exploded and killed seven onsite personnel. Thai Oil Company was blending product onsite when an operator manually opened a valve to fill a tank, which was already filled with product. It began to overfill. The rising liquid level set off two safety alarms at an offsite control room, but the control room operators did not hear the alarms. Five gasoline storage tanks and 250,000 barrels of gasoline were destroyed. The fire burned for 35 hours and total damages cost $22.3 million.
15	Conoco, Helana, MT, USA [1]	12/13/2000	0	0	0	Gasoline	Tank Overfill	Approximately 60,000 gallons of gasoline spilled from a storage tank causing the evacuation of 100 residents and restricting traffic to the area.
16	Amerada Hess Corp., Wilmington, DE, USA [1]	3/13/2000	0	0	0	Gasoline	Tank Overfill	A million gallon capacity storage tank overfilled while being filled by a barge unloading gasoline creating a vapor cloud that caused local residents to evacuate their homes.
17	Buncefield Oil Storage Depot Hemel Hempstead, Hertfordshire UK	12/11/2005	43	0	$1.5B	Gasoline	Overfill, Vapor Cloud Explosion	An overfill of an atmospheric storage tank of gasoline resulted in the development of a vapor cloud which ignited damaging 22 tanks.
18	BP Milne Point, AK, USA [1]	1/15/2009	0	0	0	Crude Oil	Tank Overfill	Approximately 24,400 gallons of crude oil spilled from an overfilled tank at BP's Milne Point oil field. Reportedly, a malfunction in the automated flow control system caused the overfill. Workers were able to manually cut off flow to the tank.

19	CAPECO, Bayamón, Puerto Rico, USA [1]	10/23/2009	3	0		Gasoline	Tank Overfill, Vapor Cloud Explosion	An overfill of a 5 million gallon capacity atmospheric storage tank with gasoline caused a vapor cloud which ignited causing multiple tank explosions and tank fires. 17 of 48 tanks were burned. The fire took three days to control.
20	Gladieux Trading and Marketing Huntington, IN, USA [1]	3/10/2010	0	0	N/A	Diesel fuel	Tank Overfill	A gasoline storage tank overflowed at Gladieux Trading and Marketing in Huntington, IN, when a pump that was transferring product was left on at the end of a shift. A high- and high-high level safety alarm activated, but it was hidden from view on the alarm monitoring screen. An offsite contracted employee spotted the product overflowing from the tank 157 minutes after the overfill occurred and alerted the control operator to the incident.
21	Aloha Petroleum Bulk Storage Facility, HI, USA [1]	11/1/2011	0	0	0	Diesel fuel	Tank Overfill	Approximately 14,700 gallons of diesel fuel spilled during transfer operations when diesel fuel was being pumped from a barge to storage tanks at the Aloha Petroleum Bulk Storage facility. Workers reportedly miscalculated the amount of fuel that could be pumped into the storage tank.
22	International-Matex Tank Terminlas, NJ, USA [1]	6/2/2014	0	0	0	Gasoline	Tank Overfill	A fuel tank overfilled during transfer operations spilling approximately 6,000 gallons of gasoline into the soil.

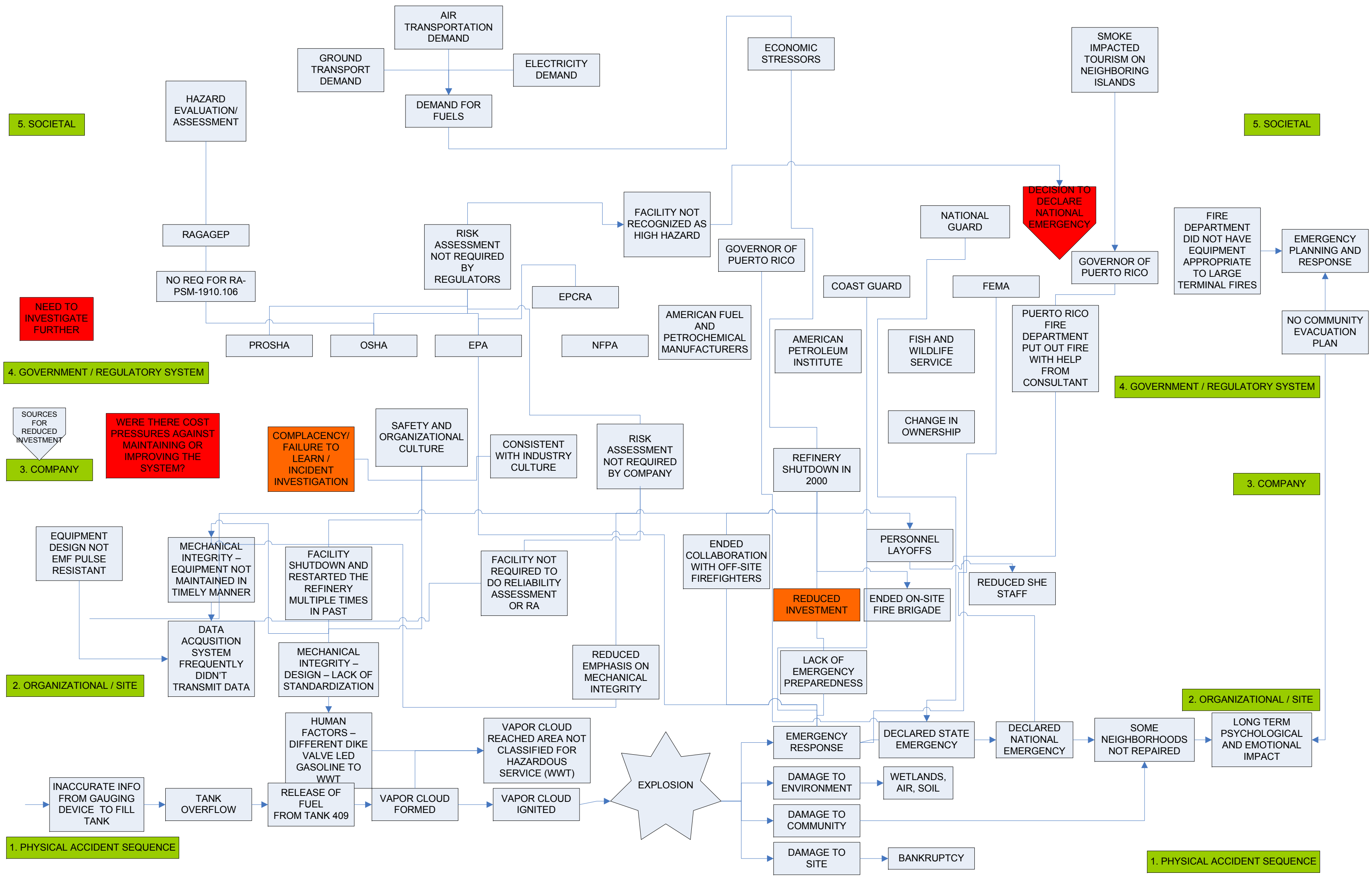
[1] CSB data.

[2] The 100 Largest Losses 1972-2001, Large Property Damage Losses in the Hydrocarbon-Chemical Industries, 20th Edition: February 2003, a publication of Marsh's Risk consulting practice.

[3] J.F. Lechaudet and Y. Mouilleau. "Assessment of an accidental vapour cloud explosion. A case study: Saint Herblain, October the 7th 1991, FRANCE," Loss Prevention and Safety Promotion in the Process Industries, 1995, 1, pp. 377-388.

[4] M. Maremonti, G. Russo, E.Salzano, et al. “Postaccident Analysis of Vapour Cloud Explosions in Fuel Storage Areas,”” Trans IChemE 1999 77 (B) 360365. Persson, H. and Lennermark, A. 2004. Tank Fires Review of fire incidents 1951-2003. SP Swedish National Testing and Research Institute. Accessed October 1, 2014.
[5] Eric M. Lenoir and John A. Davenport[v] “A Survey of Vapour Cloud Explosions, Second Update.” Hartford:” Industrial Risk Insurers, Paper No. 74d, 26th Annual Loss Prevention Symposium, AIChE, New Orleans, 1992.
[6] Lenoir and Davenport, 1992.
[7] Persson,H. and Lennermark, A. 2004. Tank Fires Review of fire incidents 1951-2003. SP Swedish National Testing and Research Institute. Accessed October 1, 2014. Available at http://rib.msb.se/Filer/pdf%5C19108.pdf. [Edward C. Avant-Frie Journal July 1974 (reprint from Fire Engineering April 1973); Herzog G. R. reprint Frie Journal July 1974; Mahley H. S. rreprint Hydrocarbon Proccessing, 1975.
[8] Persson, H. 3M Case History 7; Fire Engineering, August 1978.

Appendix C CARIBBEAN PETROLEUM ACCI MAP



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CERTIFICATE OF TITLE

10 Jan 89

COMMONWEALTH OF PUERTO RICO
LOCATION OF SITE: Isla Grande Airport, San Juan, Puerto Rico

I hereby certify that the Commonwealth of Puerto Rico is possessed of title in the hereinafter described real property as evidenced by deed recorded in Volume 73, Page 227, property number 2892, which was subsequently grouped with other parcels as evidenced by deed recorded in Volume 102, Page 37, property number 4289 of the official records of the Property Register of San Juan, Commonwealth of Puerto Rico; that the title or interest in said real property is good, valid and sufficient; and subject to no liens or encumbrances save and except the following: NONE

I further certify that the interest of the Commonwealth of Puerto Rico in and to said real property is adequate to justify the expenditure of public funds of the Commonwealth of Puerto Rico in the improvement thereof for Army National Guard purposes and subject to the limitations set forth in Title 10, U.S.C. Sections 2231-38, incl; as amended, and that the intended use of said lands and improvements by the Puerto Rico Army National Guard is in compliance with all applicable statutes, local laws and ordinances.

LEGAL DESCRIPTION

"A tract of land in the Urban Zone of San Juan, Puerto Rico with an area of 14.48 "acres" contained within land known as "Isla Grande o del Manglar" situated on the Southeast of the City of San Juan, bounded by the North with Isla Grande Runway, South East and West with land of the Ports Authority."

Being the land referred to in Agreement No. DAHA70-89-H-0006 between the United States and the Commonwealth of Puerto Rico for the Construction of Army Aviation Support Facilities at the above named site.

HECTOR RIVERA-CRUZ
SECRETARY OF JUSTICE
COMMONWEALTH OF PUERTO RICO

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
NATIONAL GUARD BUREAU
WASHINGTON, D.C. 20310-2500

NGB-ARI-C (415-10f)

07 APR 1989

MEMORANDUM FOR The Adjutant General, Puerto Rico

SUBJECT: Army Aviation Support Facility (AASF), Isla Grande (Santurce), Puerto Rico; FY88 MCARNG (Major)

1. The 01 Feb 89 Federal-State Agreement (DAHA 70-89-H-0006) and the 10 Jan 89 Certificate of Title for the subject project have been reviewed by NGB-JA, found legally sufficient and are returned herewith.

2. You may wish to review your project files and see if a previous Federal-State Agreement requires termination. If so, refer to para 3-11 and Appendix I, both of NGR 415-5, for correct procedures/format.

FOR THE CHIEF, NATIONAL GUARD BUREAU:

2 Encls
as

For FRED W. ARON
Chief, Army Installations Division

CF:
USPFO, PR (wo/encls)

PR-ED

February 10, 1989

MEMORANDUM FOR: Chief, National Guard Bureau, ATTN: NGB-ARI-C, Edgewood, Md.

SUBJECT: Federal/State Agreement, Certificate of Title for AASF, Isla Grande, Puerto Rico.

1. Included, please find two (2) copies of the Federal/State Agreement and Certificate of Title for the AASF.

2. This new documents are due to the site relocation of the new facility under design.

FOR THE ADJUTANT GENERAL:

Encl

RAFAEL FANTAUZZI-RUIZ
COL GS HQ STARC
Director, Engineering Division

CERTIFICATE OF TITLE

10 Jan 89

COMMONWEALTH OF PUERTO RICO
LOCATION OF SITE: Isla Grande Airport, San Juan, Puerto Rico

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I further certify that the interest of the Commonwealth of Puerto Rico in and to said real property is adequate to justify the expenditure of public funds of the Commonwealth of Puerto Rico in the improvement thereof for Army National Guard purposes and subject to the limitations set forth in Title 10, U.S.C. Sections 2231-38, incl; as amended, and that the intended use of said lands and improvements by the Puerto Rico Army National Guard is in compliance with all applicable statutes, local laws and ordinances.

LEGAL DESCRIPTION

"A tract of land in the Urban Zone of San Juan, Puerto Rico with an area of 14.48 "acres" contained within land known as "Isla Grande o del Manglar" situated on the Southeast of the City of San Juan, bounded by the North with Isla Grande Runway, South East and West with land of the Ports Authority."

Being the land referred to in Agreement No. DAHA70-89-H-0006 between the United States and the Commonwealth of Puerto Rico for the Construction of Army Aviation Support Facilities at the above named site.

HECTOR RIVERA-CRUZ
SECRETARY OF JUSTICE
COMMONWEALTH OF PUERTO RICO

Federal-State Agreement No. DAHA70-89-H-0006

Description of Project: Construction of AASF

Location of Project: Isla Grande, Santurce, P.R.

FEDERAL-STATE AGREEMENT

FOR NONARMORY PROJECT

ON STATE PROPERTY

BETWEEN

THE NATIONAL GUARD BUREAU
Departments of the Army and the Air Force

AND

THE ~~STATE OF~~ COMMONWEALTH OF PUERTO RICO

This Agreement by and between the United States of America hereinafter called the GOVERNMENT, represented by the Contracting Officer executing this Agreement, and the State (Commonwealth, Territory, or Possession) of PUERTO RICO, hereinafter called the STATE, covering the construction of the above-described project at ISLA GRANDE, in said State with the assistance of funds appropriated by the Congress of the United States for the GOVERNMENT contribution to the cost of said project pursuant to Chapter 133, Title 10, U.S. Code, Facilities for Reserve Components, as implemented by Department of Defense Instructions 1225.7.

WHEREAS, section 2233(a)(2), (3), (4), (5) and (6) of Chapter 133, Title 10, U.S. Code, authorizes contributions of Federal funds to the several States, Puerto Rico, District of Columbia, the Virgin Islands and Guam to support the construction of such facilities for the Reserve Components as the Secretary of Defense shall determine to be necessary; and

WHEREAS, DOD Instructions 1225.7 established policies and criteria under which Federal funds may be contributed to provide facilities for the Reserve Components; and

WHEREAS, the Secretary of Defense, as required by the above-cited sections of Title 10, U.S. Code, has determined the above-described project to be necessary; and

WHEREAS, the STATE has submitted satisfactory evidence of a perfected title to, or other adequate property interest in, acceptable and suitable real estate, and that such real estate is located in an area appropriate, under local laws and ordinances relating to location and construction, to the use for which the facility is intended; and

WHEREAS, the STATE hereby agrees to make such facility available for joint utilization with another Reserve component to the extent that the STATE shall hereafter deem it to be practicable.

NOW THEREFORE, the said parties do mutually promise and agree with each other to construct, expand, rehabilitate or convert the facilities covered by this Agreement under the conditions hereinafter provided.

NGB Form 85-2
15 June 86
Supersedes NGB Form 85-2 (LRA) dtd 1 Apr 84

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ARTICLE I. The STATE agrees:

1. To submit to the GOVERNMENT sets of plans, specifications and cost estimates for prior approval by the GOVERNMENT.

2. To contract all work, material, and/or services required to carry out this Agreement, and to require each construction contractor to furnish bonds of such type and in an amount adequate to secure faithful performance of his contract.

3. To execute construction, supply, and/or services contracts in accordance with the laws of such STATE, and under those regulations within OMB Circular A-102 which are applicable to federally-assisted programs insofar as the application of such regulations by supervisory officials of the STATE is not precluded by nor inconsistent with STATE laws. All such contracts, subcontracts and change orders or other contract modifications shall be submitted to the GOVERNMENT for prior approval by the GOVERNMENT.

4. To permit supervision and inspection by representatives of the GOVERNMENT during the performance of engineering and construction contracts.

5. To supervise and be responsible for necessary construction of the facilities authorized under this Agreement, and to make inspections of the work done under this Agreement as may be deemed necessary by the GOVERNMENT.

6. To furnish inspector's certificates, satisfactory to the GOVERNMENT, as the work progresses on the project, certifying amounts due the construction contractor as the basis for preparation of payment vouchers.

7. To maintain an accounting system for the construction work acceptable to the GOVERNMENT.

8. To make, either directly or through other agencies under STATE supervision, and to render to the GOVERNMENT, a satisfactory accounting of all original disbursements on account of the construction.

9. To waive claim to any GOVERNMENT furnished commercial Intrusion Detection System (IDS) or Joint-Service Interior Intrusion Detection Systems (J-SIIDS) equipment that is installed in this project; conduit and wires shall remain STATE property.

10. To maintain and preserve the facilities in a state of good repair during the period of this Agreement, with the assistance of the Service or Training Site agreements, between the GOVERNMENT and the STATE, subject to the availability of Federal funds and provided Federal funds do not exceed 75 percent of the total actual Operations and Maintenance (O&M) cost for facilities other than for commercial IDS and/or J-SIIDS equipment/systems and training site facilities, for which Federal funds may be 100 percent of actual O&M cost. At no time during the term of this Agreement to permit any disposition or use to be made of the facility which will interfere with its use for the administration and training of units of the Reserve Forces of the United States, or in time of war or national emergency, by other units of the Armed Forces of the United States or any other use by the Federal Government.

11. To the extent of its power or authority, to take necessary action to prohibit outside interests (such as adjacent land-owners, public utility corporations, etc.) from any utilization of adjacent land that would interfere with the use of the facility for its intended purposes.

12. To submit a "Certificate of Availability of Funds" to meet its contribution in the support of the cost of the above described project prior to any obligation of Federal funds for the construction.

ARTICLE II. The GOVERNMENT agrees:

1. To contribute Federal funds in the amount of 100 percent of the GOVERNMENT-approved cost of the project covered by this Agreement.

2. To reserve funds for the purpose of making payment to the STATE for the cost of the buildings and appurtenances thereto during the life of the contract for the construction of this project.

3. To pay the STATE or construction contractor as the work progresses for the GOVERNMENT's share of said cost on the basis of the percentages which the GOVERNMENT contribution bears to the total cost.

4. To pay the State as the work progresses for the Government's share of the cost of the services performed by the A-E under the GOVERNMENT-approved contract.

a. The Government will advance by allotment its share of the fee or fees for four services (i.e., project design, topographic survey, surface and sub-surface soil investigation, and reproduction of bidding documents) for a total cost not to exceed the amount based on the percentaage listed in the attached table (Encl 1) in column A (where project requires all new design work) or column C (where design work) consists of adapting an existing facility design to a different site) or for a combination of the two columns A and C (where both site adaptation and new design work are included in the project). The initial allotment to be provided to the State will be determined by multiplying the appropriate percentage from column A and/or C for the combined total estimated cost of the project (i.e., Federal, State, county, city, etc) times the Government's share of the estimated construction cost of the project. The GOVERNMENT's share of the fee or fees will then be adjusted at the time of contract award with the final amount to be established as follows: 1) the percentage/s from column A and/or C (or both if site adapt work has been included) will be revised to those which correspond to the lowest responsible bid (or sum of low bids when multiple contracts are used) at which a construction contract (or contracts) is to be awarded; 2) the percentage specified in column B or D for inspection and supervision services, during construction, will be determined on the same bid basis; and 3) the adjusted share will then be calculated by multiplying these designated percentages times the GOVERNMENT's share of the lowest acceptable bid for items, authorized for inclusion in the project, based on conformance with National Guard criteria. Another allotment of funds will be provided to the State for the difference between the GOVERNMENT's adjusted share and the initial allotment (or allotments in cases where there have been more than one due to significant increases in the GOVERNMENT-approved estimated construction cost of the project). This fee determination is exclusive of any lump-sum fees allotted to the State in support of supplemental agreements approved by the GOVERNMENT for work not covered by the original contract/s.

b. If the State contracts for A-E services in such a manner that the total compensation for the contract/s would be less than the amount derived from the attached Table (Encl 1), the Government's share of the lower fee or fees will be set at the same ratio to the total contracted fee or fees as the Government's share of the construction costs bears to the total construction cost; both for the initial (estimated cost) and final (actual cost) determination. The difference in amounts between the lower A-E fee or fees and the maximum allowable Federal support as based on Encl 1 cannot be used to reduce the State's (including other agency's) share of the fees below its proportional share based on the construction contract awarded costs.

c. When a project is cancelled and/or an A-E contract terminated prior to the bidding of the project for the award of a construction contract, the Government's share of the fee due for completed services shall be based on the estimated percent of the completed work (as approved by the GOVERNMENT) under the original contract/s with the theoretical total fee adjusted in line with the latest cost estimate for the project as approved by the GOVERNMENT. The remaining amount of the advanced allotment will be returned to the National Guard Bureau or an additional allotment will be provided the State if the initial allotment is insufficient to support the revised GOVERNMENT share of the adjusted fee or fees.

d. The GOVERNMENT's contribution shall at no time be at a greater ratio to the total fee or fees than the ratio of the GOVERNMENT's share of the construction contract/s to the total cost of the construction contract/s (including other agencies) unless specifically modified by a GOVERNMENT approved supplemental agreement/s to the A-E services contract/s.

5. To pay 100 per centum of the cost of operations and maintenance of any commercial IDS and/or J-SIIDS equipment and systems installed as part of this project.

6. To remove any commercial IDS and/or J-SIIDS equipment from the facility if and when the unit or activity relocates to another facility or deactivates. Conduit and wiring shall remain in the facility.

ARTICLE III. It is further expressly understood and agreed between the GOVERNMENT and the STATE that:

1. STATE funds for the STATE share under the provisions of this Agreement shall not be used or pledged under other Agreements under which the GOVERNMENT contributes funds.

2. The GOVERNMENT shall determine what costs incurred by the STATE are allowable under the terms and condition of this Agreement.

3. Contract clauses prescribed by OMB Circular A-102 for use in Federally-assisted programs will be included in all State contracts for the project covered by this agreement.

4. This Agreement shall remain in full force and effect for a period of 25 years from date of acceptance by the STATE and GOVERNMENT of the facility constructed hereunder.

5. This Agreement may be terminated, subject to the approval of the Secretary of Defense, or his designee, prior to the expiration of the term stated in paragraph 4 above, provided that:

a. When the existing facility is adequate and still required by the reserve component, the STATE replaces the facility in kind without further Federal contribution and executes an agreement on the unexpired term of the agreement to be terminated, or

b. When the existing facility is either inadequate and/or it is no longer required by the reserve component, the STATE agrees to reimburse the Federal Government for its equity in the facility, calculated as that proportion of the Federal contribution or grant as the unexpired term of the agreement bears to the full term of the agreement.

ARTICLE IV. Approval. This Agreement shall be subject to the approval of the Chief, National Guard Bureau, or his duly authorized representative, and shall not be binding until so approved.

ARTICLE V. Alterations. The following alterations have been made in the provisions of this Agreement.

NONE

IN WITNESS WHEREOF, the parties hereto have executed this Agreement on this 1st day of Feb , 19 89 .

THE UNITED STATES OF AMERICA

By JOSE MALDONADO
COL NGB
USPFO for Puerto Rico
(Official Title)

Witnesses as to signature of State Representative

RAFAEL FANTAUZZI RUIZ
COL GS HQ STARC
Director, Engineering Division
(Address)

ISMAEL MALDONADO
MAJ FA

Engineering Division
(Address)

STATE OF PUERTO RICO

BY ALFREDO J. MORA
Major General
The Adjutant General
(Official Title)

CERTIFICATE

By virtue of the authority vested in me by Article 63, Political Code 1902 (State Statute or Legislative Act) under the laws of the State of PUERTO RICO I hereby certify that the execution of this Agreement was duly authorized and that this Agreement is legal and binding upon said State.

HECTOR RIVERA-CRUZ
SECRETARY OF JUSTICE
COMMONWEALTH OF PUERTO RICO
Attorney General
(or Legal Representative)

NATIONAL GUARD BUREAU
UNIFORM STANDARDS FOR THE PAYMENT OF ARCHITECT-ENGINEER
SERVICES FOR ARMY NATIONAL GUARD
ARMORY AND NONARMORY PROJECTS
(SHORT TITLE: ARNG A-E FEE SCHEDULE)

ESTIMATED PROJECT COST OR LOWEST RESPONSIBLE BID AWARDED FOR CONTRACT (Cost of construction changes not to be included)	NEW WORK			SITE ADAPTATION		
	Total Percent	Col A (75%)	Col B (25%)	Total Percent	Col C	Col D
Less than $50,000	10.7	8.03	2.67	8.7	6.03	2.67
$ 50,000 and under $53,000	10.6	7.95	2.65	8.6	5.95	2.65
53,000 and under 56,000	10.4	7.80	2.60	8.4	5.80	2.60
56,000 and under 60,000	10.2	7.65	2.55	8.2	5.65	2.55
60,000 and under 65,000	10.0	7.50	2.50	8.0	5.50	2.50
65,000 and under 70,000	9.8	7.35	2.45	7.8	5.35	2.45
70,000 and under 75,000	9.6	7.20	2.40	7.6	5.20	2.40
75,000 and under 80,000	9.4	7.05	2.35	7.4	5.05	2.35
80,000 and under 87,000	9.2	6.90	2.30	7.2	4.90	2.30
87,000 and under 95,000	9.0	6.75	2.25	7.0	4.75	2.25
95,000 and under 105,000	8.8	6.60	2.20	6.8	4.60	2.20
105,000 and under 115,000	8.6	6.45	2.15	6.6	4.45	2.15
115,000 and under 125,000	8.4	6.30	2.10	6.4	4.30	2.10
125,000 and under 135,000	8.2	6.15	2.05	6.2	4.15	2.05
135,000 and under 150,000	8.0	6.00	2.00	6.0	4.00	2.00
150,000 and under 165,000	7.8	5.85	1.95	5.8	3.85	1.95
165,000 and under 190,000	7.6	5.70	1.90	5.6	3.70	1.90
190,000 and under 215,000	7.4	5.55	1.85	5.4	3.55	1.85
215,000 and under 250,000	7.2	5.40	1.80	5.2	3.40	1.80
250,000 and under 300,000	7.0	5.25	1.75	5.0	3.25	1.75
300,000 and under 360,000	6.8	5.10	1.70	4.8	3.10	1.70
360,000 and under 440,000	6.6	4.95	1.65	4.6	2.95	1.65
440,000 and under 530,000	6.4	4.80	1.60	4.4	2.80	1.60
530,000 and under 620,000	6.2	4.65	1.55	4.2	2.65	1.55
620,000 and under 720,000	6.1	4.58	1.52	4.1	2.58	1.52
720,000 and under 850,000	6.0	4.50	1.50	4.0	2.50	1.50
850,000 and under 1,000,000	5.9	4.43	1.47	3.9	2.43	1.47
1,000,000 and under 1,200,000	5.8	4.35	1.45	3.8	2.35	1.45
1,200,000 and under 1,500,000	5.7	4.28	1.42	3.7	2.28	1.42
1,500,000 and under 2,200,000	5.6	4.20	1.40	3.6	2.20	1.40
2,200,000 and over	5.5	4.13	1.37	3.5	2.13	1.37

NOTES:

1. Column A percentages equal the total allowed for four (4) items of work consisting of original design, investigation of site soil conditions, topographic survey of the project site, and reproduction of bidding documents.

2. The portion of the Column A percentage allocated to only original design work (i.e., exclusive of soil investigation, topographic survey, and bidding document costs) cannot exceed the Congressional statutory limit of 6.00 percent.

3. Columns B and D percentages equal the total allowed for supervision and inspection services during the construction period of the project.

4. Column C percentages equal the total allowed for the same four (4) items of work as Column A but with a 2 percent reduction to reflect the reduced design work required (including the design of exterior supporting features needed for the facility), to adapt a previously designed facility to a different location.

Encl 1

GOVERNMENT OF PUERTO RICO
Ports Authority

AGREEMENT

2020-000031

AP-19-20-(4)-031

In San Juan, Puerto Rico, to August 19, 2019

APPEAR

AS PARTY OF THE FIRST PART: THE PUERTO RICO PORTS AUTHORITY, a public corporation and governmental instrumentality of the Government of Puerto Rico, created by the Law No. 125, approved May 7, 1942, as amended, hereinafter referred to as the "Authority", and represented by its Executive Director, Anthony O. Maceira Zayas, of legal age, single, and resident of San Juan, Puerto Rico.

AS PARTY OF THE SECOND PART: THE PUERTO RICO NATIONAL GUARD, a government agency of the Government of Puerto Rico, created by Act No. 62 approved June 23, 1962, hereinafter referred to as the "National Guard", and represented by the Adjutant General, Brigadier General José Juan Reyes Peredo, of legal age, married and resident of Carolina, Puerto Rico.

Parties appearing freely and spontaneously:

STATE

WHEREAS: The Authority owns the Fernando L. Ribas Dominicci Airport, in the Municipality of San Juan, of the Government of Puerto Rico, hereafter called the "Property".

WHEREAS: The Puerto Rico National Guard is part of the Reserve Component of the United States Army and Air Force and as such it augments the Armed Forces in time of war and other conflicts. It is also the constitutionally created organized militia of the Government of Puerto Rico tasked to perform Defense Support to Civilian Authorities in case of domestic emergencies, Homeland Security, Counterdrug Operations and other military missions in defense of the island.

THEREFORE: The parties agree that the Puerto Rico National Guard is interested in maintaining its Army Aviation operations in the certain area in relation to the property object in this Agreement and other facilities and the Authority is in the best position of lease it.

TERMS AND CONDITIONS

ARTICLE 1. PROPERTY

The Authority leases to the National Guard and agree to the lease the area and facilities designated and described in Exhibit No. 41-687 dated October 3, 2014, we form an integral part of

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this Agreement, which consists of the following: Hangar Area of 43,051 square feet, Offices Area of 7,692 square feet, and Open Area of 566,969 square feet for the Total of 607,812 square feet.

The Authority recognizes that on, 1 February 1989, the United States Government, through and by the National Guard Bureau, and the Commonwealth of Puerto Rico entered into a Federal-State Agreement (DAHA 70-89-H-0006) for the Construction of the Puerto Rico Army National Guard Army Aviation Support Facility (AASF) at Isla Grande. The AASF was constructed with congressional appropriated funds based on the needs of the state and approved by the Secretary of Defense. Under the original terms of the construction agreement the same remained in full force and effect for a period of 25 years from the date of acceptance by the State and Government of the US.

The PRNG still requires the use of the facility as a Reserve Component installation.

ARTICLE 2. TERM

A. The term of this Agreement shall be **Five (5) years.**

B. If the National Guard has interest of amend, extend, or renew this Agreement, or in any way extend the term thereof, the National Guard notify the Authority your interest at least one hundred and twenty **(120)** days prior to the date of expire of the Agreement. If the Authority does not respond to such notification within a period of thirty **(30)** days from the date of the notification, means that the Authority has rejected the application for amendment, extension, renewal or extension of the National Guard.

ARTICLE 3. AUTHORIZED REPRESENTATIVE

A. The **Director of Airport Management** or authorized personnel is responsible to administer the dispositions of this Agreement.

ARTICLE 4. USE OF PREMISES

A. The National Guard shall be entitled to the use of the demised premises, during the term of this Agreement for the following purposes and such purposes only: The premises includes the military installation known as the Army Aviation Support Facility. Its purpose is to support both the Federal and State Army Aviation Missions. **That facility has the responsibility of providing Army aircraft and equipment readiness, train military personnel, and conduct flight training and operations.**

B. However, refers to any provision to the contrary, and expressly agrees that the rights recognized in this Agreement are not exclusive and the Authority reserves the right to grant privileges to other Lessees.

ARTICLE 5. CANON OF LEASE AND OTHER CHARGES

A. The National Guard agrees to pay to the Authority, for rights and privileges accorded, a canon of lease of minimum **One dollar ($1.00) monthly.**

B. Exemptions from Landing and Parking Fees, according to IG-1 tariff resolution, Article 4.0, of the Ports Authority.

C. This monthly income is an annual rent of **Twelve dollars ($12.00).**

D. The total amount of this Agreement for a period of **Five (5) years** of lease is for **Sixty dollars ($60.00).**

E. The rent will be paid in full each year, within the term of 30 days.

F. Any other charges related to sales, payment of fees, or any other payment which should refer to the Authority, will pay in advance on or before day 10 of each month using direct deposit through the Puerto Rico Department of Treasury, in case of problems with the system, may be paid at the Central Office of the Authority or in any other place designated by the Authority within the same term of derogation. Any sum due and exposed under this Agreement which has not been paid by the National Guard within the grace period of ten (10) days from the first of each month, accrued interest of nine percent annual (9%) without notice of your breach, such interest computed from the first day of each month until the full amount owed is paid by the National Guard.

G. The National Guard will make payments to the Puerto Rico Ports Authority through the Puerto Rico Department of Treasury, using Postal Service. Ports Authority will insure that its bank account is registered with the Puerto Rico Department of Treasury in order to receive the deposit to its account. Ports Authority shall send an invoice to the National Guard for payment of rent. The National Guard cannot make payments directly by electronic transfer:

Electronic Payment Instruction:	
Name of the bank and branch:	Banco Popular de Puerto Rico
Institution Name:	Puerto Rico Ports Authority
Route Number (ABA):	021502011
Account No.:	#030-076242

H. Means that the rent and other charges set forth in this Agreement have been computed on the basis of the rates contained in the applicable resolutions according to IG-1 tariff resolution, Article 4.0, of the Ports Authority, as promulgated and that such income and other charges are subject to adjustments according to fees, stipends, rentals and other charges to be adopted from time to time, in accordance with the law of the Authority. The National Guard agrees to pay the canon and other charges, as determined by the Authority in accordance with its Regulations and the provisions of law.

I. Payments in advance to the Authority did not constitute an amendment to the original terms of the Agreement, nor an "Accord in Satisfaction", or an amending novation of the Agreement with respect to term (validity), amounts, (income, penalties, etc.) or others.

J. Equally the Authority reserves the right to withdraw or cancel cards for ID before the breach of the National Guard or licensees for unpaid royalties.

K. The National Guard consents and agrees to pay from the date of occupation or possession of the property or local object of the present Agreement, the additional income billed the Authority in the event that room or area of the corresponding surface turns out to be initially greater than that specified in the Agreement.

L. On the date of signing of this Agreement Lessee shall deliver to the Authority as a guarantee of payment of rents, charges and stipends and the faithful fulfillment of obligations under this Agreement a bond or "Lease Bond" equivalent to ***Exempt from bond*** *or "Lease Bond" payment.* This bond or "Lease Bond" shall be valid during the whole term of the Agreement and required notification of renewal. On the date of the sign this Agreement, the Lessee shall provide to the Authority such bail terms and amounts before mentioned. The case that the terms of the bond or "Lease Bond" does not satisfy the Authority, it may refuse its acceptance and require amendments or changes that it deems appropriate.

ARTICLE 6. PUBLIC SERVICES

A. The National Guard has an electricity meter **number 64667747** therefore no fee for electricity will apply.

B. The facility has a water meter **number 16050514**. This water meter belongs to Ports Authority, therefore, the National Guard will make the appropriate actions in order to change the account to his name. The Authority will bill the National Guard the pending balance until the account is change under the National Guard name. The National Guard shall be responsible for the direct payment of utilities such as water, electricity, safety, and maintenance of the leased areas.

ARTICLE 7. RELOCATION OF PREMISES

A. The Authority reserves the right during the term of this Agreement, if possible, assign to the Lessee another location in the same area contracted in any other area or facilities that are built to serve it, with approximately equal space to the rented here, under the condition that has areas available, and if not any, the Ports Authority is not obliged and the Lessee must vacate the leased area. The relocation described here will be to respond to unexpected situations of high value for the economic development of Puerto Rico and the Ports Authority and previous authorization of the Board of Directors. It must also be part of a Plan for economic development approved by the Board of Directors. The costs of such relocation will be paid by the Lessee. The Authority may not be unreasonable, arbitrary or capricious when determining the need for relocation as referred to in this clause.

B. This Agreement is executed for a period of five (5) years, while construction of our new Aviation Facility is completed at Camp Santiago Joint Training Center in Salinas, Puerto Rico. Construction of this facility will be completed through a MILCON PROJECT and should be finalized and ready for relocation within five (5) years.

ARTICLE 8. INSPECTION BY THE AUTHORITY

A. The Authority shall have the right to enter the property subject of this Agreement, with the purpose of making repairs, replacements, or alterations, the Authority will coordinate with the National Guard its entrance to the area. The National Guard has the responsibility to maintain or repair their own facilities and equipment. The Authority reserves the right to inspect from time to time through their representatives and authorized agents, the facilities of the National Guard subject of this Agreement during business hours, in order to determine if the National Guard is in compliance with the obligations it has assumed under this Agreement, subject to comply with current security and safety requirements established by Army and National Guard Bureau (NGB) regulations and policies. There are areas off limit to outside personnel due to the specific military mission of the Army Aviation facility (national security).

ARTICLE 9. INDEMNITY

A. The National Guard agrees to relieve and exempt the Authority regardless of determination on negligence, all liability and assume any legal obligation in respect of claims for damage to property or for personal injury or any other or death caused to any person as a result of the operations of the National Guard in the property covered by this Agreement. The National Guard shall assume the defense of any judicial or administrative claims arising against the Authority by such damage, injury or death, and will pay any compensation or judgment to be granted. The Authority is aware that military operations are self-insured by the Federal Government.

B. If the National Guard does not comply with the aforementioned provisions and this will involve the imposition of fines or penalties against the Authority, the National Guard undertakes to reimburse to the Authority all of the fine or penalty imposed.

C. The National Guard shall be liable for any loss or damage to the property of the Authority that occurs as a result of its negligence or carelessness in the compliance with the provisions of this Agreement.

ARTICLE 10. INSURANCE

A. The National Guard will keep in force, during the term of this Agreement, policies of public accountability to be issued by an insurance company authorized to do business in Puerto Rico to ensure the National Guard against liability for damage to property and personal injury, including personal injury or death caused by the use and occupation by the National Guard of the property subject of this Agreement and any other installation operations and acceptable to the Authority of the Authority (the liability insurance policy should cover area adjacent parking for visitors to the Ports Authority).

B. The limits of the **General Liability, "Commercial General Liability"** policy shall not be less of $2,000,000.00 for general aggregate; $2,000,000.00 for products and completed operations aggregate, $1,000,000.00 for personal injury & advertising injury, $1,000,000.00 for each occurrence, $500,000.00 for damage to rented premises (each occurrence), $5,000.00 for medical expenses (any one person). Employer's liability stop gap, $1,000,000.00 by accident (each accident), $1,000,000.00 by disease (aggregate limit), and $1,000,000.00 by disease (each employee), as applicable under the statutes of the jurisdiction where the services are rendered. That endorsement will have any loss shall be payable to the Authority.

C. The **General Liability, "Commercial General Liability"** policy will contain the following endorsement: *The cover of this policy may not be amended for the purpose of decreasing the protection below the specified limits or under any other circumstances, nor it can be canceled without prior notification in writing to the Authority thirty (30) days in advance. In addition, will be notified in writing to the Authority thirty (30) days in advance in case of non-renewal of the policy.*

D. The policy will also include an endorsement of "Hold Harmless" in favor of the Port Authority and will include it as an additional insured.

E. The **General Liability, "Commercial General Liability"** policy shall not contain deductible, except that the National Guard provides another policy covering the risk not covered by the deductible amount.

F. The National Guard shall maintain workers compensation insurance, according to a policy issued by the Puerto Rico State Insurance Fund Corporation.

G. The National Guard agrees, no more later than thirty (30) days prior to the expiration of any of the policies required by this Agreement or any policies that the National Guard has in force at the time of granting, submit to Authority insurance certificate or a certified copy of all policies required by the Agreement.

H. The National Guard will provide the Authority, copy of the above-mentioned policies of insurance within thirty (30) days from the date of signature and must submit evidence of the renewal.

I. If overdraft obligations on insurance and bonds set forth in this Agreement, or if the Authority is obliged to incur expenses to cover the risks described here, the National Guard will come obliged to pay or reimburse the Authority any expenditure or dispensing it incurred as a result of such breach.

J. In the event of the National Guard expose this obligation to maintain insurance and bonding required by this Agreement into force, the Authority will be assessed a penalty of **$1,000.00** per month until they comply with this obligation.

K. In the event that the National Guard do not submit insurance policies within thirty (30) days prior to expiration, this action shall be regarded as a violation of the terms and conditions of this Agreement, and the National Guard will be subject to a penalty payment an Agreement cancellation.

ARTICLE 11. FIRE EXTINGUISHING EQUIPMENT

A. The National Guard will keep in its facilities the fire extinguishing equipment required by the Authority, the State Fire Department and safety codes for this type of operation, without limiting itself to the codes established by the National Fire Protection Association, in addition to any other applicable regulations in relation to the handling of fuel. **The Authority will provide the National Guard their requirements, mentioned in this article, no later than thirty (30) days after signature of the Agreement.**

ARTICLE 12. NATIONAL GUARD'S OBLIGATIONS

A. The National Guard must comply with all rules and regulations of the Ports Authority.

B. From the beginning of its operations, and during the term of the Agreement, the National Guard must operate the local leased in continuous, consonant manner and according to the standards of conduct set out in the regulations, schedule and quality imposed by the Authority.

C. The National Guard will not place signs advertising signs inside or outside of the leased premises that other than those approved by regulations of law.

D. The hirer undertakes to keep its own system of surveillance or security to understand necessary within the leased premises. The National Guard shall be solely responsible for the supervision of your property.

E. The National Guard undertakes and requires to ensure that none of its employees or visitors locate, park or deposit waste, materials or equipment in the public areas and facilities of the property covered by this Agreement in which there is vehicular and pedestrian traffic.

ARTICLE 13. CONSERVATION AND MAINTENANCE

A. The National Guard will keep the property subject of this Agreement in a satisfactory state of health, sanitation and cleaning at all times during the term of this Agreement.

B. The National Guard will preserve, protect and keep in good use that property, including the collected garbage, assuming its cost. Work required in order to comply with such requirements will be prior authorization in writing by the Authority.

C. Breach of the National Guard with the designated above, will result in the imposition of a daily penalty equivalent to the monthly rent established in this Agreement and not correct the renter situation over a period of thirty (30) days, the Authority shall proceed with the Agreement cancellation.

ARTICLE 14. REPAIRS, ALTERATIONS AND IMPROVEMENTS

A. The National Guard has examined and knows the present condition and state of repair of the facilities covered by this Agreement and also accepts them and acknowledges that the Authority has not agreed or agrees to alter, enhance, adapt or repair any facilities or parts thereof during the term of this Agreement. The National Guard acknowledges that the Authority has not made any representation on conditions or current status of the property subject of this Agreement which has not been made indicating.

B. The Authority reserves the right to make any repairs or improvements to property leased for the duration of the Agreement, if it is deemed proper and necessary in direct coordination with the National Guard.

C. The National Guard will not establish any claim by inconvenience, discomfort, or adverse effect on its business because of repairs or replacements in the property covered by this Agreement. However, activities must be coordinated with the National Guard to avoid military mission impairment.

D. The National Guard may not make alterations, additions or substantial or structural improvements to the property subject of this Agreement without the prior permission in writing of the Authority.

Presence of Material containing asbestos or lead-based paint:

a. The Authority recognizes that the property to be leased, by their nature, may contain material containing asbestos or lead-based paint, as this either inside or outside. The Authority might not have performed a study or assessment of property to determine if it contains material containing asbestos or lead-based paint, but in the event that the National Guard intends to carry out an activity of construction, reconstruction, renovation, alteration or demolition in the property, hereinafter "Activities", this is committed to performing the corresponding studies or evaluations on the property before carrying out activities to determine if in the same exists material containing asbestos or lead-based paint. If based on studies or assessments to the property, it is subject to be affected by the activities areas contain material containing asbestos or lead, the National Guard, at its cost, shall carry out the corresponding Plan Management or Mitigation, as the case may be. The hirer undertakes to comply with the applicable laws and regulations for the inspection, assessment and mitigation activities for the management of materials containing asbestos or lead-based paint, which will ensure that contractors, employees, agents, or representatives designated for these works have the corresponding certifications required by the environmental quality board or any other agency with inherent in activities.

b. The National Guard must notify with no less than fifteen (15) days in advance, the date in which intends to carry out the inspection of the property for the purposes of this clause. Also, the National Guard shall deliver to the Authority copy of studies or assessments carried out to the property and in the event that mitigation is required you must provide copy of licenses and/or certifications of companies performing the same. The National Guard will be responsible for that material containing asbestos or paint lead that is remove, be transported for disposal by a company authorized to this effect and that installation of final disposal has at the same time the necessary authorizations to dispose of the waste. The National Guard, at the end of mitigation activities, will deliver a final report, which describe all of the work performed and accompanied copy of final disposal manifests.

c. Failure to comply with the conditions laid down here may be cause for cancellation of this Agreement, as set out in Article 17. In the event the National Guard decides to not carry out mitigation activities, the Authority, at its option, may make such activities being the National Guard forced to reimburse the Authority the costs associated with this work.

Title of the improvements at the termination of the Agreement:

a. Ownership of all alterations, additions or substantial or structural improvements made and installed by the National Guard will be the National Guard, but the expiration of this Agreement, the title will be transferred to the Authority, free of charge for this and free of liens and, provided that the Authority may require the National Guard to remove or demolish all or part of the alterations, additions or improvements, and return the property subject of this Agreement to its original state except for the deterioration due to normal wear and tear, upon which the National Guard has no control and "force majeure". The National Guard is obliged to carry out such works of removal within the period of ninety (90) working days subsequent to the request in writing of the Authority, subject to availability of funds. Not proceed in accordance with the requirements, means that the National Guard has abandoned the Authority such property and Authority shall be entitled to dispose of the same in the manner that it deems advisable or desirable and its cost will assume by the National Guard.

ARTICLE 15. INSTALLATION OF FIXTURES

A. The National Guard may, assuming its cost, install signs related to his military mission and any other accessories necessary for the ordinary course of its operations, so that you do not mutilate, spoil or a fee property subject of this Agreement. The National Guard may not install such ads or accessories without prior, written permission of the Authority.

B. Within sixty (60) working days following the date of termination of this Agreement, for any reason, the National Guard will withdraw from the leased premises all equipment, personal property, accessories, advertisements, structures and moving improvements, machinery and items or merchandise built, made, kept or deposited by the National Guard in such facilities and will restore the property subject of this Agreement, to its original state prior to the award of this Agreement upon assuming their cost. If the National Guard does not proceed with removal of their property, as indicated in the preceding paragraph, means that the National Guard has abandoned the Authority throughout this property and this may dispose of it in the form that it deems advisable or desirable, whose cost will assume the National Guard.

ARTICLE 16. LIENS

A. The National Guard will not do, or will allow to make, on or in connection with the property subject of this Agreement, any action that will result in a lien or right in rem over such property; and promptly take the necessary action to lift or do raise any embargo, lien or right in rem arising out of or may exist at any time with respect to that property or any alteration, addition, improvement or changes. If the Authority has to resort to any legal action of eviction, collection of money, damages, or any other action related to this article the National Guard will pay costs, expenses and attorney's fees.

ARTICLE 17. TERMINATION OF THE AGREEMENT AND/OR CANCELLATION AND EVICTION

A. The Authority, in its sole discretion and for any reason, will be able to terminate the Agreement, by written notice to the National Guard, with sixty (60) working days prior to the date of termination.

B. Furthermore, and in addition to any other remedy or right that the Authority may exercise under the provisions of this Agreement, the Authority may cancel this Agreement for any of the following events occur:

1. Abandonment of the property subject to this Agreement by the National Guard or the liquidation of the assets of the National Guard:

2. Occupation or other third party under court order or confiscation of the assets of the lessee located on property subject to this Agreement, if such occupation, embargo or seizure is not terminated within fifteen (15) days subsequent to the date on which it began:

3. Breach by the National Guard of any of its obligations, covenants or Agreements under this Agreements or breach by the Lessee of any other obligation of payment of liquid and overdue debt by any other concept, covenant or Agreement for the Authority, which is not covered under this Agreement if such breach is not corrected within fifteen (15) days subsequent to the date on which the Authority so required him to.

4. Non-compliance with laws and environmental regulations, including but not limited to the Environmental Protection Agency (EPA), Coast Guard, Federal Aviation Administration, the Environmental Quality Board (EQB), Department of Environmental and Natural Resources, the Department of Transportation and Public Works of the Government of Puerto Rico and federal, among others.

C. At the time this Agreement is terminated, the Lessee will vacate and deliver the possession or the key of the Leased Premises in a period of ninety (90) working days. If, on the date this Agreement expires or is terminated, the Lessee does not leave and deliver the possession and/or the key of the Leased Premises to the Authority, the Lessee will pay the Authority a penalty of **10%** of the monthly rental fee **for each day** subsequent to the date of the termination of this Agreement. Also, the Lessee will pay the Authority a sum equivalent to the monthly rent established in this Agreement, as compensation for the use and occupation of the Leased Premises beyond its termination. Compliance by the Lessee with this paragraph does not prevent the Authority from taking any and all legal actions it deems necessary to force the Lessee to vacate or surrender possession or the key of the Leased Premises. The acceptance by the Authority of the amounts referred to in this paragraph shall not give rise to an interpretation that the Agreement has been amended, extended, or renewed, or that a tacit renewal has taken place.

D. In the event that the Lessee does not leave or deliver the possession or the key of the Leased Premises when the Agreement terminates, the Lessee accepts and submits to a summary eviction procedure under the jurisdiction of the Puerto Rico First Instance Court of San Juan.

E. The Lessee agrees beforehand to pay the Authority any costs and attorney's fees related to any legal action of eviction, collection of money, damages, or any other legal action caused by the breach of the Lessee with any of its obligations under this Agreement if the Authority prevails.

F. Upon the occurrence of any of the above mentioned facts, in which appropriate termination or cancellation of the Agreement, the Authority may take immediate possession of the property subject of this Agreement and the Lessee shall pay to the Authority as liquid damage, without the need for court action, a sum equivalent to lease fees set out in this Agreement from the date on which the event occurred until the normal expiration of this Agreement date expenses and Attorney's fees if the property is not evicted.

ARTICLE 18. NON AUTHORIZED USE

A. The National Guard is an agency of the Government of Puerto Rico and is part of the Reserve Component of US Armed Forces. On this subject, it cannot be applied a gross income penalty. As such it does not generate its own income as it is funded by Congress through the Department of Defense. However, this clause shall not mean as an authorization to carry out activities not specifically authorized by this or any other Agreement and the payment of such penalty shall not constitute a waiver of the right that the Authority reserves to cancel the Agreement for such breach.

ARTICLE 19. ASSIGNMENTS AND SUBLEASE

A. The Autority may assign this Agreement or any of its rights, interests, or obligations hereunder at its sole discretion and without the consent of the National Guard. The National Guard may not mortgage, pledge, assign as collateral or, in any way transfer or dispose of the leased premises or register in the Registry of Property, if it qualified, this Agreement or any of its rights, interest, or obligations hereunder without the prior written approval of the Authority.

B. The property or rights of this Agreement may not be transferred, assigned, or subleased, in whole or in part and in any way by National Guard, without the prior permission in writing of the Authority.

C. The Agreement assignor/assignee/sub National Guard and sub lessor shall comply with any provision on transfer established in the Agreement, unless this constitutes a limitation. In addition, they must comply with the criteria laid down.

D. Prior to any transfer or assignment, in whole or part of property or rights objects of this Agreement, the National Guard or the part that interests you to assume the Agreement you must settle any amounts due to the Authority until the date that is performed or perform the transfer or assignment. Also, the National Guard of the assignor or the assignee, according to Agreement between the parties, pay to the Authority an administrative fee equal to three (3) months of rent.

E. The transferee, prior to any transfer or assignment, in whole or part of property or rights objects of this Agreement, shall process and obtain credit with the Authority as a prerequisite for the approval of the transfer or assignment.

F. The National Guard will not allow, or authorize that deal or offer goods or services object of the concession previously has concluded a sublease or assignment in writing and meets all the above requirements. If the Authority has to resort to any legal action of eviction, collection of money, damage or any other action related to such assignment or sublease and this prevail, the National Guard shall pay costs, expenses and Attorney's fees. The terms and conditions of the Agreement to original (to be assigned) will remain unchanged and the transferor must be in compliance with all the terms and conditions of the same.

G. The National Guard warrants that for the transfer, as assignor of the Agreement, not requested, nor will subsequently requested, received or will receive any Commission or per cent of any nature on the part of the assignee, no money, pay, payment, or economic benefit. Failure to comply with this condition will be sufficient cause to cancel the assignment and terminate any Agreement that by reason of such transfer, the Authority has granted the National Guard or transferee. In such a case, the Authority reserves the right to reject the request of the transferee as the National Guard or licensee of the Authority.

ARTICLE 20. SECURITY CLAUSE

A. The National Guard will not allow personnel who are not authorized to enter into the operational areas or any other area that are marked as restricted on state or federal regulations within the premises covering this Agreement. In the case that the Authority was penalized or fined by any local or federal agency, or by a Court of Justice, for the violation of any law or regulations related to the access to restricted areas and that such breach is due to that the National Guard has failed to comply with this section, the National Guard shall reimburse such penalty or fine in the next sixty (60) days of being notified.

ARTICLE 21. ENVIRONMENTAL CLAUSE

A. The National Guard shall comply with all laws and regulations of the state and federal agencies for authorizations, endorsements and permits that are issued by them during the term of the Agreement, including, in addition, the protection of the environment and the workplace and/or to regulate the handling, use, generation, treatment, storage, transport or disposal of dangerous and toxic substances including fuel, solid waste and other substances regulated, within and outside the place of lease. This will also be extended to other substances that although they are not considered dangerous, these characteristics can cause damage to the environment or to health.

B. Prior to the start of operations, the National Guard shall request and obtain all the permits and licenses which are necessary for its adequate operation, Federal Government agencies, such as but not limited to: The Environmental Protection Agency, the United States Army Corps of Engineers, the Puerto Rican Environmental Quality Board, the Department of Natural & Environmental Resources, the Solid Waste Authority, the Commission of Public Service, among others.

C. During the term of the lease, the Authority, its employees or agents, shall have the right to enter the leased property and verify the compliance of the National Guard with all laws and regulations, permits and applicable environmental licenses, in direct coordination with the National Guard Environmental Branch. These confirmation activities include among other things: carry out physical inspections where feasible, testing and sampling; installation, service and inspection of devices or environmental compliance plans; inspect and copy records and documents dealing with the National Guard compliance with laws, regulations, licensing and environmental permits, (except documentation considered confidential).

D. The National Guard shall notify and inform at all times to the Authority of any breach of the laws, regulations or breach of the terms and conditions of applicable environmental permits or licenses, or any other matter that may give way to environmental liability of the Ports Authority. This notification must be in writing in a period not greater than five (5) working days from the date in which occurs the violation or non-compliance. In the case that matches the violation or failure to comply with an environmental emergency situation, the National Guard shall notify such event the same day communicating at the earliest and that same day with staff operations and/or air rescue of the Authority, and subsequently notified in writing within the next five (5) working days.

E. If during the term of this lease, the National Guard violates any law, regulation, or you fail to comply with the terms and conditions of licenses and/or applicable environmental permits, or act in any way which could give way to environmental liability of the Ports Authority, the Authority reserves the right at the expense of the National Guard, subject to availability of funds, to:

i. Implement corrective actions as defined in the Comprehensive Environmental Response, Compensation and Liability Act, and the Resources Conservation and Recovery Act to immediately remedy the environmental damage caused.

ii. Compel the National Guard, at its cost, to make any remedial action that is needed to repair the environmental damage caused, either through the implementation of the measures contained in the provisions of the acts referred to in paragraph (i) above or under any another applicable regulation.

iii. The actions set forth shall not constitute under no circumstances a right to reduction in income, either while carrying out any investigate or remedial action.

F. The National Guard will not cause or allow the use, storage, generation or disposal of any hazardous substance at or within the leased premises by its agents, employees, contractors, or invited, without previously obtaining the written consent of the Authority and without due permissions or authorizations that govern these actions. In the event that are used, stored, generate or have hazardous substances, on or within the premises, or that the properties become contaminated in any way the National Guard will be legally responsible to the Authority and any other person who is affected by such action, and this you shall indemnify and hold free of responsibilities to the Authority of any and all claims, damages, fines, judgments, penalties, expenses, responsibilities, or losses (including, without limitation, a decrease in value of the properties, damages caused by loss or restriction of space usable or profitable or any damage caused by adverse impact in the market space, and any and all sums paid for the settlement of claims, Attorney's fees and fees of experts and consultants) arising during or after the term of the lease and arising as a result of this contamination by the National Guard. This indemnification includes, without limitation, any and all expenses incurred by reason of any investigation of the place or any cleaning, removal or restoration ordered by an agency or federal, State or local political subdivision.

G. Hazardous substance means for purposes of this Agreement, any substance that is toxic, inflammable, reactive or corrosive and that is regulated by any competent authority of the Commonwealth of Puerto Rico or the Government of the United States. Hazardous substance includes any and all material or substance as defined as "hazardous waste", "extremely hazardous waste" or a "hazardous substance" in accordance with State or federal law. whether as defined by the Resource Conservation and Recovery Act of 1976, as it is amended from time to time, and regulations promulgated under his protection; any "dangerous substance" as defined by CERCLA (Comprehensive Environmental Response, Compensation and Liability Act of 1980), as it is amended from time to time and promulgated regulations under their protection; including any oil, oil product, or its derivatives and any substance be or not get to be regulated by any federal authority or the Commonwealth of Puerto Rico as such.

H. The National Guard will not cause or allow any hazardous material be brought or maintained, used in or near the premises leased, by its agents, employees, contractors or guests, except those hazardous materials that are necessary and useful to the business of the National Guard, in which case the "Safety Data Sheet (SDS)" must be kept at the installation, and must have the equipment and materials necessary to handle a spill of such substances.

I. All hazardous materials will be kept in safe containers properly designed and labeled for such purposes; they will be used, maintained, stored, and arranged so that they comply with all applicable federal and Government of Puerto Rico laws and regulations.

J. The National Guard will not discharge, spill or issue or allow any material to be discharged, spilled or released to the atmosphere, soil, sewer or any body of water, insofar as that material (as reasonably determined by the Authority or any competent governmental authority) infect or contaminate or can infect or contaminate them or may adversely affect the health well-being or the safety of persons, are inside or outside of the land or premises, condition, use, or enjoyment of the building or any other movable or immovable property within or outside the airport.

K. The National Guard agrees to be fully responsible for all costs and disbursements related to the use, storage and disposal of hazardous materials maintained in the land or premises, and will warn, and shall promptly notify the Authority, of any violation or potential violation. The National Guard will defend, indemnify and hold free of responsibilities to the Authority and its agents from and against any claims, demands, penalties, fines, responsibilities, arrangements, damage, costs, disbursements (including, without limitation, attorneys and consultants, costs and disbursements of litigation fees) of any kind or nature, known or unknown, contingent or otherwise, arising out of, or related to: (a) the presence, disposal, release or threat of release of any of these dangerous materials that are in, or from affecting the soil, water, vegetation, buildings, personal property, people, animals, or other form; (b) any personal injury (including wrongful death) or damage to property (furniture or property) arising out of or relating to this dangerous material; (c) any lawsuit brought or threatened, reached Agreement, or governmental order relating to that dangerous material; or (d) any violation of any law applicable to the matter. The provisions of this section shall be in addition to any other liabilities in law or in equity the National Guard may have with the Authority.

L. The National Guard at its cost, should be kept in clean and appropriate conditions the operation area, keeping it free of obstructions that may cause a disruption to airport operations, as well as to keep them free of any solid waste, including liquids, debris, waste, garbage and gas among others, as defined by the law of conservation and recovery of resources and the regulation for the management of non-hazardous solid waste. Specifically, National Guard shall not use this site or allow the use of it as a deposit or dump of raw materials, waste, hazardous substances, toxic or non-toxic substances, or any. The National Guard may not make excavations in order to store, save, hide or raw materials or materials of any kind. It specifically prohibits the underground storage of hazardous or toxic substances.

M. The National Guard shall not make or allow on the property anything deemed, by its nature, extremely dangerous, or must store in property toxic or flammable products without taking proper precautions. Must comply at all times with all applicable federal and Government of Puerto Rico laws and regulations.

N. In case of the National Guard, needs to store on-site raw material of nature toxic and/or hazardous or toxic waste, it must notify the Authority of such necessity and ensure your prior authorization. Will be provided to the Authority a copy of any permit issued for such storage by any agency that regulates and endorse this type of activity. The issued document must be handed to the Authority before starting the activity.

O. The National Guard agrees, as a condition of this Agreement, which will not download its tributaries or solid, liquid or gaseous, industrial or sanitary, waste in the health system, or in another place that is not permitted by the Authority until you obtain the required authorizations of aqueducts and sewage systems or the Puerto Rico Department of Health or the Environmental Quality Board, and/or any other agency of Government with jurisdiction over it. The National Guard also agrees and undertakes to pre-treat these tributaries before downloading them, as required by the entity with jurisdiction over that action, for which is also committed to installing any equipment or system required and comply with any and all requirements that are imposed to him having to demonstrate compliance with them at the request of the Authority. The breach by the National Guard of the expressed here for a period of thirty (30) days, after having been notified, shall be considered as a violation of the provisions expressed here.

P. The National Guard, at its cost also must keep property, processes and/or operating procedures in compliance with the terms, conditions and commitments as specified in any declaration of environmental impact, environmental assessment or any other similar document produced by the Authority as the primary agency or any other agency of the Government regarding the approval or operation of the project. The Authority must consult with the National Guard the terms, conditions, and commitments prior to approval or operation of the project.

Q. The National Guard will also provide the Authority a copy of any legal claim, notice of violation, regulatory order to show cause, or any other regulatory or legal action against the National Guard in any case or matter relating to compliance with federal and the Government of Puerto Rico environmental laws and regulations, if this could result in an environmental liability to the Authority.

R. The National Guard will also provide the Authority with a copy of any environmental permit related to air emissions, discharge to water or bodies of water, the generation, storage, treatment or disposal of solid waste for any toxic, hazardous or non-hazardous waste of raw materials or products used or generated, stored, treated or disposed, or any other endorsement, authorization or permission obtained. In addition, the National Guard will provide to the Authority a copy of the Spill Prevention Control and Countermeasures Plan (SPCCP), or similar document, which ensure quick response in case of spillage of hazardous and/or special substances such as, but not limited to, fuel, oil or other similar.

S. The National Guard will also provide to the Authority with a copy of any notice, order, request, or similar action issued by any regulatory agency, whether state or federal, that it is related to any case or environmental issue of property, especially in any situation involving contamination of ground water or surface, spilling of hazardous or toxic waste and pollution of soil. Notification to the Authority will be held no later than the actual filing of the relevant documents with the regulatory agency.

ARTICLE 22. NON-DISCRIMINATION CLAUSE

A. The National Guard, in relation to the use of contracted facilities, shall not discriminate against any person, employee, or applicant for employment because of race, gender, sexual orientation, religion, color or nationality. This provision shall include, but not be limited a: employment, ascent, descent, transfer, recruitment or commercial, suspensions, dismissals or severance pay, wages or any other form of compensation or selection for training, including learning. The hirer undertakes to fix notices in places accessible to employees and applicants for employment containing provisions of this clause of non-discrimination.

B. The National Guard ensures that it will carry out a program of affirmative action as required by 14 CFR, Part 152, Sub-part E, to ensure that no person may be excluded on basis of race, religion, color, national origin or sex, participate in any employment activity covered in the 14 CFR Part 152, Sub-Part E. The National Guard ensures that no person shall be excluded on this basis, participate or receive the services or benefits of any program or activity covered by this sub-parte. The National Guard would require that its sub-organizations provide guarantee to the lessor that, similarly, carry out affirmative action programs and that they will require guarantee of its sub-organizations, as required by 14 CFR, part 152, it sub-part and, for the same purposes.

ARTICLE 23. GOVERNMENT ETHICS, FELONY AGAINST PUBLIC TREASURY AND OTHERS

A. The parties declare that no official or employee of the Authority or any member of your household has pecuniary interest direct or indirect profits or benefits product of the present Agreement.

B. The Authority certifies that none of its officials or employees who have the right to approve or authorize Agreement, or any member of your household, have or have had over the last four (4) years prior to his position, directly or indirectly, pecuniary interest with the National Guard.

C. The National Guard certifies that neither she nor any of its shareholders, partners, officers, key employees, subsidiaries or parent companies:

1. He has been convicted, or found probable cause for his arrest, for any offence against the purse, faith and public service; against the government exercise; or that involve money or public property, at federal or state level.

2. He has been convicted of offences against public integrity, as defined in the criminal code, misappropriation of public funds and that it has not declared guilty of a felony in state courts of the Commonwealth of Puerto Rico, in the federal courts or the courts of any other jurisdiction of the United States of America, or any other country. Be guilty of the offences mentioned above, the Agreement shall be determined.

3. Family members who have been public servants, are involved, or have access to, the process of decision making to determine the need for the services covered by the Agreement, or in the process of negotiating and granting the same, or have particular interests in case or matter of any kind that might create a conflict of interest or public policy during the provision of the services agreed under the Agreement, and will not accept any Agreement that may cause a conflict of interest or public policy with the Authority.

4. No employee, officer, director or shareholder of the National Guard, as the case may be, has served as civil servant or public employee related to specific services provided by virtue of this Agreement, within two (2) years preceding the signing of the same.

D. The National Guard certifies that in the Act of granting of the Agreement received a copy and agrees to be bound by the provisions of Law No. 2 dated January 4, 2018, which settles, TITLE III. CODE OF ETHICS FOR CONTRACTORS, SUPPLIERS, SERVICES AND APPLICANTS OF ECONOMIC INCENTIVES OF THE GOVERNMENT OF PUERTO RICO, the Puerto Rico Government Ethics Law and signed the certification of absence of conflict of interests, as provided in the Circular Letter No. 2002-05 the Office of Government Ethics of Puerto Rico.

In addition, the National Guard certifies that it has no pending litigation(s) against the Government of Puerto Rico, or any of its dependencies.

E. The National Guard certifies that does not receive compensation as regular employee of any agency, public corporation, municipality or government agency, and has not signed any Agreement with another agency, public corporation, municipality or government agency of the Government of Puerto Rico, except as permitted by law. Also certifies that it is not official ad honorem of no agency, public corporation, or government agency of the Government of Puerto Rico.

F. The National Guard certifies that have obtained any exemptions required by law of any government entities authorized to grant such waivers, and that copy of these has been given the Authority to be part of the record of employment.

G. The National Guard acknowledges its duty to inform the Authority on an ongoing basis during the term of this Agreement any fact which relates with that this clause. This obligation is of a continuous nature during all stages of the recruitment and performance of the Agreement.

H. The National Guard certifies and guarantees, for itself and on behalf of its shareholders and officers, which is not subject to investigation, or civil or criminal proceedings for offences against the public treasury, faith and public service-related events. The National Guard acknowledges that has an obligation to inform the Authority in this respect, both during the recruitment stage, and during the term of the Agreement, and of any investigation or civil or criminal process that it is related to public funds, testimony, public functions and public property at federal or state level.

I. If the National Guard or any of its shareholders or officers are guilty of crimes as defined by the Law No. 2-2018, this Agreement shall be resolved immediately and the Authority shall be entitled to demand the return of benefits that had been made in relation to the Agreement directly affected by the commission of the offence. The National Guard must be filed an affidavit in accordance with provisions of the Law No. 2 of January 4, 2018.

J. The National Guard and authorized its representatives will seek a professional and respectful treatment for officials or employees of the Ports Authority at all times.

ARTICLE 24. OTHER DISPOSITIONS

A. The National Guard will not be relieved of the past, present or future, fulfillment of obligations by the fact that the Authority in one or more circumstances does not require or insist on compliance with the same, nor will understand therefore that the Authority has resigned to demand, at any time the performance or implementation of the terms, covenants or conditions of this Agreement; being understood that the contractual obligations of the National Guard will continue in full force and effect; provided that the receipt and acceptance of the canon of income shall not be it as a relief for any breach or violation by the National Guard as provided by Agreement nor will invalidate or prejudice the effectiveness of the cancellation or notification, unless this is expressly agreed in writing by the Authority. Successors, Trustees, Trustees, administrators and assigns of the National Guard will be bound by the Covenants and conditions herein contained.

B. This Agreement will not have any effectiveness, as long as the National Guard meets the requirements that settle down here and the Authority shall not be obliged to conditions here until the Agreement not signed by the Executive Director and the Comptroller Office.

C. This Agreement is the only Agreement between the parties on the Agreement object and it may not be changed, modified or extended, except by supplemental Agreement duly granted in writing between the parties.

D. This Agreement leave without effect any other express or implied agreements existing between the parties and not be may alter, modify, amend or rescind, except by written Agreement of the parties.

ARTICLE 25. NON-COMPLETION

The failure, neglect, or abandonment of duties covered by this Agreement, as well as conduct unbecoming of the National Guard or any of its shareholders, directors, officers or employees, shall constitute sufficient cause for the Authority to terminate this Agreement, not before notifying the National Guard with ninety (90) days in advance of such intention, and releasing the Authority from all liability under this Agreement.

ARTICLE 26. NOTICES

A. Notifications to the Authority shall be made in writing and delivered by courier or sent by redirected mail, addressed to the Executive Director, Puerto Rico Ports Authority, P.O. Box 362829, San Juan, Puerto Rico, 00936-2829. Notification to the Puerto Rico National Guard will have to similarly direct to: Brigadier General, José Juan Reyes Peredo, Adjutant General, 552 Borinqueneer, TRL Fort Buchanan, PR 00934.

B. In the event that the National Guard may have a complaint or claim related to the operations authorized under this Agreement, or of any other nature, it will do so in writing, addressed to the Executive Director of the Authority, by certified mail with return receipt requested.

ARTICLE 27. COMPLIANCE WITH LAWS AND REGULATIONS

A. The National Guard will obey and shall comply with the laws and regulations of the Government of Puerto Rico, laws and federal regulations, as well as the municipal ordinances, and applicable regulations and resolutions of the Ports Authority, including those regulations or resolutions that the Ports Authority can approve or modify from time to time, the statutes of the Federal Aviation Administration and any judicial or administrative mandate related to the occupation and operation in facilities object of this Agreement. The National Guard will be obligated to pay or reimburse the Authority any fine or penalty imposed on this as a result of a breach of the National Guard with the provisions stated in this article.

B. Furthermore, this lease Agreement will be subject to the provisions of any existing or future Agreement between the Authority and the Government of the United States related to operations or the maintenance of the concession and other facilities, whose execution is required or may be required as a precondition to the disbursement of federal funds for the development of the concession object of this Agreement and other facilities.

ARTICLE 28. JURISDICTION AND APPLICABLE LAW

A. The parties irrevocably submit to the jurisdiction of the Court of First Instance of San Juan, any dispute related to this Agreement. If necessary the Authority to present a legal action for breach of Agreement against the National Guard, the seller will pay expenses, costs and fees.

B. This Agreement will be governed and must be interpreted in accordance with the laws of the Government of Puerto Rico, and any cause of action arising out of this only may be brought in the courts of the Government of Puerto Rico. The laws and regulations of this jurisdiction here are incorporated by reference in this Agreement to the extent that those laws, rules and regulations are required and shall prevail over any provision in conflict with this Agreement. If required by any law or regulation, the Contracting Parties may amend this Agreement for the sole purpose of complying with the provisions of the law or regulation.

ARTICLE 29. SEPARABILITY CLAUSE

If any provision or condition of this Agreement is determined court or administratively null and illegal by reason of any regulation, law or public policy, all other clauses and conditions continue to have validity in full force and effect.

ARTICLE 30. RENDERING SERVICES

This Agreement is not valid until it has been filed for registration at the Puerto Rico Comptroller's Office according to Law No. 18 of October 30, 1975, as amended.

******This Agreement substitute AP-88-89-(4)-096.***

IN WITNESS WHEREOF the parties hereto have signed this Agreement on ________ __of 2019.

PUERTO RICO PORTS AUTHORITY

Anthony O. Maceira Zayas, Esq.
Executive Director
EIN: 660-43-3854

PUERTO RICO NATIONAL GUARD

Brigadier General José J. Reyes Peredo
Adjutant General
EIN: 660-43-3418

Revised and recommended by:

Melissa Marchany Carrasquillo, Esq.
General Legal Counsel

Mr. José A. Riollano Irizarry
Director of Airport Management

LTC William E. O'Co or
LTC, JA
Staff Judge Advocate
Puerto Rico National Guard

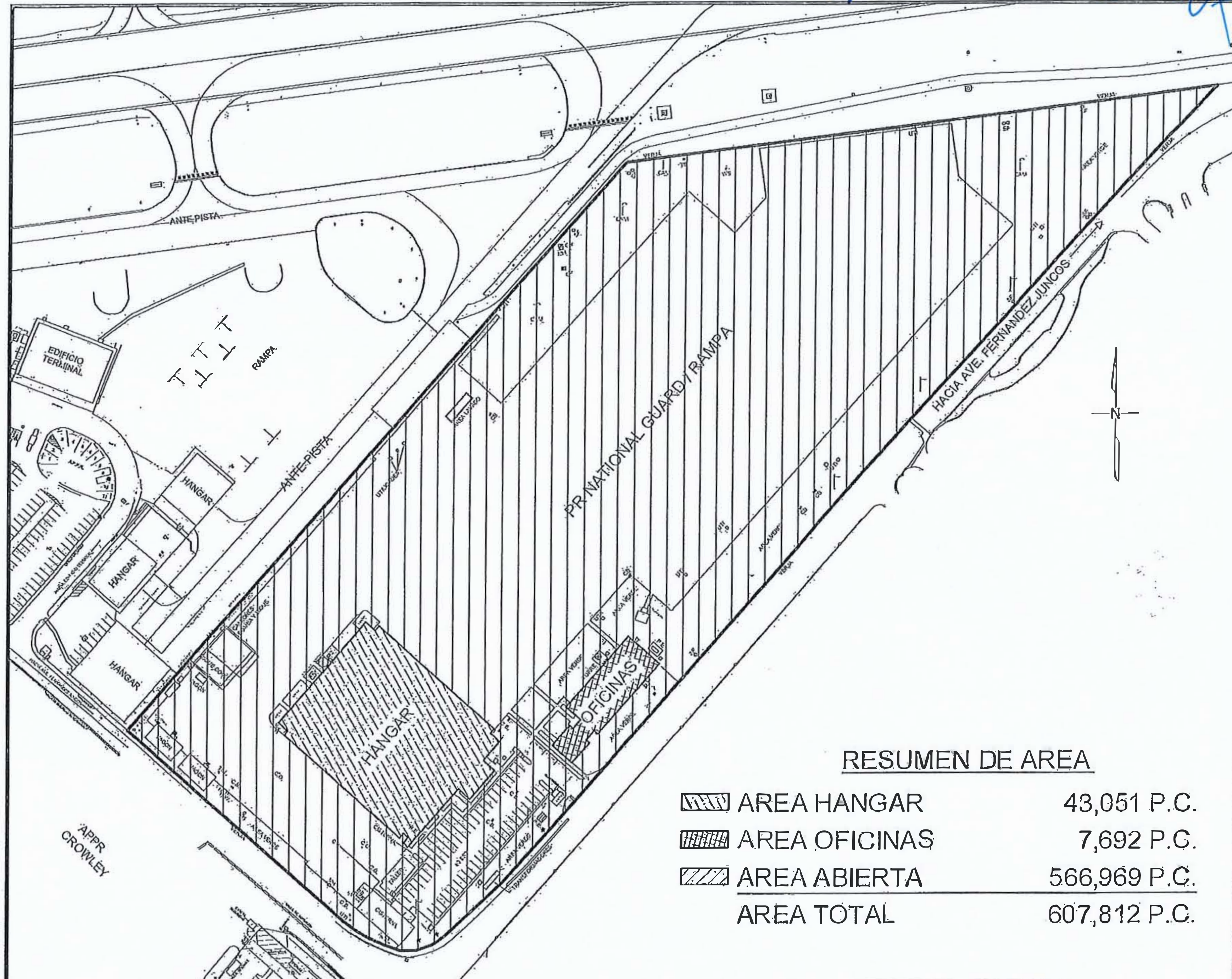
COL Carlos Caez
Const. and Facilities Management Officer
Puerto Rico Army National Guard

Silvia M. Aponte Arroyo, Esq.
General Legal Counsel
Puerto Rico National Guard

Written, revised and recommended by Ramón Alberto Lugo, Counsel of the Puerto Rico Ports Authority, asserting that all necessary clauses and conditions required by the Puerto Rico Ports Authority for this transaction have been included.

Ramón Alberto Lugo
Counsel

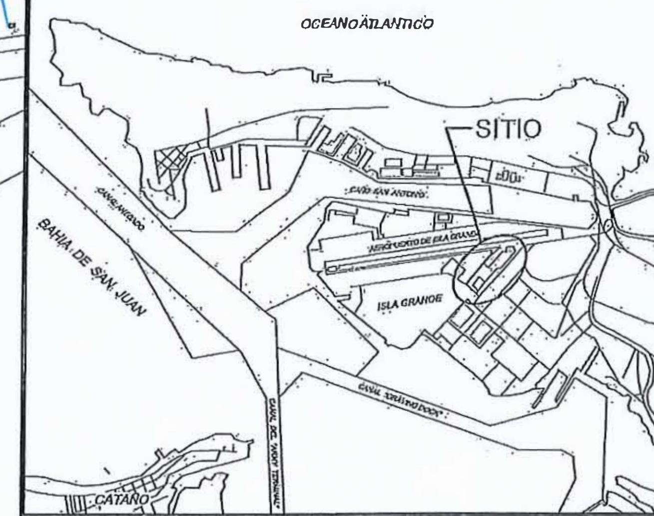
RAL/migb



RESUMEN DE AREA

AREA HANGAR	43,051 P.C.
AREA OFICINAS	7,692 P.C.
AREA ABIERTA	566,969 P.C.
AREA TOTAL	607,812 P.C.

ESTE DOCUMENTO NO ES OFICIAL NI VINCULANTE HASTA LA FIRMA DEL CONTRATO DE ARRENDAMIENTO



PLANO DE LOCALIZACION NO ESCALA

EXHIBIT (41-687)

AUTORIDAD DE LOS PUERTOS de PUERTO RICO

DIRECCION DE PLANIFICACION, INGENIERIA, CONSTRUCCION Y ASUNTOS AMBIENTALES
SECCION DE AGRIMENSURA

AEROPUERTO FERNANDO L. RIBAS DOMINICCI
ISLA GRANDE, SAN JUAN, PUERTO RICO

AREA A SER ARRENDADA A:
GUARDIA NACIONAL DE PUERTO RICO

CODIGO NUM.:
SOLICITUD NUM.: A-106-34
APROBADO POR:
EXHIBIT NUM.: 41-687
FECHA: 3 OCTUBRE 2014
HOJA NUM: 1 DE 1
CBSA

Appendix B
Preliminary Assessment Documentation

Appendix B.1
Interview Records

PA Interview Questionnaire - Environmental Manager

Facility: AASF
Interviewer: J. Witte
Date/Time: 5/20/2019 0830

Interviewee: [redacted] **Title:** CW 2 / Safety Officer **Phone Number:** **Email:** [redacted]	Can your name/role be used in the PA Report? Y or N Can you [redacted] Y or N [redacted]

1. Roles or activities with the Facility/years working at the Facility.

CW2, Safety Officer

2009-Present

*The PRARNG is expected to vacate this facility within 5 years

2. Where can I find previous facility ownership information?

* Lease information has been requested through [redacted]

*The AASF was built in 1992. The area was used by NAS Miramar until the 1960s.

3. What can you tell us about the history of PFAS including aqueous film forming foam (AFFF) at the Facility? Was it used for any of the following activities, circle all that apply and indicate years of active use, if known? Identify these locations on a facility map.

Maintenance - 1 test, 1 incidental release
Fire Training Areas - Wash rack
Firefighting (Active Fire) - none
Crash - no ARNG crashes, off-facility non-ARNG crashes have occurred
Fire Suppression Systems (Hangers/Dining Facilities) - yes
Fire Protection at Fueling Stations - no
Non-Technical/Recreational/ Pest Management - no
Metals Plating Facility - no
Waterproofing Uniforms (Laundry Facilities) - no
Other - no

4. Fill out CSM Information worksheet with the Environmental Manager.

5. Are any current buildings constructed with AFFF dispensing systems or fire suppression systems? What are the AFFF/suppression system test requirements? What is the frequency of testing the AFFF/suppression system? Do you have "As Built" drawings for the buildings?

Yes, the main hangar has an AFFF deluge system (Ansul 3%). As-built drawings have been requested. The system was tested once in ~2009, and had an accidental release between 2006-2008. Both were estimated to be full releases (900 gallon tank).

PA Interview Questionnaire - Environmental Manager

Facility:_______________
Interviewer:_______________
Date/Time:_______________

6. Are fire suppression systems currently charged with AFFF or have they been retrofitted for use of high expansion foam? If retrofitted, when was that done?

   Yes, currently charged with Ansul 3% AFFF; however, the deluge system is not functional. The system includes a 900 gallon tank stored in a pump house connected via pipes to the AASF. 4 "guns" discharge AFFF in the AASF when the system is triggered.

7. How is AFFF procured? Do you have an inventory/procurement system that tracks use?

   AFFF is no longer procured. The method of its procurement is unknown.

8. What type of AFFF has been/is being used (3%, 6%, Mil Spec Mil-F-24385, High Expansion)? Manufacturer (3M, Dupont, Ansul, National Foam, Angus, Chemguard, Buckeye, Fire Service Plus)?

   Ansul 3% is charged in the deluge system

9. Where is the AFFF stored? How is it stored (tanks, 55-gallon drums, 5-gallon buckets)? What size are the storage tanks? Is the AFFF stored as a mixed solution (3% or 6%) or concentrated material?

   900 gallon tank in the detached pump house. AFFF is also stored in Trimaxes at the AASF: 2 are located inside the hangar, 2 are located on the flightline. 1 empty, condemned 60 gal Trimax is ~~stored~~ stored in the POL storage area.

10. How many FTAs are/were on this facility and where are they? Locate on a map. How many FTAs are active and inactive? For inactive FTAs, when was the last time that fire training using AFFF was conducted at them?

   Fire training is only performed, and has only ever been performed, at the Wash Rack area. Training ocurred once annually, usually with 1 trimax being fully discharged to the wash rack drain. Until recently (~3 yrs ago), a city fire academy near the former Hangar 21 would sometimes ignite a fire at the wash rack during training but would not spray AFFF.

PA Interview Questionnaire - Environmental Manager

Facility:________________
Interviewer:________________
Date/Time:________________

11. When a release of AFFF occurs during a fire training exercise, now and in the past, how is the AFFF cleaned and disposed of? Were retention ponds built to store discharged AFFF? Was the AFFF trickled to the sanitary sewer or left in the pond to infiltrate? AFFF is allowed to drain to the wash rack drain / OWS (during training). AFFF released from the deluge system drains to floor drains in the hangar. The ultimate discharge location for all AASF pipes is unknown, but presumed to be the bay.

12. Can you recall specific times when city, county, and/or state personnel came on-post for training? If so, please state which state/county agency or military entity? Do you have any records, including photographs to share with us?

No other police, FD, DoD entities came onto the AASF to train with AFFF. A fire academy ignited fuel pans at times during onsite training but never brought or sprayed AFFF.

13. Did military routinely or occasionally fire train off-post? List the units that you can recall used/trained at various areas. No

14. Did individual units come with their own safety personnel, did they also bring their own AFFF? Was training with AFFF part of these exercises? How were emergencies handled under these circumstances?

Fire academy only came to ignite fire, but never brought or sprayed AFFF.

15. Are there specific emergency response incident reports (i.e., aircraft or vehicle crash sites and fires)? If so, may we please copy these reports? Who (entity) was the responder?

No ARNG crashes or fires are known to have occurred. An incident report for the accidental release in 2006-2008 is not expected to exist. Chief [redacted] will request a crash list from the neighboring airport.

PA Interview Questionnaire - Environmental Manager

Facility:________________
Interviewer:________________
Date/Time:________________

16. Do you have records of fuel spill logs? Was it common practice to wash away fuel spills with AFFF? Is/was AFFF used as a precaution in response to fuel releases or emergency runway landings to prevent fires? Fuel spills were not responded to with AFFF. AFFF was sprayed on the adjacent runway ~2005 to prevent fire during the attempted landing of a malfunctioning Cessna 412.
17. Was AFFF used for forest fires or fire management on-post/off-post? If so, please describe what happened and who was involved? No
18. Are there mutual aid/use agreements between county, city, and local fire department? Please list, even if informal. If formalized, may we have a copy of the agreement? The Isla Grande Airport (SIG) Aviation Department Rescue & Firefighter section provides emergency response for the airport and surrounding parcels between 7am-7pm. The San Juan FD in Santurce responds to emergencies between 7pm-7am.
19. Can you provide any other locations where AFFF has been stored, released, or used (i.e. hangars, buildings, fire stations, firefighting equipment testing and maintenance areas, emergency response sites, storm water/surface water, waste treatment plants, and AFFF ponds)? It is unknown whether AFFF was stored/used at the former Hangar 21. AFFF containers at the adjacent DNR building (occupied by the police) were observed during the site walk. AFFF storage locations for the SIG FD are unknown, but crash rescue truck locations were pointed out.
20. Are you aware of any other creative uses of AFFF? If so, how was AFFF used? What entities were involved? No known creative uses.

PA Interview Questionnaire - Environmental Manager

Facility:_______________
Interviewer:_______________
Date/Time:_______________

21. Are there past studies you are aware of with environmental information on plants/animals/ groundwater/soil types, etc., such as Integrated Cultural Resources Management Plans or Integrated Natural Resources Management Plans?

Environmental docs and engineering docs were requested ~~to~~ through [redacted]

22. What other records might be helpful to us (environmental compliance, investigation records, admin record) and where can we find them?

- SWPPP, CSI, SIG crash list, land titles/leases
  ↳ All requested through [redacted] & Chief [redacted]

23. Do you have or did you have a chrome plating shop on base? What were/are the years of operation of that chrome plating shop?

No known chrome plating shop

24. Do you know whether the shop has/had a foam blanket mist suppression system or used a fume hood for emissions control? If foam blanket mist suppression was used, where was the foam stored, mixed, applied, etc.?

NA

25. How is off-spec AFFF disposed (used for training, turned in, or given to a local Fire Station)? If applicable, do you know the name of the vendor that removes off-spec AFFF? Do you have copies of the manifest or B/L?

Some AFFF ~~is~~ was disposed of following a 2017 memo. The AFFF disposed was stored in buckets. It was disposed of via DRMO or DLA. The email notification of disposal has been requested from Chief [redacted]

PA Interview Questionnaire - Environmental Manager

Facility:_______________
Interviewer:_______________
Date/Time:_______________

26. Do you recommend anyone else we can interview? If so, do you have contact information for them?

Yes: MAJ [redacted] (unavailable)
SGT [redacted]
FD staff from SIG

PA Interview Questionnaire - Other

Facility: AASF
Interviewer: J.Witte
Date/Time: 5/20/19 1300

Interviewee: [redacted] **Title:** SIG Rescue/Firefighter Supervisor **Phone Number:** [redacted] **Email:** [redacted]	Can your name/role be used in the PA Report? Y or N Can you recommend anyone we can interview? Y or N Police Department Contact

Roles or activities with the Facility/Years working at the Facility:

Isla Grande Airport (SIG) Aviation Department Rescue and Firefighter Section Supervisor
Approximately 2017 - Present
(adjacent property)

PFAS Use: Identify accidental/intentional release locations, time frame of release, frequency of releases, storage container size (maintenance, fire training, firefighting, buildings with suppression systems (as builts), fueling stations, crash sites, pest management, recreational, dining facilities, metals plating, or waterproofing). How are materials ordered/purchased/disposed/shared with others?

• SIG Fire trucks carry 6% AFFF solution	**Known Uses**
• AFFF also stored at the SIG office	Use
• Nozzle testing (w/ water) performed in the middle	Procurement
of the runway area	Disposition
• Equipment testing / training performed with water and	Storage (Mixed)
AFFF (when it is expiring) on the east and west ends of	Storage (Solution)
the runway approximately once per month.	Inventory, Off-Spec
	Containment
• The use of AFFF by the police department (adjacent)	SOP on Filling
is unknown	Leaking Vehicles
	Nozzle and Suppression System Testing
	Dining Facilities
	Vehicle Washing
	Ramp Washing
	Fuel Spill Washing and Fueling Stations
	Chrome Plating or Waterproofing

PA Interview Questionnaire - Other

Facility: AASF
Interviewer: J. Witte
Date/Time: 5/20/2019 0900

Interviewee: [redacted] **Title:** **Phone Number:** **Email:**	Can your name/role be used in the PA Report? Y or N Can you recommend anyone we can interview? Y or N FD staff
Roles or activities with the Facility/Years working at the Facility:	
1999 - Present	
* [redacted] was interviewed concurrently with Chief [redacted]	

PFAS Use: Identify accidental/intentional release locations, time frame of release, frequency of releases, storage container size (maintenance, fire training, firefighting, buildings with suppression systems (as builts), fueling stations, crash sites, pest management, recreational, dining facilities, metals plating, or waterproofing). How are materials ordered/purchased/disposed/shared with others?

	Known Uses
• Hangar 21 only had a water sprinkler system	Use
• In the 1980s, Hangar 21 was the location of a batallion, including hueys.	Procurement
• The former NAS Miramar comprised the area including the airport and north across the bay.	Disposition
	Storage (Mixed)
• AFFF has never been used in response to an emergency at the AASF.	Storage (Solution)
	Inventory, Off-Spec
• In 2006-2008, a fire marshall inspector accidentally triggered the AFFF deluge system. The hangar doors were open. Approx. all 900 gallons of AFFF were released, resulting in ~6 ft of standing foam on the hangar floor. Foam escaped the hangar via the NE & SW doors, entering hangar floor drains and stormwater drains on the tarmac and near the wash rack. The majority of foam flowed southwest. Remaning foam was hosed or swept towards the wash rack/OWS.	Containment SOP on Filling Leaking Vehicles Nozzle and Suppression System Testing Dining Facilities Vehicle Washing Ramp Washing Fuel Spill Washing and Fueling Stations
• In 2009 a test release was conducted. The AFFF had the same fate as it did during the 2006-2008 accidental release.	Chrome Plating or Waterproofing

PA Interview Questionnaire - Other

Facility:

Interviewer:

Date/Time:

- The drains at the AASF have unknown discharge points.
- AFFF trimax units have been stored at the AASF since at least 1999. The trimax units have a 12 year lifespan. Fire training with the trimaxes has occurred annually for the entirety of SGT Velazquez's tenure (1999) and presumably before. During training, 1 trimax was typically discharged to the Wash Rack. At times, a nearby Fire Academy would assist by igniting a fire in the Wash Rack. PRARNG often used expiring trimaxes for training.
- There is no present USAF, NAVY, or ANG presence at or adjacent to the AASF, nor any mutual training that occurs.
- No ARNG crashes are known to have occurred at the AASF. 1 crash was recounted on the adjacent runway: Around 2005, a Cessna 412 had malfunctioning nose landing gear. It made several touchdowns in attempts to loosen the gear. The SIG FD sprayed AFFF on the runway to prevent a fire.
  ↳ No other known uses of AFFF by the SIG FD or crashes were recounted

* Between 1992-1997 a fire department was located at the AASF. A fire truck was stored at the fire station. After the fire department was closed in 1997, the fire truck remained until 2004. The practices of the fire department (AFFF storage/training) are unknown. The truck was not used during the tenure of PRARNG interviewees.
- City water is provided to the AASF for drinking water.

- Fishing and swimming occurs in the waters surrounding the AASF. Additionally an Iron Man competition occurs

Appendix B.2
Visual Site Inspection Checklists

Visual Site Inspection Checklist

Names(s) of people performing VSI: J. Witte, C. Sandoval, CPT Hess, T. Peck

Recorded by: J. Witte

ARNG Contact: CPT Hess

Date and Time: 5/20/2019 0800 - 1415

Method of visit (walking, driving, adjacent): Walking / Driving

Source/Release Information

Site Name / Area Name / Unique ID: Isla Grande AASF

Site / Area Acreage:

Historic Site Use (Brief Description): AASF (ARNG)
NAS Miramar (Navy)

Current Site Use (Brief Description): AASF (ARNG)

Physical barriers or access restrictions: Fence & gate

1. Was PFAS used (or spilled) at the site/area? **Y** / N

   1a. If yes, document how PFAS was used and usage time (e.g., fire fighting training 2001 to 2014):
   Annual fire training at the wash rack, 2006-2008 accidental deluge system release, 2009 deluge test

2. Has usage been documented? Y / **N**

   2a. If yes, keep a record (place electronic files on a disk):

3. What types of businesses are located near the site? **Industrial / Commercial / Plating / Waterproofing / Residential**

   3a. Indicate what businesses are located near the site
   Airport

4. Is this site located at an airport/flightline? **Y** / N

   4a. If yes, provide a description of the airport/flightline tenants:
   - A police station occupies the neighboring DNR building.
   - SIG airport main building.
   - Crowley Maritime shipping corporation

Visual Survey Inspection Log

Other Significant Site Features:

1. Does the facility have a fire suppression system? Y / N (Y circled)

1a. If yes, indicate which type of AFFF has been used:

Ansul 3%

1b. If yes, describe maintenance schedule/leaks:

One known deluge test in 2009

1c. If yes, how often is the AFFF replaced:

AFFF is no longer replaced

1d. If yes, does the facility have floor drains and where do they lead? Can we obtain an as built drawing?

Yes, the floor drains flow in unknown directions.

Transport / Pathway Information

Migration Potential:

1. Does site/area drainage flow off installation? Y / N (Y circled)

1a. If so, note observation and location:

To floor drains and stormwater drains

2. Is there channelized flow within the site/area? Y / N (Y circled)

2a. If so, please note observation and location:

In floor drains / storm drains

3. Are monitoring or drinking water wells located near the site? Y / N (N circled)

3a. If so, please note the location:

No drinking water wells. Stormwater sampling occurs near POL storage

4. Are surface water intakes located near the site? Y / N (Y circled)

4a. If so, please note the location:

The bay and surrounding waters

5. Can wind dispersion information be obtained? Y / N (N circled)

5a. If so, please note and observe the location.

6. Does an adjacent non-ARNG PFAS source exist? Y / N (Y circled)

6a. If so, please note the source and location.

SIG airport, potentially the former NAS

6b. Will off-site reconnaissance be conducted? Y / N (Y circled)

Visual Survey Inspection Log

Significant Topographical Features:

1. Has the infrastructure changed at the site/area? Y / N

1a. If so, please describe change (ex. Structures no longer exist):

However, Hurricane Maria devastated the area and repairs have been made

2. Is the site/area vegetated? Y / N

2a. If not vegetated, briefly describe the site/area composition:

Mostly not, partially landscaped area

3. Does the site or area exhibit evidence of erosion? Y / N

3a. If yes, describe the location and extent of the erosion:

4. Does the site/area exhibit any areas of ponding or standing water? Y / N

4a. If yes, describe the location and extent of the ponding:

Receptor Information

1. Is access to the site restricted? Y / N

1a. If so, please note to what extent:

Perimeter fence

2. Who can access the site? **Site Workers / Construction Workers / Trespassers / Residential / Recreational ~~Users /~~ Ecological**

2a. Circle all that apply, note any not covered above:

3. Are residential areas located near the site? Y / N

3a. If so, please note the location/distance:

4. Are any schools/day care centers located near the site? Y / N

4a. If so, please note the location/distance/type:

5. Are any wetlands located near the site? Y / N

5a. If so, please note the location/distance/type:

Appendix B.3
Conceptual Site Model Information

Preliminary Assessment – Conceptual Site Model Information

Site Name: AASF, San Juan

Why has this location been identified as a site?

The site is an AASF and may have stored or used AFFF in the past

Are there any other activities nearby that could also impact this location?

The Isla Grande Airport exists adjacent to the AASF.

Training Events

Have any training events with AFFF occurred at this site? Yes, annual training with TRI-MAXE extinguishers took place between 1999 (or earlier) and 2016

If so, how often? Once per year

How much material was used? Is it documented? One TRI-MAX 30 gallon extinguisher discharged per event

Identify Potential Pathways: Do we have enough information to fully understand over land surface water flow, groundwater flow, and geological formations on and around the facility? Any direct pathways to larger water bodies?

Surface Water:

Surface water flow direction? Unknown

Average rainfall? 68 inches per year

Any flooding during rainy season? None known at the AASF

Direct or indirect pathway to ditches? Direct to drains

Direct or indirect pathway to larger bodies of water? Direct

Does surface water pond any place on site? No

Any impoundment areas or retention ponds? No

Any NPDES location points near the site? Unknown, documentation unavailable

How does surface water drain on and around the flight line? Drains away from SIG flightline

Preliminary Assessment – Conceptual Site Model Information

Groundwater:

Groundwater flow direction? Unknown, expected to be radial towards San Juan Bay

Depth to groundwater? Unknown

Uses (agricultural, drinking water, irrigation)? None known

Any groundwater treatment systems? No

Any groundwater monitoring well locations near the site? No

Is groundwater used for drinking water? No

Are there drinking water supply wells on installation? No

Do they serve off-post populations? NA

Are there off-post drinking water wells downgradient Unknown, but the city is on municipal water

Waste Water Treatment Plant:

Has the installation ever had a WWTP, past or present? No

If so, do we understand the process and which water is/was treated at the plant? No

Do we understand the fate of sludge waste? No

Is surface water from potential contaminated sites treated? No

Equipment Rinse Water

1. Is firefighting equipment washed? Where does the rinse water go?

No firefighting equipment is washed, but when it is used it flows into floor drains, the Wash Rack, and the OWS

2. Are nozzles tested? How often are nozzles tested? Where are nozzles tested? Are nozzles cleaned after use? Where does the rinse water flow after cleaning nozzles?

No

3. Other?

Preliminary Assessment – Conceptual Site Model Information

Identify Potential Receptors:

Site Worker Yes

Construction Worker Yes

Recreational User Yes

Residential No

Child Yes

Ecological Yes

Note what is located near by the site (e.g. daycare, schools, hospitals, churches, agricultural, livestock)?

The AASF is in a commercial/industrial zone adjacent to the SIG airport

Documentation

Ask for Engineering drawings (if applicable).

Has there been a reconstruction or changes to the drainage system? When did that occur?

Appendix C
Photographic Log

Appendix C - Photographic Log

Army National Guard, Preliminary Assessment for PFAS	Army Aviation Support Facility	San Juan, Puerto Rico

Photograph No. 1

Date 5/20/2019
Time 10:00

Description:
Tri-Max AFFF mobile fire extinguisher staged next to an AFFF "gun" in the AASF hangar.

Orientation:
NA

Photograph No. 2

Date 5/20/2019
Time 9:55

Description:
900-gallon Ansulite 3% AFFF tank stored in the Pump House adjacent to the hangar to the southwest.

Orientation:
NA

Appendix C - Photographic Log

Army National Guard, Preliminary Assessment for PFAS	Army Aviation Support Facility	San Juan, Puerto Rico

Photograph No. 3

Date 5/20/2019
Time 9:50

Description:
Silv-ex Class A fire control concentrate staged near the pump house

Orientation:
NA

Photograph No. 4

Date 5/20/2019
Time 9:45

Description:
Wash Rack area south of the AASF hangar

Orientation:
South

Appendix C - Photographic Log

Army National Guard, Preliminary Assessment for PFAS	Army Aviation Support Facility	San Juan, Puerto Rico

Photograph No. 5

Date 5/20/2019

Time 9:40

Description:

Condemned 60-gallon Tri-Max AFFF mobile fire extinguisher staged near the POL storage area at the AASF.

Orientation:

Northeast

Photograph No. 6

Date 5/20/2019

Time 9:35

Description:

Wheeled mobile fire extinguishers with unknown contents staged at the police station adjacent to the AASF

Orientation:

Northeast

Appendix C - Photographic Log

Army National Guard, Preliminary Assessment for PFAS	Army Aviation Support Facility	San Juan, Puerto Rico

Photograph No. 7

Date 5/20/2019

Time 9:30

Description:

Tri-Max AFFF mobile fire extinguisher staged in the aircraft parking area at the AASF

Orientation:

Northeast