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FIELD INVESTIGATION TEAM ACTIVITIES AT UNCONTROLLED HAZARDOUS SUBSTANCES FACILITIES — ZONE I

NUS CORPORATION
SUPERFUND DIVISION

02-8902-44-PA
REV. NO. 0

FINAL DRAFT
PRELIMINARY ASSESSMENT
LAGA BUILDING/VIRGIN ISLANDS
DEPARTMENT OF EDUCATION
ST. THOMAS, U.S. VIRGIN ISLANDS

PREPARED UNDER

TECHNICAL DIRECTIVE DOCUMENT NO. 02-8902-44
CONTRACT NO. 68-01-7346

FOR THE

ENVIRONMENTAL SERVICES DIVISION
U.S. ENVIRONMENTAL PROTECTION AGENCY

MARCH 24, 1989

NUS CORPORATION
SUPERFUND DIVISION

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POTENTIAL HAZARDOUS WASTE SITE PRELIMINARY ASSESSMENT

PART I: SITE INFORMATION

1. Site Name/Alias Laga Building /Virgin Islands Department of Education

Street Route 38, Tutu District

City Tutu District State U.S.V.I. Zip 00802

2. County NA County Code NA Cong. Dist. NA

3 EPA ID No. New Site

4. Latitude 18° 20' 37" N. Longitude 64° 53' 10" W.

USGS Quad. Eastern St. Thomas, U.S. Virgin Islands

5. Owner Virgin Islands Dept. of Education Tel. No. 809-774-2183

Street Route 38, Tutu District

City St. Thomas State U.S. Virgin Islands Zip 00802

6. Operator Same as above Tel. No.

Street

City State Zip

7. Type of Ownership

☐ Private ☐ Federal ☐ State

☐ County ☐ Municipal ☐ Unknown ☒ Other U.S.V.I. Dept of Education

8. Owner/Operator Notification on File

☐ RCRA 3001 Date ☐ CERCLA 103c Date

☒ None ☐ Unknown

9. Permit Information

Permit	Permit No.	Date Issued	Expiration Date	Comments
None				

10. Site Status

☒ Active ☐ Inactive ☐ Unknown

11. Years of Operation Unknown to Present

TUT 002 0061

12. **Identify the types of waste units (e.g., landfill, surface impoundment, piles, stained soil, above- or below-ground tanks or containers, land treatment, etc.) on site. Initiate as many waste unit numbers as needed to identify all waste sources on site.**

(a) **Waste Management Areas**

Waste Unit No.	Waste Unit Type	Facility Name for Unit
1	Drums	Drums behind Laqa Building

(b) **Other Areas of Concern**

Identify any miscellaneous spills, dumping, etc. on site; describe the materials and identify their locations on site.

No other spills, incidents of dumping, etc. were observed on the site during the NUS Corp. Region 2 FIT on-site reconnaissance on 2/15/89.

13. **Information available from**

Contact Amy Brochu **Agency** U.S. EPA **Tel. No.** (201) 906-6802

Preparer Joseph Mayo **Agency** NUS Corp. Region 2 FIT **Date** 3/31/89

PART II: WASTE SOURCE INFORMATION

For each of the waste units identified in Part I, complete the following six items.

Waste Unit 1 - Drums, Drums behind Laga Building

1. **Identify the RCRA status and permit history, if applicable, and the age of the waste unit.**

   There are no known current or previous RCRA permits for the Laga Building site. The age of the waste unit is unknown.

2. **Describe the location of the waste unit and identify clearly on the site map.**

   The drums are located less than 100 feet northwest of the northwest corner of the Laga Building.

3. **Identify the size or quantity of the waste unit (e.g., area or volume of a landfill or surface impoundment, number and capacity of drums or tanks). Specify the quantity of hazardous substances in the waste unit.**

   Twenty-two drums were visible in the brush behind the Laga Building. The area where the drums are located is overgrown with thick brush. The drums were deposited in an uncontrolled manner; some were on their sides, and some were corroded and empty. At least one was full. Twenty-one of the drums were steel and one was plastic. All of the drums in the disposal area had capacities of 55 gallons each.

4. **Identify the physical state(s) of the waste type(s) as disposed of in the waste unit. The physical state(s) should be categorized as follows: solid, powder or fines, sludge, slurry, liquid, or gas.**

   At least one of the drums in the waste unit contained liquid. The physical state of the waste in the remaining drums is unknown.

5. **Identify specific hazardous substance(s) known or suspected to be present in the waste unit.**

   No specific hazardous substances are known to be present in the waste unit. The Virgin Islands Department of Planning and Natural Resources (DPNR) indicated that prior to ownership by the Department of Education, the Laga Building was a textile facility which used solvents in textile processing.

6. **Describe the containment of the waste unit as it relates to contaminant migration via groundwater, surface water, and air.**

   There is essentially no containment of the waste unit. Drums are deposited in a haphazard manner; some are on their sides and some are badly corroded. There are no containment structures associated with the drums; therefore, the potential exists for waste in the unmaintained and corroding drums to be released to the environment and transported to groundwater and surface water.

Ref. Nos. 1, 20

PART III: HAZARD ASSESSMENT

GROUNDWATER ROUTE

1. Describe the likelihood of a release of contaminant(s) to the groundwater as follows: observed, alleged, potential, or none. Identify the contaminant(s) detected or suspected, and provide a rationale for attributing the contaminant(s) to the facility.

The potential exists for contaminants to be released to groundwater. The drums are deposited in a haphazard manner, and some are corroded through. There are no containment structures surrounding the drums to prevent a release of the contents to the environment. The drums have not been sampled and there is no historical information that indicates what their contents were. The DPNR indicated that the Laga Building was a former textile processing facility that used solvents in its processes.

Ref. No. 1

2. Describe the aquifer of concern; include information such as depth, thickness, geologic composition, permeability, overlying strata, confining layers, interconnections, discontinuities, depth to water table, groundwater flow direction.

The rock units of St. Thomas and St. John are divided into three major groups: the Water Island Formation, the Virgin Island Group, and an unnamed group of dioritic plutons. The Water Island Formation, which is late lower Cretaceous in age, consists of keratophyre and spillates. The Virgin Island Group, which is probably early Cretaceous or Albian in age, consists of andesitic-pyroclastic rocks and sedimentary formations. The Virgin Island Group is divided into four formations: the Louisenhoj Formation, which consists of augite-andesite breccia, tuff, and conglomerate; the Outer Brass Limestone, which consists of partially silicified-tuffaceous-radiolarian-limestone; the Tutu Formation, which consists of tuffaceous wacke, including megabreccia near the base and limestone near the top; the Hans Lollik Formation, which may be Eocene in age and consists of augite-andesite breccia and tuff. The final group is made up of one or more dioritic plutons. These unamed dikes and plugs of quartz-andesine hornblende porphory are Upper Cretaceous and Lower Tertiary in age. Alluvian deposits are quarternary in age.

The Water Island Formation, which consists of 95 percent volcanic flow breccias, was probably extruded on a relatively level ocean floor. The absence of terrigenous sediments from this formation indicates that there were no emergent islands present in the area at the time of extrusion. Emergent islands would have served as a source of weather sediments or detritus, which are not present in this formation. There is evidence that sea floor subsidence occurred during the greater part of the accumulation of this formation. However, the subsidence was not rapid enough to maintain a constant water level, thereby causing explosive eruptions near the top of the formation. Regional uplift occurred near the end of the Water Island.

The Louisenhoj Formation of the Virgin Island Group unconformably overlies the Water Island Formation and crops out on about half of the land area on St. Thomas. Pillsbury Sound between St. Thomas and St. John was the origin of this formation. Evidence of this center is based upon the coarseness of volcanic ejecta in the formation in nearby eastern St. Thomas and western St. John. Material is less coarse and tuffs are more predominant as one moves further east and west away from the center or origin. This augite-andesite formation ranges in thickness from 4,000 to 13,000 feet. In certain areas of St. Thomas and St. John conglomerates are interbedded with andesitic rocks at the base of this formation. The depositional environment of this conglomerate varies from location to location throughout this formation.

The Outer Brass Formation of the Virgin Island Group is mostly siliceous limestone which overlies the Louisenhoj Formation. This limestone formation is an offshore deposit formed by radiolarian and foraminiferal remains including a minor amount of tuff. Thicknesses are known to be at least 600 feet

Overlying the Outer Brass Formation is the Tutu Formation. The Tutu Formation is fine- to coarse-grained volcanic wackes, which are termed flysch. This formation is derived from eroding sediments from the Louisenhoj andesites. Exposed thicknesses are known to be as much as 6000 feet. Within this formation is a megabreccia lithofacies with an average thickness of 30 feet, and a limestone member with thickness up to 300 feet.

The Hans Lollik Formation, which consists of at least 10,000 feet of augite-andesite pyroclastic rocks, crops out on Little Hans Lollik Island. Dioritic plutons are located in Pillsbury Sound between St. Thomas and St. John; in the narrows, between St. John and the British Virgin Islands; and south of St. Thomas. The exact delineation of these plutons is uncertain. Throughout the islands isolated dikes of quartz-andesine porphyries, andesine-hornblende porphyries, lamprophyres, breccias, and pegmatites appear.

Folding occurred after the deposition of the Virgin Island Group. Rocks were tilted to form a northward-dipping homocline, which is cut by sets of faults trending N 45°W, N 55°E, and north. Well-defined joint sets parallel each of the major fault trends. Dips range from 15° to 90° with the average being 40°. Strike-slip faults have horizontal offsets of less than 1 mile. Two major strike-slip graben structures or fault systems exist. The first passes through Redhook, St. Thomas, and the eastern tip of Lovango Cay. The second crosses St. John, from Contact Point on the southwest to Brown's Bay on the northeast.

Most recent Pleistocene to Holocene alluvial deposits occurred primarily in coastal embayments. However, a narrow bank of alluvium extends up to Turpentine Run on the east end of the island. Most of these deposits are composed of silt, clay, and thin, discontinuous beds of sand and gravel. Maximum thickness of these is 50 feet.

Groundwater movement is limited to openings and joints along fault zones. Regional geologic information is insufficient to determine whether these fractures and fault zones are present in all of the above-described formations; however, for this report it is assumed that the fractures and fault zones are present in all of these formations. The valleys on the island are the result of weak zones caused by faulting and jointing and are primary recharge areas for groundwater. Alluvial deposits have a high porosity but low permeability, making this aquifer unfavorable for groundwater production. In coastal embankments throughout the island, saltwater intrusion is widespread in alluvial deposits. In most areas, alluvial deposits are interconnected with bedrock and act to recharge precipitation to the underlying bedrock.

The direction of groundwater flow in the Turpentine Run Basin Aquifer is south-southeast which is generally along the direction of flow of Turpentine Run. Depth to groundwater in the aquifer ranges from 5 to 60 feet, and the altitude of the water levels ranges from 1 to 209 feet above mean sea level.

Ref. Nos. 11, 16

3. **Is a designated sole source aquifer within 3 miles of the site?**

There are no sole source aquifers, as designated in the Federal Register, within 3 miles of the site.

Ref. No. 8

4. **What is the depth from the lowest point of waste disposal/storage to the highest seasonal level of the saturated zone of the aquifer of concern?**

Drums in the waste unit were deposited on the ground surface. Depth to groundwater in Virgin Island Housing Authority (VIHA) Well Nos. 1 and 2 was reported to be 56 and 60 feet, respectively. VIHA well Nos. 1 and 2 are located approximately 175 feet west of the Laga Building.

Ref. Nos. 1, 9

5. **What is the permeability value of the least permeable continuous intervening stratum between the ground surface and the aquifer of concern?**

There are no continuous intervening strata between the ground surface and the bedrock aquifer. Soils are generally thin in the area around the site. The water-bearing formations in the Turpentine Run Basin are composed primarily of fractured and jointed volcanic rocks. The range of hydraulic conductivities associated with these formations is 10^{-3} to 10^{-5} cm/sec.

Ref. Nos. 10, 11, 16

6. **What is the net precipitation for the area?**

Net precipitation is usually calculated by subtracting mean annual lake evaporation (a surrogate measure for evapotranspiration) from normal annual total precipitation. Mean annual lake evaporation was not available for St. Thomas; however, evapotranspiration data were available. These data indicate that 95.8 percent of the incident precipitation on St. Thomas is lost through evapotranspiration. The normal annual total precipitation for St. Thomas is 43.74 inches, but because of orographic effects on the Island, normal annual total precipitation can range from 35 inches to 50 inches over short distances. In the Turpentine Run Basin, normal annual precipitation is 40 inches. Calculations for net precipitation are provided below:

40 inches precipitation x 95.8 percent lost to evapotranspiration = 38.32 inches lost to evapotranspiration

40 inches precipitation - 38.32 inches lost to evapotranspiration = 1.68 inches net precipitation.

Ref. Nos. 3, 5, 12, 13

7. **Identify uses of groundwater within 3 miles of the site (i.e., private drinking source, municipal source, commercial, industrial, irrigation, unusable).**

Groundwater within 3 miles of the site is used as a source of private and municipal drinking water, and for commercial purposes. There are at least 41 wells within 2 miles of the site. Thirty-five of these wells are within 1 mile of the site.

Ref. Nos. 6, 9

8. **What is the distance to and depth of the nearest well that is currently used for drinking or irrigation purposes?**
Distance 175 feet **Depth** 150 feet

The nearest well is the VIHA well No. 2, which is located approximately 175 feet west of the Laga building. This well is believed to be used for drinking. A nearby well, VIHA No. 1, was ordered closed because of contamination with volatile organic compounds. VIHA well No. 2 is not listed as being closed due to contamination, and its designated use is for domestic purposes.

Ref. Nos. 6, 9

9. **Identify the population served by the aquifer of concern within a 3-mile radius of the site.**

It is difficult to estimate the population served by groundwater on St. Thomas as there are few records available on groundwater withdrawal, sale, and transport. The locations of some wells in St. Thomas are unknown, and there are reports of illegal drilling on the island. It is estimated that there are 500 to 600 private wells on St. Thomas. Most of these are used for nondrinking domestic uses such as washing and flushing, although some may be used for drinking. There are a number of wells that are used for commercial purposes. Water from these wells is trucked to private houses and pumped into cisterns to augment the rainwater collected from roofs. Groundwater is also bottled and sold in supermarkets

There are at least 41 wells in the Turpentine Run Basin. Recently, 16 of these wells have been ordered closed because they were found to be contaminated with volatile organic compounds. One of these wells was a major supplier of water to the eastern end of the island. Estimates of the population using groundwater as a source of drinking water range from none to approximately 11,000--the population of the Turpentine Run Basin which is not served by water from a desalinization plant. The actual population served by groundwater is probably less than 11,000, as desalinated water and water from wells outside the 3-mile radius is trucked into the area.

Ref. Nos. 9, 13, 15, 18, 19

SURFACE WATER ROUTE

10. **Describe the likelihood of a release of contaminant(s) to surface water as follows: observed, alleged, potential, or none. Identify the contaminant(s) detected or suspected, and provide a rationale for attributing the contaminants to the facility.**

A potential exists for contaminants to be released to surface water. The location of the drums is at the top of a steep hill, and at the base of the hill is a tributary to Turpentine Run -- an intermittent stream which drains the Tutu area and discharges to the Caribbean Sea. The drums have not been sampled, and there is no historical information that indicates what their contents are. The DPNR indicated that the Laga Building was a former textile processing facility which used solvents in its processes.

Ref. Nos. 1, 2

11. **Identify and locate the nearest downslope surface water. If possible, include a description of possible surface drainage patterns from the site.**

The nearest downslope surface water is the Mangrove Lagoon which is hydraulically connected to the Caribbean Sea. Turpentine Run is an intermittent stream that drains the Turpentine Run Basin. The distance from the site to the nearest surface water, along the course of Turpentine Run, is 2.4 miles. It should be noted that because of the steeply sloping nature of the topography on St. Thomas (35-percent slopes are not uncommon), there are no natural perennial streams on the island. On St. Thomas orographic effects produce frequent, brief rainstorms. Runoff from these rainstorms can be significant, and therefore, short-term flow rates of the intermittent streams can be high.

Ref. Nos. 2, 4, 5

12. **What is the facility slope in percent? (Facility slope is measured from the highest point of deposited hazardous waste to the most downhill point of the waste area or to where contamination is detected.)**

The drum area is relatively flat with a slight slope toward the north and east. Near the margin of the drum area there is a steep slope to the northeast. Facility slope is estimated to be between 0 and 3 percent.

Ref. Nos. 1, 2

13. **What is the slope of the intervening terrain in percent? (Intervening terrain slope is measured from the most downhill point of the waste area to the probable point of entry to surface water.)**

The slope of the intervening terrain is as follows:

- Elevation of waste area - 240 ft
- Elevation at point of entry - 0 ft
- Path length - 12,700 ft

$\frac{240\ ft - 0\ ft}{12{,}700\ ft} \times 100 = 1.9\%$ slope

Ref. Nos. 1, 2

14. What is the 1-year 24-hour rainfall?

One-year 24-hour rainfall data were not available for the U.S. Virgin Islands. However, it is known that rains exceeding 1 inch in 24 hours occur six or seven times a year on St. Thomas. Two-year 48-hour rainfalls range from 4 to 15 inches. It has also been reported that it is not uncommon for 24-hour rainfalls to be 2 to 3 inches.

Ref. Nos. 4, 6

15. What is the distance to the nearest downslope surface water? Measure the distance along a course that runoff can be expected to follow.

The nearest downslope surface water is the Mangrove Lagoon, which is hydraulically connected to the Caribbean Sea. The distance from the site to the above surface water is 2.4 miles.

Ref. No. 2

16. Identify uses of surface waters within 3 miles downstream of the site (i.e., drinking, irrigation, recreation, commercial, industrial, not used).

Surface water within 3 miles downstream of the site is used for recreation including swimming, fishing, and boating. The DPNR has designated the area of the Mangrove Lagoon for preservation.

Ref. Nos. 2, 14

17. Describe any wetlands, greater than 5 acres in area, within 2 miles downstream of the site. Include whether it is a freshwater or coastal wetland.

There are no wetlands greater than 5 acres within 2 miles downstream of the site. However, there is a coastal mangrove wetland approximately 2.4 miles downstream. The Mangrove Swamp is designated as a preservation area in the Coastal Zone Management Program of the DPNR.

Ref. Nos. 2, 14

18. Describe any critical habitats of federally listed endangered species within 2 miles of the site along the migration path.

There are no known critical habitats of federally endangered species within 2 miles of the site. The Virgin Islands Tree Boa (epicrates monensis granti) is an endangered species in the U.S. Virgin Islands; however, no critical habitat has been identified for this species.

Ref. No. 7

19. What is the distance to the nearest sensitive environment along or contiguous to the migration path (if any exist within 2 miles)?

There are no sensitive environments within 2 miles of the site that lie along or contiguous to the migration pathway.

Ref. Nos. 2, 7, 14

20. **Identify the population served or acres of food crops irrigated by surface water intakes within 3 miles downstream of the site and the distance to the intake(s).**

There is no population served and there are no food crops irrigated by surface water intakes within 3 miles downstream of the site. The nearest surface water is saline. There is a desalinization plant which uses seawater to supply drinking water, but the intake is greater than 3 miles from the site.

Ref. Nos. 2, 13

21. **What is the state water quality classification of the water body of concern?**

No water quality classification is known to exist for the Mangrove Lagoon or the Caribbean Sea, although the mangrove swamp surrounding the lagoon is designated as a preservation area by the DPNR.

Ref. Nos. 14

22. **Describe any apparent biota contamination that is attributable to the site.**

No apparent biota contamiantion was observed during the on-site reconnaissance conducted by NUS Corp. Region 2 FIT on February 15, 1989.

Ref. No. 1

AIR ROUTE

23. **Describe the likelihood of a release of contaminant(s) to the air as follows: observed, alleged, potential, none. Identify the contaminant(s) detected or suspected, and provide a rationale for attributing the contaminant(s) to the facility.**

A slight potential exists for release of contaminants to the air. If corroded and uncontained drums rupture, the potential exists for a release to the atmosphere. The type of wastes in the drums is unknown; however, prior to ownership by the Department of Education, the building housed a textile processing facility that is reported to have used solvents.

No readings above background were detected on the OVA flame ionization detector or the HNu photoionization detector during the on-site reconnaissance of the drum area conducted by NUS Region 2 FIT on February 15, 1989.

Ref. No. 1

24. **What is the population within a 4-mile radius of the site?**

Based on the 1980 census, the population within 4 miles of the site is approximately 36,000.

Ref. No. 17

FIRE AND EXPLOSION

25. **Describe the potential for a fire or explosion to occur with respect to the hazardous substance(s) known or suspected to be present on site. Identify the hazardous substance(s) and the method of storage or containment associated with each.**

A small potential exists for fire or explosion to occur at the site. Solvents were reportedly used in the textile processing that took place in the Laga Building. If these solvents are contained in the drums, there is a potential for fire or explosion. Drums on the site were in poor condition, and there were no containment structures around the drums.

Ref. No. 1

26. **What is the population within a 2-mile radius of the hazardous substance(s) at the facility?**

Based on 1980 census data, the population within 2 miles of the site is approximately 19,000.

Ref. No. 17

DIRECT CONTACT/ON-SITE EXPOSURE

27. Describe the potential for direct contact with hazardous substance(s) stored in any of the waste units on site or deposited in on-site soils. Identify the hazardous substance(s) and the accessibility of the waste unit.

The potential exists for direct contact with hazardous substances at the facility. The drums are uncontained and were deposited in an uncontrolled manner. It is not known whether the drums contain hazardous substances; however, solvents have been associated with this site in the past. The waste is not surrounded by a fence, and children were observed near the drum area. There are residences 230 feet east and downhill from the drum area.

Ref. Nos. 1, 2

28. How many residents live on a property whose boundaries encompass any part of an area contaminated by the site?

It is not known whether any area has been contaminated by the site.

29. What is the population within a 1-mile radius of the site?

Based on 1980 census data, the population within 1 mile of the site is approximately 11,000.

Ref. No. 17

PART IV: SITE SUMMARY AND RECOMMENDATIONS

The Laga Building Site is located in the Tutu area of St. Thomas, U.S. Virgin Islands. The Laga Building was formerly the site of a textile manufacturing facility and is currently occupied by the Virgin Islands Board of Education. The area within approximately 1 mile of the site is densely populated, and includes some commercial properties. There are large housing developments north, northwest, and southeast of the site. The nearest residence is 320 feet east of the site. Beyond 1 mile, there are scattered smaller villages and towns. The densely populated and highly commercial town of Charlotte Amalie, which is the capital of St. Thomas, is located 2.5 miles west of the site.

On February 15, 1988, NUS Corp. Region 2 FIT conducted an on-site reconnaissance of the Laga Building Site. Twenty-two 55-gallon drums were found behind the building. The drums were deposited in an uncontrolled manner, and most of them were in poor condition. Some of the drums were rusted, some were perforated, some were deposited on their sides, some were empty, and at least one was full. Vegetation has grown around most of the drums, and a few were nearly completely overgrown. There were no discernible labels on the drums. No stains were noted near the drums, and no readings above background were detected on the OVA flame ionization detector or the HNu photoionization detector. There are no containment structures surrounding the drums, and the DPNR indicated that solvents were used by the textile processing facility that previously occupied the building.

The above conditions indicate that there is a potential for contaminants to be released to the environment from the drum area behind the Laga Building Site. A tributary of Turpentine Run is located downhill and approximately 250 feet east of the drum area. Turpentine Run is an intermittent stream that drains the Turpentine Run Basin and discharges to the Mangrove Lagoon, which is hydraulically connected to the Caribbean Sea. If hazardous substances are released from the drums, the potential exists for them to be transported to the Mangrove Lagoon via Turpentine Run. The DPNR has designated the mangrove wetlands for preservation.

There is also concern that hazardous substances that may be in the drums will be released to groundwater. The site is atop the Turpentine Run Basin Aquifer, which is the most productive aquifer on St. Thomas. There are numerous wells in the Turpentine Run Basin Aquifer, and collectively they are permitted to draw up to 1 million gallons per day from the aquifer. Some of these wells draw water for drinking purposes. Currently, the water main from a public water supply desalinization plant does not extend to the Tutu area.

There is also a potential for fire and/or explosion, direct contact, and air contamination from the drums. The drums may contain solvents that may be flammable or explosive. Direct contact is possible if hazardous substances are present in the drums. The nearest residence is 235 feet east of the site, and children have been observed walking near the drums. The potential for air contamination exists if volatile compounds are released from the drums.

The previous owners of the Laga Building have been identified as one of nine potentially responsible parties in the contamination of groundwater in the Tutu area. In July and August of 1987, EPA confirmed by sampling that volatile organic compounds were present in a number of wells in the Tutu area. DPNR has issued orders to close 16 wells in the area. One of the wells was a major source of commercially provided potable water for the eastern end of the island. Removal action activities in the Tutu area included sampling of wells and cisterns, removal of contaminated water from cisterns, cleaning of cisterns, and supplying clean water on a regular basis to affected residents.

The Laga Building Site is given a **MEDIUM PRIORITY** for further action for the following reasons:

- Waste containment is poor as evidenced by perforated and corroding drums.
- Groundwater in the vicinity of the site is used for domestic purposes, and the water main from the desalinization plant does not currently extend to the Tutu area.
- The potential exists for runoff from the site to reach the Mangrove Lagoon via Turpentine Run.
- The waste area is accessible, and there are homes 230 feet east and downhill of the drum area.

Further efforts should focus on determining whether there are hazardous substances in the drums. Efforts should also be directed toward determining whether any hazardous substances have been released to the environment. Drum sampling and soil sampling in the vicinity of the drums and soil sampling in the drainage pathway to Turpentine Run are recommended. Sampling of wells in the vicinity of the site is also recommended. It should be noted that a number of the wells are contaminated with volatile organic compounds; therefore, judgement should be used to select appropriate wells for sampling.

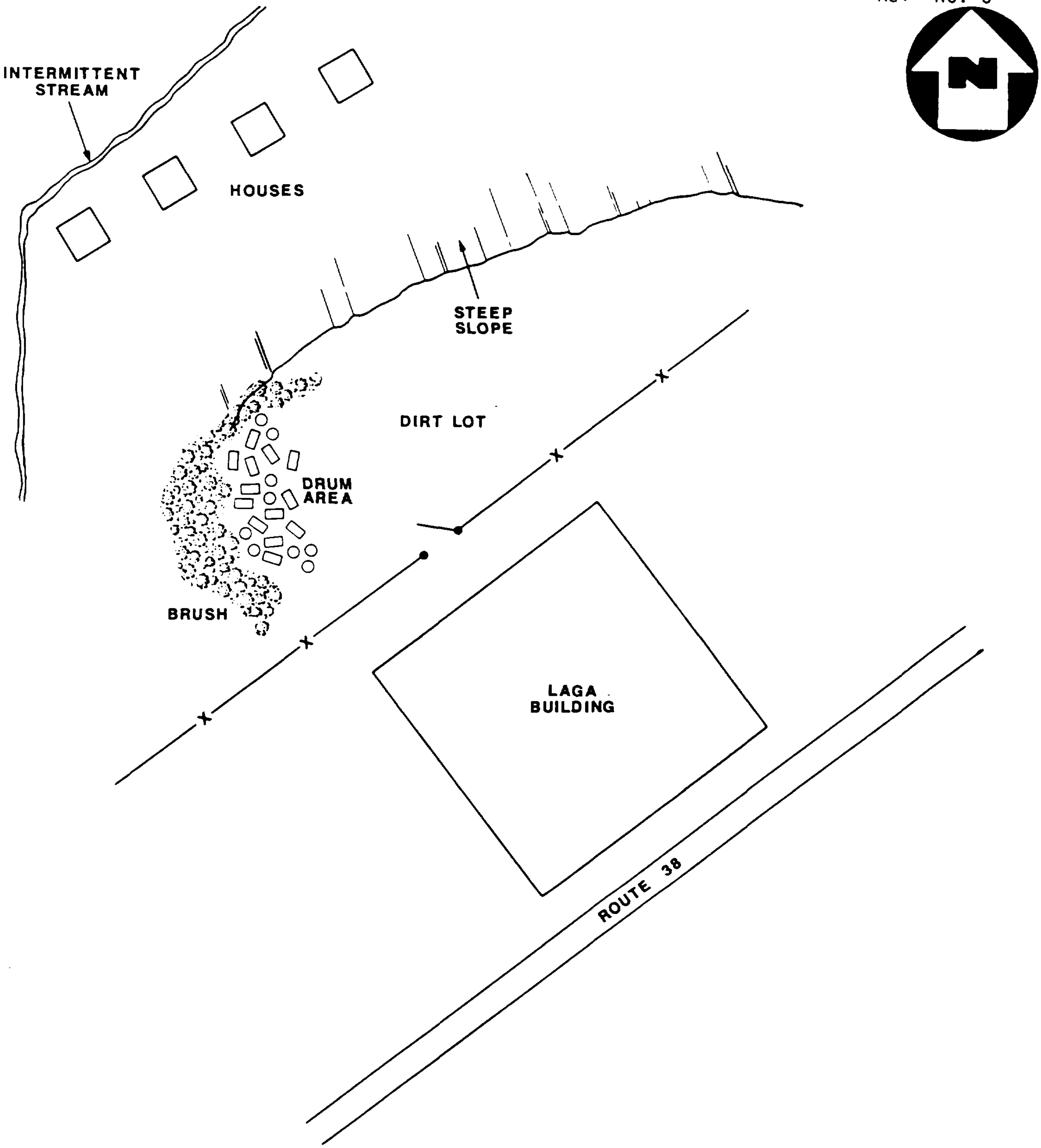
ATTACHMENT A

MAPS AND PHOTOS

LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS

CONTENTS

02-8902-44-PA
Rev No. 0



TUT 002 0075

SITE MAP
LAGA BUILDING,
ST. THOMAS, U.S. VIRGIN ISLANDS

NOT TO SCALE

FIGURE 2

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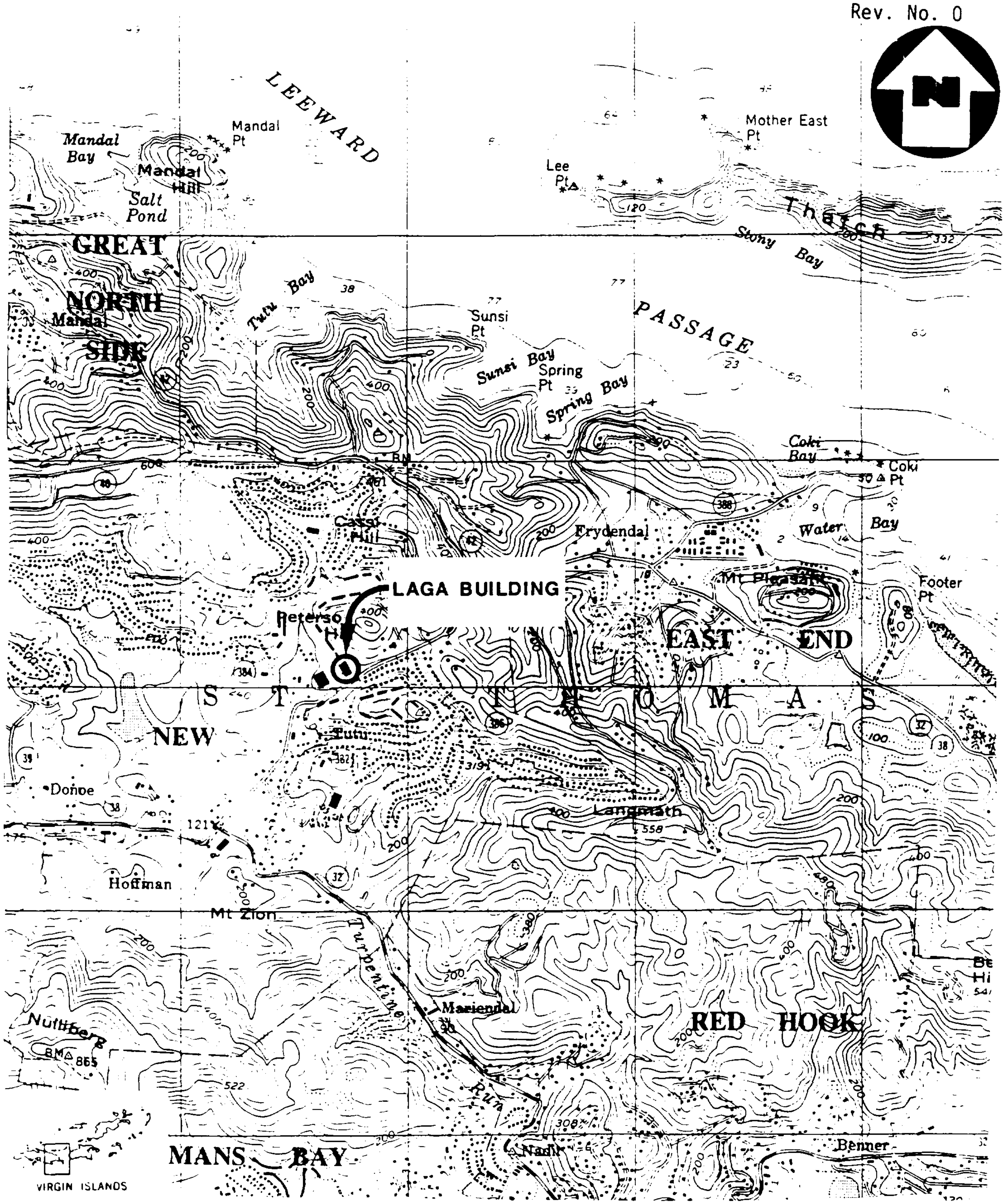

(QUAD) EASTERN ST. THOMAS, V.I.

TUT 002 0076

FIGURE 1

SITE LOCATION MAP
LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS

SCALE: 1" = 2000'

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LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS
FEBRUARY 15, 1989

PHOTOGRAPH INDEX

ALL PHOTOGRAPHS TAKEN BY DIANE TRUBE.

Photo Number	Description	Time
R3-P17	Drums behind Laga building.	1525
R3-P18	Drums behind Laga building.	1525
R3-P19	Drums behind Laga building.	1525

02-8902-44-PA
Rev. No. 0

LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS

R3-P17 February 15, 1989 1525
Drums behind Laga building.

NUS CORPORATION

02-8902-44-PA
Rev. No. 0

LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS

R3-P18 February 15, 1989 1525
Drums behind Laga building.

02-8902-44-PA
Rev. No. 0

LAGA BUILDING
ST. THOMAS, U.S. VIRGIN ISLANDS

R3-P19 February 15, 1989 1525
Drums behind Laga building.

ATTACHMENT B

REFERENCES

REFERENCES

1. Field Notebook No. 0398, U.S. Virgin Islands Drum Reconnaissance, TDD No. 02-8902-29, NUS Corp. Region 2 FIT, Edison, New Jersey, February 14 to 17, 1989.

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19. Telecon Note: Conversation between D. Goetz of Polycaribe and D. Trube, NUS Corp., on 3/14/89 at 1430 hours. RE: Wells and water use on St. Thomas.

20. Telecon Note: Conversation between L. Reed, DPNR, and D. Trube, NUS Corp., on 3/3/89 at 1640 hours. RE: Permits for site on St. Thomas.

REFERENCE NO. 1

NUS CORPORATION

II

0398

TUT 002 0085

02-8901-29 VI Drum Recon

Table of Contents

D. Fruhe 2/22/89 J. Mayo 2/23/89

0630 Met w/ R. Feinberg, J Mayo for equipment
0800 Arrived at VI Dept Planning - Nat Res (DNR)
0825 Met Carlos O'Neil, Chris Danato (Edison TAT), and Arnado Martinez, + Leonard Reed (DNR). TAT was here to sample Ramsey Motors, Gassetts Rentals, Tutu Esso, + Tutu Texaco. No pcb's found. Carlos said Yacht Haven Marina is of particular concern. The four sampled sites are part of a removal action. Nothing done yet except sampling. Samples exceeded holding times. Emerg action has been providing water after wells were shut down. Texaco + Esso stations had old tanks replaced. TCE found in Texaco's waste oil. Laga Bldg was textile facility, now ~~operated~~ owned by Dept of Education. Solvents used in processes.

Amer. Yacht Harbor - leaking tank near harbor
Yacht Haven - drums + tank
Gassett Rental (formerly consolidated)
Gassett, Tutu Underg. tanks
Esso, Tutu Texaco.

Leonard added one site off ~~Howards~~ Harwood Hwy
Sibily Auto Repair near an Gottlieb Esso.

Leonard will try to arrange a vehicle for St John.
Energy Office granting $250,000 to remove oil.
Arrangements in works for subcontracting
Access has been arranged for all sites except Sibily.

0900 Greg Rhymer arrives
Paula ~~Camarat~~ Cammarrata (EPA Edison Emerg. Response) ~~in charge of rem~~ is contact for removal project.

Diane Trinko 2/14/89 JJ Mayo 2/23/89

1505 Spoke with Operations Mgr. Thomas Gutshall. All waste oils put into underground tank; then ~~pumped~~ + removed by ESSO Corp. They do not accept waste oils from others. No solvents, cleansers, etc are put into tank.

Underground Tank is under garage (under tires) last tested by EPA 6 mo. ago.

1519 Stopped by Laga Bldg. No solvent, oils etc currently stored on site. Allowed to go behind building. 22 drums visible, some overgrown many in poor repair. Some appear empty, others full. No elevated air readings. One drum contains liquid JM 3/

28 cpm on minirad

No stained soil visible. No labels visible.
Children were observed crossing area on foot.
Drums are rusted, some broken or perforated.
Drums are 55 gal metal (except 1 is plastic)

1530 left site

1700 Called Ron + Tim at NUS office + informed them of progress, + that TAT team from Edison were also here, working on some of the same properties.

2200 ~~1900~~ DL I received a message from Leonard Reed that Ms Monsanto will meet us at DNR office at 0730-0800 hr tomorrow to show us where airport sites are.

Diane Lube 2/15/89 JM 2/23/89

0617 Received a call that Mr Reed will meet us at 0730-0800 at DNR office

0630 Met J Mayo + R Feinberg to collect equipment for the day.

0725 Arrived at DNR offices

0800 Mr. Reed arrived. We reviewed our recons

His comments:

- Tutu Texaco has 2 underground tanks for waste oil - may be at capacity since they were now using drums
- Ramsey well was supposed to be closed for all use - it's still being used for car washing
- He will try to provide GW, well geology, target pop. info.
- wells @ Virgin Grande Hotel
  @ VI University
- I suggested that NUS send a copy of PA form so Leonard can see the type of info we need at a minimum

0845 Ms. Monsanto going with us to airport

0900 Checking in at airport - Locations of waste oil drums

Arawak ~~Aerowac~~ + Four Star East side

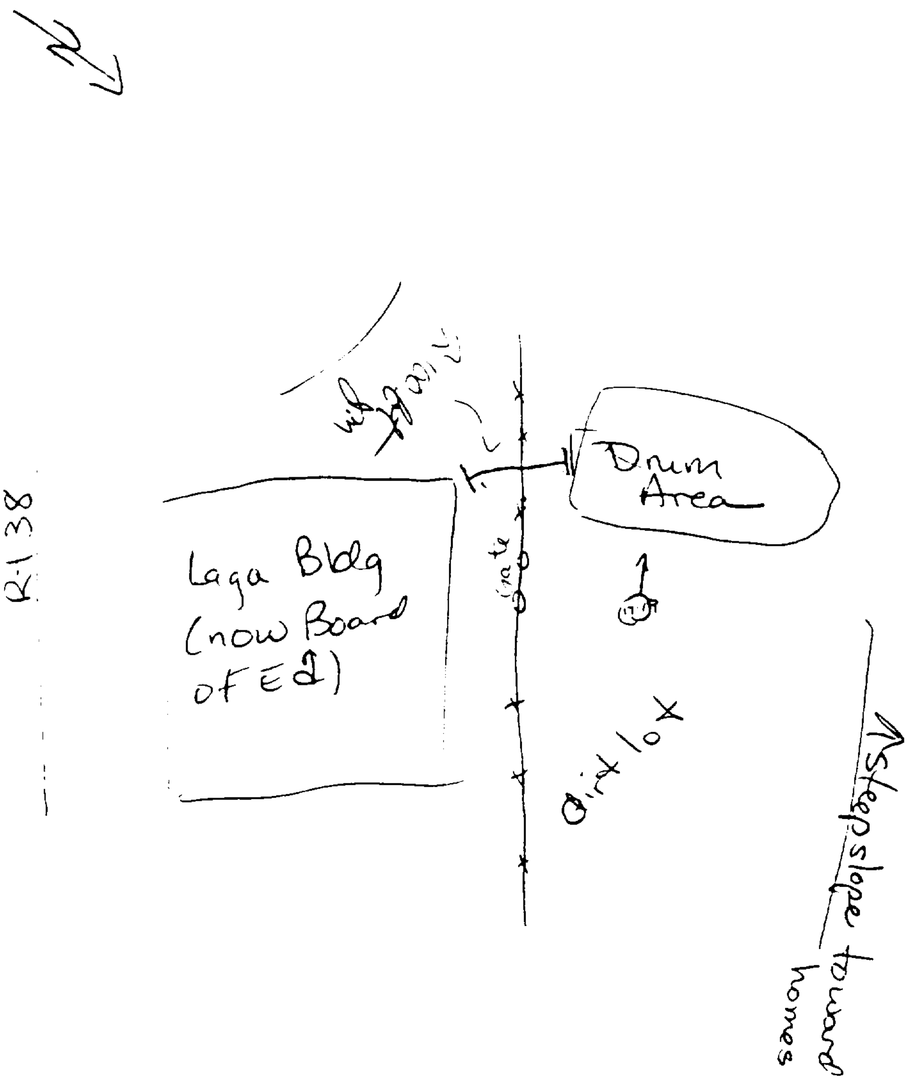
* Virgin Air + Tropic Aircraft Maintainance - North side

We are waiting for Mr. Reed to call here to tell us which locations to recon.

Airport personnel provided us with copies of airport map. Ms Monsanto prepared a letter of intro for NUS for the airport, referring also to an attached EPA letter of intro for Joe Mayo.

Diane Trube 2/16/89

Laga Bldg



R-138

D Grube 2/15/89
J M Mayo 2/23/89

TUT 002 0030

02-8901-
1505 Spoke
oils
+ remo
waste
are p
Undergr
last tes
1519 St
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many
No el
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No sta
Children
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Ms
0730
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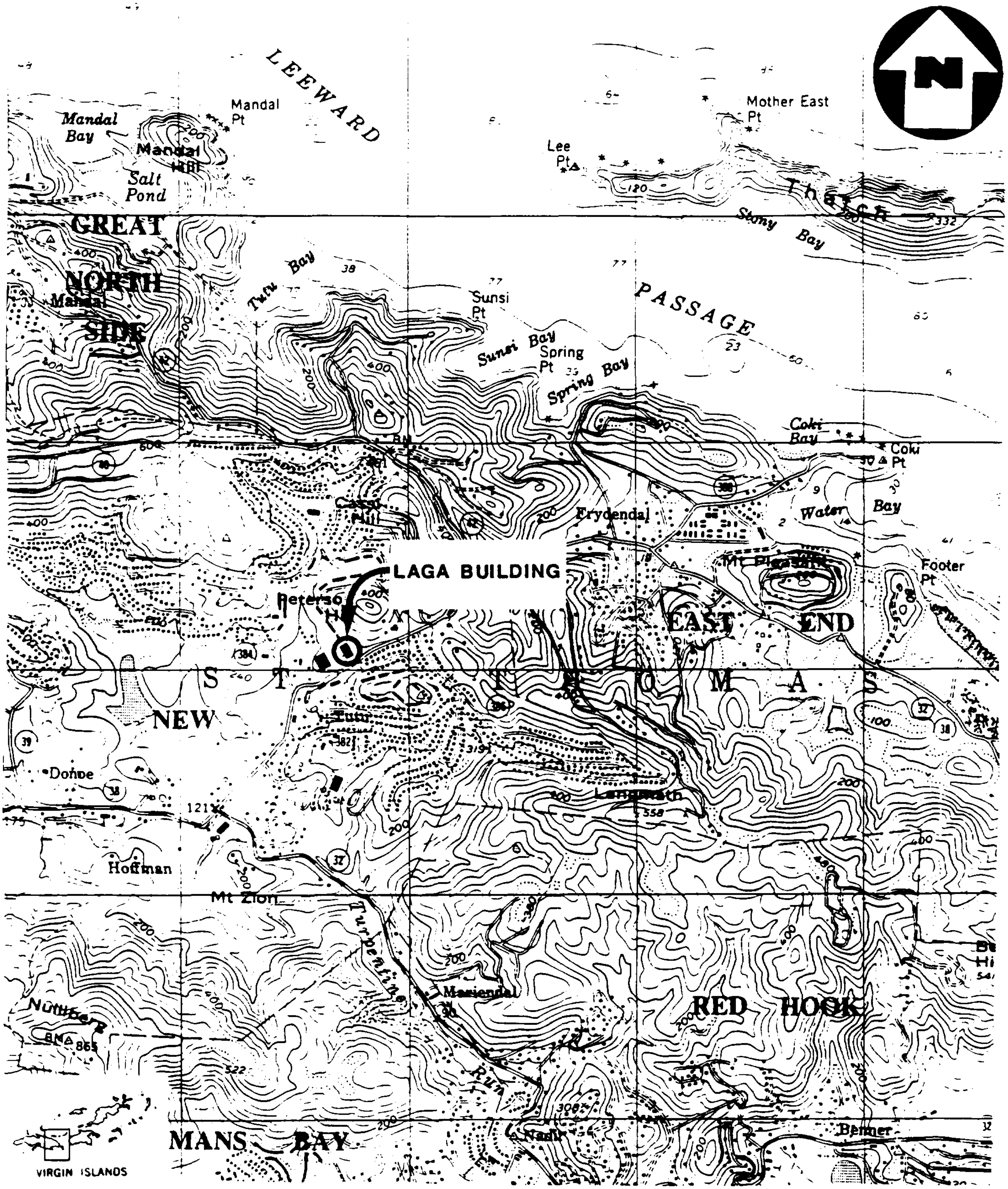
Diane

REFERENCE NO. 2



(QUAD) EASTERN ST. THOMAS, V.I.

LAGA BUILDING

ST. THOMAS, U.S. VIRGIN ISLANDS

SCALE: 1"= 2000'

REFERENCE NO. 3

Summary Appraisals of the Nation's Ground-Water Resources—Caribbean Region

By FERNANDO GÓMEZ-GÓMEZ and JAMES E. HEISEL

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-U

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1980

TABLE 4. – *Water budget, in cubic hectometers per year (hm^3/yr) and percent, for Puerto Rico (by*

	Puerto Rico													
	North Coast Province						South Province							
	West coast to Rio Grande de Arecibo		Rio Grande de Arecibo to Rio de La Plata		Rio de La Plata to Rio Espiritu Santo		Patillas to Ponce		Tallaboa to Guanica		Lajas Valley		West Coast province	
	hm^3/yr	Percent	hm^3/yr	Percent	hm^3/yr	Percent	hm^3/yr	Percent	hm^3/yr	Percent	hm^3/yr	Percent	hm^3/yr	Percent
Input														
Precipitation	1,680	73.0	1,280	55.4	670	53.2	410	50.6	60	25.5	100	72.8	360	29.0
Streamflow	620	27.0	1,030	44.6	590	46.8	320	39.5	175	74.5	4.4	3.2	880	71.0
Diversions	-	----	----	----	----	----	80	9.9	----	----	33	24.0	----	----
Output														
Evapotraspiration	1,410	61.3	804	34.8	300	23.8	430	53.1	60	25.5	120	87.3	270	21.8
Stream outflow	865	37.6	1,360	58.9	920	73.0	190	23.5	100	42.6	11	8.0	920	74.2
Ground-water loss to wetlands or sea	15	.7	86	3.7	20	1.6	20	2.5	15	6.4	6.3	4.6	40	3.2
Ground-water withdrawals[1]:														
Total	10	.4	60	2.6	20	1.6	170	21.0	60	25.5	.1	.1	10	.8
Industry	9	----	26	----	5	----	19	----	21	----	----	----	10	----
Irrigation	----	----	8	----	----	----	143	----	37	----	----	----	----	----
Public supply	1	----	26	----	15	----	8	----	2	----	----	----	----	----

[1] All ground water withdrawn was assumed to be for consumption since it is not available for other uses.

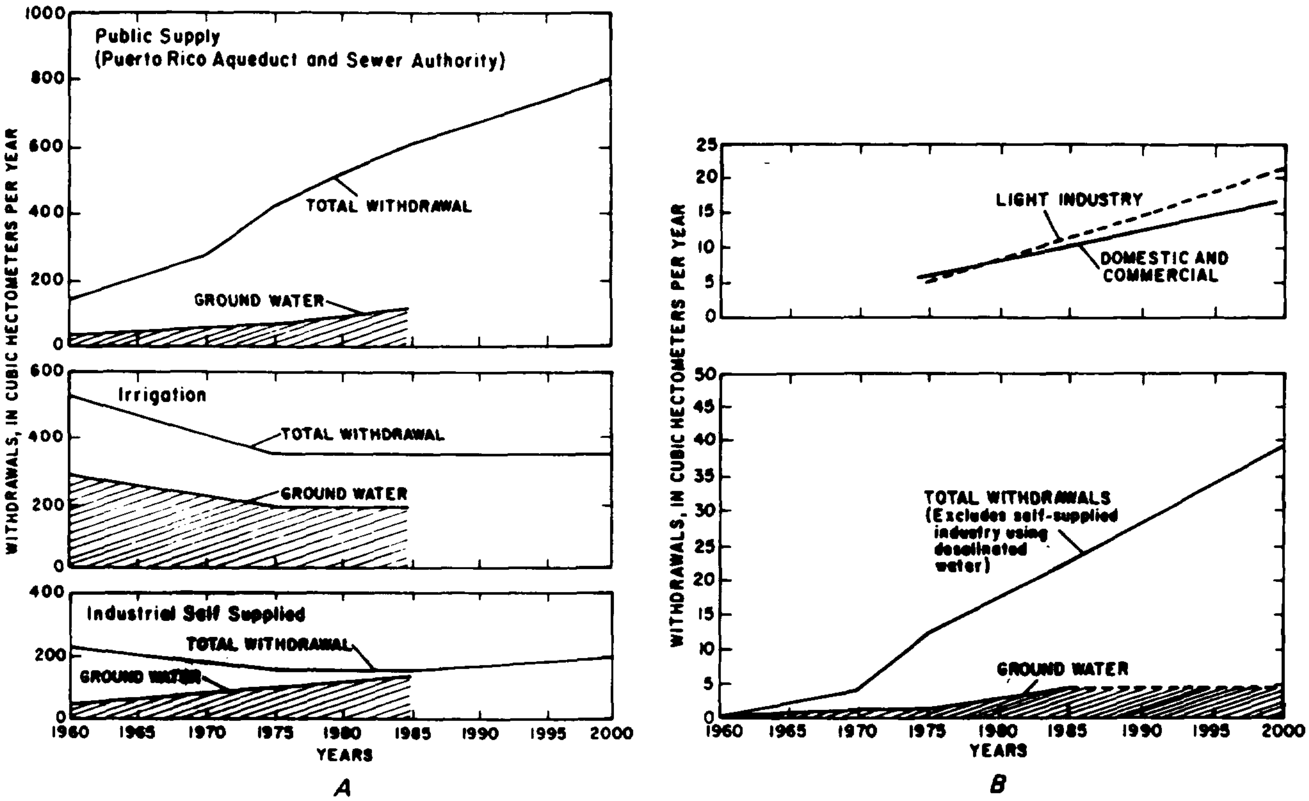


FIGURE 17. – Water-use estimates. *A*, For Puerto Rico; public-supply data provided by the Puerto Rico Aqueduct and Sewer Authority (modified from Morris, 1976). *B*, For the U.S. Virgin Islands.

TUT 002 0095

province) and its offshore islands (Vieques, Culebra, and Mona Islands) and for the U.S. Virgin Islands, 1975

Puerto Rico—Continued							
						Puerto Rico's offshore islands	
East Coast province		Interior province		Puerto Rico Island total		Vieques	
hm³/yr	Percent	hm³/yr	Percent	hm³/yr	Percent	hm³/yr	Percent
Input—Continued							
390	43.3	10,870	100	15,820	100	120	100
510	56.7	----	----	----	-	----	----
----	----	----	----	----	----	----	----
Output—Continued							
278	31.0	6,512	59.9	10,156	64.2	110	91.7
580	64.4	4,342	39.9	5,046	31.9	6	5.0
30	3.3	----	----	260	1.6	3.3	2.7
12	1.3	16	.2	358	2.3	.7	.6
10	----	4	----	104	----	----	----
----	----	----	----	188	----	----	----
2	----	12	----	66	----	----	----

Puerto Rico—Continued				U.S. Virgin Islands					
Puerto Rico's offshore islands									
Culebra		Mona		St. Croix		St. Thomas [4]		St. John	
hm³/yr	Percent	hm³/yr	Percent	hm³/yr	Percent	hm³/yr	Percent	hm³/yr	Percent
Input—Continued									
25	100	45	100	220	100	95	100	55	100
----	-	----	----	----	----	----	----	-	----
----	----	----	----	----	----	----	----	----	----
Output—Continued									
24.0	95.8	39.5	87.8	205	93.2	91	95.8	54	98.2
.7	2.8	0	0	8	3.6	2.6	2.7	.4	.7
.3	1.2	5.5	12.2	5.5	2.5	1.2	1.3	.6	1.1
.04	.2	0	0	1.5	.7	.2	.2	----	0
----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----

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PROBLEMS AFFECTING USE OF WATER RESOURCES

MANAGEMENT—PUERTO RICO

By adoption of Law No. 23 of January 1973, the Puerto Rico Department of Natural Resources (DNR) was charged with the responsibility for implementation of the operational phase of the public environmental policy of Puerto Rico. Law No. 23 also provides for centralization of operational functions and implementation of regulations that had previously been dispersed throughout many governmental agencies. In addition, the new Water Law, No. 136 of June 3, 1976, assigned to the Secretary of DNR the responsibility to plan and regulate the use of and to improve, conserve, and develop the waters of Puerto Rico. In acknowledgment of the need for a centralized information center, the new water law also stipulates that the Secretary be assisted by a staff that has representatives from the Planning Board, the Puerto Rico Industrial Development Company (PRIDCO), the Environmental Quality Board (EQB), the Puerto Rico Aqueduct and Sewer Authority (PRASA), the Puerto Rico Water Resources Authority (PRWRA), the Department of Agriculture (DOA), the Department of Health (DOH), the Department of Transportation and Public Works, and the University of Puerto Rico.

Although numerous government agencies (State and Federal) and institutions are involved in the use, planning, management, and investigation of the water resources, the DNR, EQB, U.S. Environmental Protection Agency (EPA), PRWRA, PRASA, Puerto Rico Sugar Corporation, and heavy water-use industries established by PRIDCO exert the greatest influence over the future of this resource. The responsibilities these agencies and public corporations have with respect to water resources are listed as follows:

DNR. The functions of this Puerto Rican agency were established by Laws No. 23 and No. 136, previously stated.

EQB. This is the Puerto Rico policy-making and regulatory agency responsible for the enhancement and protection of water quality; it is invested with quasijudicial powers to enforce its regulations. For purposes of the Federal Water Pollution Control program (Public Law 92-500) the Board is designated the State water-pollution control agency.

EPA. This is the Federal agency charged with administration of Public Law 92-500 aimed at restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters. Among the programs the agency administers are establishment of effluent limitations, administration of the National Pollutant Discharge Elimination System, and management and planning for public water-supply treatment-works construction.

PRWRA. The authority produces and distributes electrical energy and administers and operates the irrigation systems supported by releases from reservoirs and the hydroelectric power-generation network on the south coast and in northwestern Puerto Rico.

PRASA. The authority is charged with development, construction, operation, and maintenance of water and sewer systems and providing adequate water and sewer services and any other related services and facilities.

Puerto Rico Sugar Corporation. A public corporation created by legislative action in 1973 to consolidate the operations of the sugar industry (cultivation and refining). The corporation manages all the 11 mills on the island, 7 of which are government owned. The corporation also manages cane cultivation on 29,600 ha of both government-owned and leased land.

PRIDCO. This is the principal Puerto Rico governmental agency charged with the responsibility for the economic development of Puerto Rico. With its associated public corporation, the Government Development Bank, it devises methods to accelerate economic development, especially through industrial promotion and tourism. This agency must submit to DNR and EQB an environmental-impact statement for each industrial project it proposes to develop. The agency also cooperates closely with the Planning Board in preparing its plans and programs.

The new centralized form of management stipulated in Law No. 136 of June 3, 1976, is intended to improve institutional structures to aid optimum water-resources development.

MANAGEMENT—U.S. VIRGIN ISLANDS

In the U.S. Virgin Islands, the Department of Conservation and Cultural Affairs is charged with the administration and enforcement of all laws relating to water resources and water pollution, under Title 3, Chapter 22, of the Virgin Islands Code as of June 4, 1968. Other agencies involved with the management of the water resources are the Public Works Department, the Water and Power Authority, and the Virgin Islands Planning Office. The functions of each of these are outlined as follows:

Public Works Department. Under Title 30, Section 51, of the Virgin Islands Code, the Commissioner of Public Works is designated to supervise and control the construction, repair, maintenance, operation, and administration of the potable-water systems. The potable-water system was defined as "all fresh water stored or collected by the government, whether in catchments, dams, wells, or reservoirs, for public distribution."

Virgin Islands Water and Power Authority (WAPA). This authority was established in 1964 under Virgin Islands Code, Section 103, Title 30, for production and distribution of electrical energy and provision of potable water from its water-distillation systems. In the enabling legislation is a provision, 104e, for the transfer of the water-supply functions of the Public Works Department to WAPA at a date to be determined by law. The transfer of functions has not been acted upon by the legislature, and WAPA sells the distilled water to the Public Works Department.

U.S. Virgin Islands Planning Office. This office is designated as the government agency in charge of water-management planning; the agency is also entitled to appropriate funds received under the title 3 program.

The Public Works Department is by far the major ground-water user. Agriculture is almost nonexistent in the islands, and industries that depend heavily on water obtain their water from self-owned desalination plants. For these reasons, a lack of coordination among water users is not a major problem affecting ground-water resources in the Virgin Islands.

WATER RIGHTS

Water rights and laws regulating water use have been established by society to assure the minimum requirements of individuals and communities, to promote the beneficial development of water resources, and to respect legal access to water sources. These laws, which have been implemented to reduce friction between users, ironically become constraints if they are not adapted to the needs of a modern technological society.

On June 3, 1976, the Commonwealth Legislature approved the Law of Waters (Law No. 136) for Puerto Rico, which declared all waters within Puerto Rico the patrimony and wealth of the People of Puerto Rico; endowed the Secretary of Natural Resources with the power to plan and regulate the use, conservation, and development of the water resources and to implement the public policy and regulations related to the waters of Puerto Rico; and annulled two provisions of the Civil Code and the Law of Waters of March 12, 1903.

The 1903 water law was essentially that which had been in effect in Spain since 1879 and had been extended over Puerto Rico by order of the King in 1886. Article 16 of Law No. 136 recognized acquired rights that make beneficial and reasonable use of water and were in existence prior to June 3, 1976, including those concessions from the Spanish Crown.

Acquired rights under the old Spanish law were obtained according to the prior-appropriation doctrine. For example, "any landowner may utilize the pluvial and other waters flowing intermittently in public channels or along roads" (Art. 6, 176, 177); "after use for one year and a day, he establishes a temporary right that is superior to that of any subsequent user," on the principle that first in time is first in right (Art. 7); "after water has been used without interruption for 20 years, the appropriator acquires the right to continue the use indefinitely" (Art. 8). Similarly, as to "artesian wells, tunnels, or galleries," (major ground-water developments as opposed to "ordinary wells," which are defined (Art. 20) as those for which no other motive power than man is employed for raising the waters), the right of the person discovering and bringing the water to the surface is recognized "in perpetuity," as long as such development does not interfere with preexisting rights to public or private waters (Art. 23). These rights (surface- or ground-water appropriation) were also recognized for all individuals who had enjoyed the use of public waters for a period of 20 years (prior to 1886) even though no proper authorization had been obtained.

The order of preference in utilization stipulated by the previous law (Art. 160 of the Spanish Water Law) expressed the needs of the past century. First priority was given to water supply of towns, followed by water supply of railroads, irrigation, navigational canals, mills and other factories, ferry boats and floating bridges, and fishponds. The economic importance of water-using industries was not foreseen, and a low preference as to water concessions was stipulated. Duration of the concessions was limited to 99 years of town supplies (Art. 170) and all other uses but was "in perpetuity" for irrigation (Art. 188) and fishponds and also for industry, as long as effluents were not harmful to health or vegetation (Art. 220).

As of 1909 there were approximately 250 concessions in Puerto Rico that were originally granted by the Spanish Crown (Report of the Governor of Puerto Rico, 1909). The majority of these grants were given to landowners in the South Coast province for the irrigation of approximately 21,000 ha. The surface-water concessions included rights to flood-waters, spring and winter waters, or a definite daily flow.

An updated inventory of vested owners, diversion amounts, and land under irrigation is necessary to determine the degree to which these rights could affect a water-use and distribution plan.

In the Virgin Islands, all waters are in public ownership and are subject to appropriation for beneficial use as stipulated in Chapter 5, Title 12, of the Virgin Islands Code. Under this policy, vested rights are recognized prior to other appropriation. Vested rights may be nullified by the government of the Virgin Islands (Commissioner of Conservation and Cultural Affairs) when it is determined that the exercise of such rights would imperil health or welfare by endangering, impairing, or destroying available sources of water. Nevertheless, the occurrence of such circumstances is very remote, as most private installations are for domestic use and withdraw less than 2 m^3/d. An exception could be those individuals and companies that sell water obtained from wells. Under Section 153 of Title 12, appropriation permits are not required if pumpage is less than 2 m^3/d for beneficial use.

Under Chapter 3, Title 12, of the Virgin Islands Code, trees and other vegetation adjacent to watercourses are protected by law. This regulation protects the esthetic values of stream channels but results in a significant loss of ground water to evapotranspiration by the deep-rooted vegetation. A modification of this law would be necessary in order to exclude from such provision those watercourses that are used for public supplies or are in hydraulic connection with aquifers tapped for supply.

PRACTICES DETRIMENTAL TO GROUND-WATER QUALITY

LAND USE

Land use may affect recharge to an aquifer and the quality of its water. Although there has been no extensive evaluation of the effects of various land uses on aquifers in the Caribbean Region, data from scattered sources indicate that this could be a major problem in the near future.

Urbanization has taken over large portions of the recharge areas of aquifers in metropolitan San Juan, Ponce, and Mayagüez in Puerto Rico and throughout the Virgin Islands of St. Croix and St. Thomas. Unless artificial recharge is provided or withdrawals are reduced to compensate for the loss of recharge, the seawater-freshwater interface will move inland in most of these areas.

Aquifers in the Caribbean Region are threatened by pollution from domestic, municipal, and industrial sources. The most widespread source of pollution is probably sewage from cesspools, leaking sewage lines, and overloaded or improperly operating sewage plants. In Puerto Rico about 37 percent of the population is served by sewers, and in the U.S. Virgin Islands approximately 77 percent is served. In general, the only areas served by sewers are those within the urban limits of towns.

Industrial wastes have been discharged to aquifers through sinkholes and disposal wells or have entered aquifers from accidental spillage (D.G. Jordan, written commun., 1969; R.C. Vorhis, written commun., 1972). Of the 15 disposal wells known to exist in 1972, only 2 could be designated as deep injection wells, and the others could better be designated waste-disposal holes. All the known disposal holes were between 24 and 213 m deep. Wastes disposed in sinkholes and disposal holes include sewage, oil, neutralized acid, organic compounds, dyes, pickling liquors, pineapple-cannery wastes, and brewery wastes. Jordan (written commun., 1969) estimated there were at least 40 such disposal holes in Puerto Rico in 1969.

It has also been observed that unproductive wells are either abandoned without plugging or are not thoroughly sealed. As a result many are used as receptacles for wastes. The effects on water quality and the extent of damage this has caused in the Caribbean Region have not been assessed. In the Lajas Valley, Vazquez and Ortiz-Velez (1967) observed that a downward hydraulic gradient existed at various abandoned irrigation wells. These wells probably are serving as hydraulic connectors between perched water tables and the underlying regional water table. The effect of these "hydraulic connectors" on water quality is unknown.

Disposal of refuse in landfills poses another threat to aquifers in Puerto Rico. Most landfills were estalished after 1972 (fig. 18), and although migration of leachates may be slow at some sites, with time these will inevitably affect to some degree the local ground-water sources. In the U.S. Virgin Islands, landfills have been established near the coast on St. Croix and St. Thomas, and contamination of freshwater sources is not a threat. The landfill on St John, however, is located in the interior Guinea Gut Basin, where potential for ground-water development exists.

IRRIGATION PRACTICES

Irrigation of crops occurs primarily in southern Puerto Rico. The basic means of distributing water within cultivated lands is by furrows, although overhead sprinklers are used at some farms in the early months of sugarcane cultivation. Giusti (1971) estimated that approximately 30 percent of the applied water in the South Coast province (Coamo area) was recharged to the aquifer. Bennett (1976) indicated that the ground-water reservoir in the South Coast province is "vertically oriented," in that local recharge and discharge tend to be high in any given locality relative to lateral ground-water flow. In areas where irrigation water is derived from wells, recycling of the irrigation water will result in an increase in the dissolved-solids concentration of the ground water.

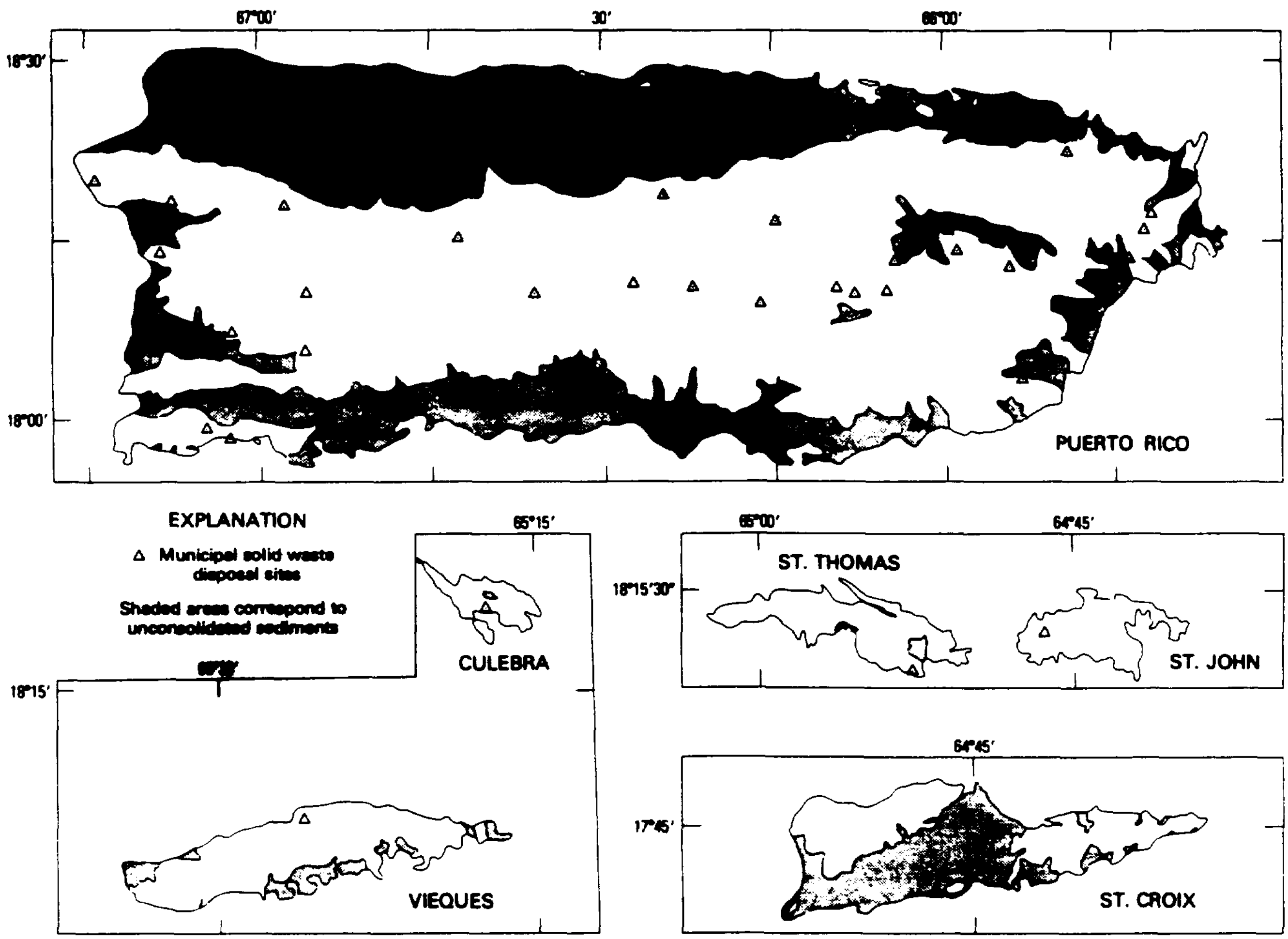

FIGURE 18. – Solid-waste disposal sites in the Caribbean Region.

During the mid-1960's, drought nearly eliminated surface-water supplies that were used in the South Coast province area for irrigation, and ground-water production was increased to make up the deficit. By 1968, after 3 years of increased pumpage, the ground water in storage was drastically depleted. An estimated 1,000 hm^3 of the 1,500 hm^3 in available storage had been withdrawn. The depletion in storage was accompanied by a decline in ground-water levels to below sea level over large areas (pl. 1A). The chloride concentration in the ground water increased slightly in the more severely depleted areas, but major seawater intrusion did not occur, apparently because of a slight ground-water mound in the coastal areas and the lower hydraulic conductivity of the coastal part of the aquifer. Heavy rains later in 1968 recharged the aquifer, but it has never recovered to early 1960 levels. A few areas where ground-water levels were below sea level still persisted in 1976 (pl. 1B), but there has been no significant increase in chloride concentration indicative of seawater intrusion.

OPTIMIZATION OF USE OF WATER RESOURCES

In general, until recent years the effort devoted to optimizing the use of water resources of the Caribbean Region has been minimal. Within Puerto Rico this lack of effort may have been due to the relative abundance of freshwater in relation to demand in most areas. In the U.S. Virgin Islands the poor quality of the ground water and the knowledge that the limited freshwater resources could not meet the demand led to reliance on seawater-desalination plants.

Two major approaches are available for optimizing the use of water resources. These are conjunctive use of surface- and ground-water sources and water conservation. The potential for application of such measures in the Caribbean Region is discussed separately.

CONJUNCTIVE USE OF SURFACE- AND GROUND-WATER SOURCES

The greatest potential for conjunctive use of surface- and ground-water sources in the Caribbean Region may be on the island of Puerto Rico, where both sources are relatively plentiful. This use may be achieved by reservoir management, augmenting natural recharge, ground-water salvage, ground-water mining, and use of seawater.

RESERVOIR MANAGEMENT

Agriculture is the largest single water user in the South Coast province. The estimated ground-water withdrawal for irrigation (180 hm^3/yr) constitutes almost 80 percent of the total pumpage. Therefore, the most productive efforts to solve the "water shortage" may involve an improvement of irrigation practices. To some degree, the irrigation efficiency likely could be improved by coordinating the activities of PRWRA with those of the Puerto Rico Sugar Corporation and by changing the priority of the functions of reservoirs serving the south coast.

Under present operating conditions, reservoirs are maintained at the highest stage possible for hydroelectric generation, thus reducing the runoff-capture potential. With the available reservoirs and the implementation of a more efficient water-management system, more water could be made available for irrigation. The hydroelectric-energy loss could possibly be compensated for by thermoelectric generation through burning of bagasse, the plant residue left after the juice has been extracted from sugar cane. During the 1973 fiscal year, PRWRA bought from the sugar mills (which operate from about December to April) 826 million kilowatt-hours of energy generated through burning of bagasse (Puerto Rico Planning Board, 1976). Hydroelectric generation was only about 97.5 million kilowatt-hours during the 1973 fiscal year, partly by north-coast hydroelectric plants.

AUGMENTING NATURAL RECHARGE

Although aquifers receive recharge by natural means, it may be practical in some areas to increase this amount artificially. Within urbanized centers the loss of rainfall infiltration capacity may be compensated for by construction of infiltration ponds, which may also serve for recreation. Flow into the ponds could be supplied from urban runoff or by pumpage from nearby streams. These infiltration ponds could be situated in the upland coastal areas, where coarse sediments (sand and gravel) predominate and thickness of unsaturated material and therefore storage volume is greatest. Areas of Puerto Rico that could benefit most from such modifications are those zones where urban development has decreased the infiltration capacity of aquifers (essentially the San Juan metropolitan area and Ponce). In the San Juan metropolitan area, possible sites would be the San Sebastian outcrop and areas between the haystack hills (mogotes). At Ponce the most favorable area may be near the foothills, where depth to the water table is between 15 and 20 m. Infiltration induced by this method may make it feasible to establish and continuously operate public-supply wells within city limits, thus reducing dependence on interbasin water transfer. These well fields would also be invaluable in the event of hurricane damage to centralized water-purification and distribution systems. If the recharged water is destined for domestic use, measures would have to be taken to avoid contamination with toxic substances, which may even though ground-water development may be minimal in some areas. Within aquifers for which preliminary areal models have been constructed, monitoring networks should be maintained to determine whether or not conditions follow those predicted. If significant deviation is detected, the cause can be evaluated and remedial measures can be taken as appropriate.

Among the most important needs for improving the knowledge about aquifers in the Caribbean Region are listed as follows:

1. Better definition of conditions within the two major aquifers: knowledge needed about the following:
   a. Hydrologic relationship between bedrock and alluvium in the South Coast province of Puerto Rico and stream-aquifer interrelationships
   b. Extent of the artesian system in the North Coast province of Puerto Rico
   c. Ground-water flow within the North Coast province west of Arecibo
2. Areal studies made concerning the following:
   a. Ground-water flow system in Lajas Valley
   b. Water-balance for unstudied aquifers in the East Coast, West Coast, and Interior provinces
   c. Water-table monitoring throughout Puerto Rico, the offshore islands, and U.S Virgin Islands
   d. Qualitative and quantitive assessment of saline-water reserves of St. Croix and in the coastal aquifers of Puerto Rico
   e. Chemical-quality data to assess the extent of contamination and seawater intrusion

Besides these basic needs, research is also lacking on evapotranspiration and its relationship to soils and vegetation under the climatic conditions in the Caribbean Region. At present it is unknown if under long-term conditions thick vegetation and plant debris aid ground-water recharge by reducing runoff, enhancing infiltration, and reducing direct evaporation of rainfall or whether they use more water from the soil through transpiration. Archaeological sites, surface features, and historical notes indicate that water was much more plentiful at now parched areas in Puerto Rico's offshore islands and in the U.S. Virgin Islands.

SUMMARY

The Caribbean Region consists of the Commonwealth of Puerto Rico (8,990 km²) and the U.S. Virgin Islands (350 km²). It is among the most densely populated areas in the world, with an overall population of approximately 3,200,000 people. Within the past 25 years the islands have undergone a rapid transformation from an agriculturally based economy to one dependent on industrial development, tourism, and related services.

Water is among the most abundant and valuable natural resources in the Caribbean Region, but its availability varies significantly in both space and time. Rainfall contributes an annual average of 1,800 mm in Puerto Rico and 1,060 mm in the U.S. Virgin Islands. Of this amount, 1,130 mm (or 64 percent) in Puerto Rico and 990 mm (or 93 percent) in the U.S. Virgin Islands is lost to evapotranspiration. The water available for use in liquid form amounts to about 5,400 hm^3/yr in Puerto Rico and 24 hm^3/yr in the U.S. Virgin Islands. These amounts would theoretically satisfy the total water needs of both areas, which are about 919 hm^3/yr and 20 hm^3/yr, respectively (1975). In reality, most of this flow is contributed by intensive rainstorms and is lost to the ocean as runoff. Potential for retaining a large part of this flow exists on the island of Puerto Rico, but presently the total usable reservoir storage capacity is only about 230 hm^3. In the U.S. Virgin Islands, small dams and ponds have a storage capacity of about 2 hm^3.

Aquifers constitute a valuable water resource in the Caribbean Region. In Puerto Rico, ground-water withdrawals provide about 38 percent of the total water requirements, whereas in the U.S. Virgin Islands, they provide 10 percent. Excluding desalinated-water supplies in the U.S. Virgin Islands, ground water provides about 72 percent of the freshwater used. Of the 350 hm^3/yr ground-water withdrawal in Puerto Rico, irrigation uses 53 percent; industry, 29 percent; and public water supply, 18 percent. In the U.S. Virgin Islands, ground water is withdrawn about equally from private wells and public water-supply wells. Based on past trends and future economic outlook in the region, estimates are that by 1985 ground-water pumpage in Puerto Rico will be about 426 hm^3/yr and in the U.S. Virgin Islands, about 4.5 hm^3/yr. This withdrawal is the estimated maximum sustained yield of all aquifers in the U.S. Virgin Islands under natural-recharge conditions.

Most large-scale ground-water developments in Puerto Rico are in the North Coast and South Coast provinces. The North Coast province contains the island's most productive aquifer, which has been undergoing rapid development for industrial water supply since 1968, when a major artesian system was tapped. The extent of this artesian system is unknown, but it has been tapped within the lower part of the Cibao Formation (Montebello Limestone Member) and in the upper part of the Lares Limestone. The South Coast province aquifer consists of deep alluvial deposits. It has been extensively developed for irrigation of sugarcane and for industrial water supply. Unlike the north-coast aquifer system, which has large untapped resources, this aquifer will support only minor future development if effective management practices are not introduced.

In the U.S. Virgin Islands, the most extensive aquifer is the fragmented igneous rock. It contributes little water to wells, but weighed against the costs of desalinated water, its exploitation is feasible for supplementing domestic water needs. The most productive aquifer consists of marl and alluvium deposits in central St. Croix. Although this aquifer contributes less than 6.3 L/s to individual wells, it yields about 0.86 hm^3/yr to public water-supply wells and about 0.54 hm^3/yr to private wells. Future development of this aquifer could probably produce an additional 1.0 hm^3/yr.

Ground-water resources will continue to play an important role in the future development of both Puerto Rico and the U.S. Virgin Islands. In order to meet future needs, it is necessary that hydrologic principles be effectively applied in managing the total water resource.

Optimization of the water resources can be accomplished through conjunctive use of surface and ground waters and through conservation practices. Optimal use may involve artificial recharge, ground-water salvage, saline- or fresh-ground-water mining, use of seawater, waste-water reuse, and use of underground space for temporary storage of wastes, which could otherwise contaminate valuable water supplies.

Efficient development of the water resources within a basin also requires a thorough knowledge of the relationship that exists between surface and subsurface water. Among the most urgent needs in the Caribbean Region is a computerized data bank containing information on ground-water withdrawal, consumptive use, surface diversions, and such other flows necessary for water-budget estimates. These data can be used with the available knowledge of the aquifers to construct digital or analog models. Such an approach would serve to point out areas where new information is needed, aid in assigning investigation priorities, and contribute to effective management of the total water resource.

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REFERENCE NO. 4

THE NEW YORK ACADEMY OF SCIENCES

SCIENTIFIC SURVEY

OF

PORTO RICO and the VIRGIN ISLANDS

VOLUME [illegible]

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NEW YORK
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The nature of the shorter-period pressure variations in relation to the weather and the general circulation are discussed below under The Upper Air and General Circulation, etc.

PRECIPITATION

Rain is the climatic element of most practical concern in the islands because it is often insufficient to mature sugar cane in one or two seasons; a drought of six or nine consecutive months occurs every decade or so, causing much hardship to the townspeople and small native farmers as well as to sugar and cotton estates and cattle ranches.

Since early in the nineteenth century rainfall in the Virgin Islands has been measured in a unique unit of depth, called the "line". The reason for the adoption of this measure is not known. It is an old English measure, in which 1 inch = 8 lines (= 25.40 millimeters). In Denmark they once used the Paris measure of 12 *Linien* = 1 *Tomme* (Paris inch) = 27.07 *millimeters* = 1.0658 *inches*. 1 *Paris line* = 2.256 mm = .0888 inch = 1/144 foot, whereas the *Danish West Indian (or English) line* = 3.175 mm = 1/8 inch. It is conceivable that as many of the residents were British this "line" was adopted locally from using English rain-measuring glasses or sticks graduated in eighths of an inch. Since the American occupation inches have been used.

Accuracy of the Measurements

The accuracy of rainfall measurements is a difficult problem in general, and is especially serious in tropical countries.* We have already referred to the lack of standards in the instruments and observation procedures at Virgin Islands stations, and here we must add that where the rainfalls are frequently light and the monthly and annual totals are small the errors of measurement are greatest on a percentual basis. The common practice of measuring the catch only once each 24 hours allows some water to evaporate from the gage before it is read, particularly in a warm windy climate. The use of a funnel is common and tends to cut down the evaporation. Where most of the rain falls at night, it is better to read the gage in the morning, and where it falls more in the day an evening observation hour is preferable; two readings a day would be still better, and best of all the use of recording gages or the habit of reading the gage after each shower. It has been shown that a considerable difference in a given

* For a comprehensive discussion see Brooks, C. F., Need for universal standards for measuring precipitation, snowfall, and snowcover. Trans. Meet. Int. Comm. Snow and Glaciers, Int. Assoc. Hydrol. Bull. **23**: pp. 1-52. Riga. 1938.

month's total may result at the same spot between a gage read each morning and a gage read each evening. But it is difficult to estimate the magnitude of this effect in the Virgin Islands except to say that the results from gages read only in the morning are probably somewhat lower than they would be if read only in the evening. The hours of observation at the various stations are not stated or known in many cases and at some stations they were changed from time to time.

Rain gages of different diameter and different height of orifice above the ground do not give comparable catches, but it is believed nearly all the gages used in the Virgin Islands since 1870 have been of the standard 8-inch diameter with rim about 3 feet high (cf. appendix A). The wind eddying around the gage may keep away some of the rain that should go in the gage. In windy places the catch may average 20 per cent too low from this cause, but we judge from tests made elsewhere with shielded gages that this error in the Virgin Islands probably does not average over 10 per cent (i.e., readings are 10 per cent too low on average from the wind effect alone). If we may assume that this error applies roughly equally to all the gages in the Caribbean region, it may be overlooked in practical comparisons. However, the error due to wind effect increases as the wind velocity increases and therefore the catch during severe storms, hurricanes, is apt to be more than 10 per cent too low. High wind sometimes blows the gage over resulting in loss of a large catch of rain. Occasionally during heavy rains the gage may overflow before it is read. Considering all these sources of error, it is evident that on the average the recorded rainfalls are systematically lower than the true rainfalls.

In addition there may be mistakes and falsifications on the part of observers, which are unsystematic in their effect on the results and largely hidden in the averages. An inspection of the daily entries and the reputation of the observer are the only bases for accepting observations as genuine, where the stations are not under regular inspection of an efficient national weather service. We have not found any record of inspections by the Danish government, and the U. S. Weather Bureau inspections have been too infrequent to be effective.

General Distribution

From APPENDIX TABLES 2 and 3 we note that the *mean annual* rainfall differs considerably at the various stations, ranging between about 35 and 70 inches. The *absolute range* between driest and rainiest years at these stations is not much larger, however, the extreme annual totals ranging from about 25 inches to nearly 95 inches (APPENDIX TABLE 1). If we had

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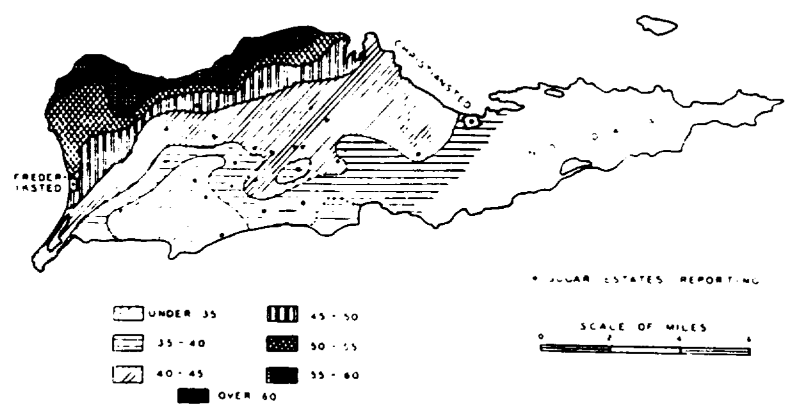

FIGURE 2. Rainfall map of St. Croix, 1921–30. (From Shaw, 1932.)

records from eastern St. Croix and from the mountain tops, these extremes would be greater, probably reaching from 15 to more than 100 inches. A rainfall map of most of St. Croix is shown in FIGURE 2.

The *seasonal distribution* generally shows two maxima, a smaller one in May or June and a larger one in October. The winter minimum is much more pronounced than the summer one. The lowest monthly amounts on record indicate that severe drought conditions can occur in almost any month; even October has sometimes had less than 2 or 3 inches at most stations (see TEXT TABLE 4). Rose points out that the middle and western sections of St. Croix have somewhat opposite tendencies in departures of rainfall from normal — from 1903 to 1908 the middle was drier than the west, but from 1909 to 1915 the middle was wetter, and after 1915 the middle was again the drier. This may possibly be due to a quasi-cyclic shift in the relative frequency of winds from slightly north and slightly south of east, which would be accompanied by changes in the average temperatures and humidities of the trade winds as well as contrasted orographic effects.

Forests and Rainfall

E. Taylor in his "Leaflets from the Danish West Indies" (London, 1888: 42) suggests that St. Croix formerly had a greater rainfall because an early book on the islands by Oldendorp (1777) reported a greater amount of forest growth than is now found. Although a change of climate is possible, the present condition is better explained by the known destruction of the forest by the inhabitants. TEXT TABLE 5 shows no *permanent* change in the rainfall of St. Croix since 1852. St. John and Tortola have the most forests at present because they are too mountainous for economi-

TEXT TABLE 4

FREQUENCY OF MONTHLY RAINFALL TOTALS GREATER THAN SPECIFIED AMOUNTS, ST. CROIX

Average of 3 stations for 63 years, 1852–1914
(From Ravn)

Month	Number of years with rainfall		
	Over 20 lines (2.50 in.)	Over 40 lines (5.00 in.)	Over 60 lines (7.50 in.)
January	25	2	–
February	13	1	–
March	13	1	–
April	33	5	1
May	37	24	11
June	38	19	9
July	44	12	3
August	50	22	8
September	57	32	10
October	60	38	18
November	54	30	13
December	39	11	4

cal sugar-cane culture, though at one time both were under considerable cultivation. There is no reason to believe that either St. John or Tortola receive much more rain than St. Thomas or St. Croix merely because they are now more forested. Indeed, the rainfall observations (cf. APPENDIX TABLES 2–6) lend no support to that notion.

Orographic Effects

The rainfall increases with elevation on all the islands, as residents and travelers can readily observe and as one would expect. But rain-gage stations are lacking at high elevations, except Pearl, Mafolie, Liliendal, Wintberg, and Dorothea. Shaw's rainfall map (FIGURE 2) based on rainfall records (see APPENDIX TABLE 7) of sugar estates on St. Croix leaves no doubt that even moderate elevations are better watered. Yet the *rate* of increase of rainfall with elevation does not here seem to be as large as in the parts of Porto Rico where the mountains rise steeply to 3000 feet or more directly in the path of the prevailing winds. Rose suggests that the rainfall of the islands is not as great as one would expect from the topography because the winds blow mostly parallel to the mountain trends. The reason

TEXT TABLE 5

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Text Table 5

Average Rainfall for Each 10-Year Period, 1852–1911 (in inches)*

"St. Croix, Virgin Islands" = (Christiansted's Fort + Kings Hill* + Frederiksted's Fort)/3
(From L. Smith)

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1852–61	1.90	1.60	1.68	3.12	5.53	3.76	3.51	4.92	7.26	8.16	4.43	2.68	48.61
1862–71	2.11	1.65	2.36	2.06	3.35	3.86	3.10	4.18	5.26	7.80	4.07	3.40	43.00
1872–81†	2.85	1.33	1.57	1.43	4.16	4.48	3.37	4.25	5.28	5.11	6.61	2.33	44.86*
1882–91†	2.78	2.10	1.15	3.27	3.22	3.97	4.06	4.62	4.92	7.50	5.92	3.67	47.50*
1892–1901	2.16	1.45	1.32	2.15	6.33	4.60	5.42	4.58	6.81	5.47	5.46	4.08	49.87
1902–11	2.52	2.31	1.12	2.52	4.26	3.40	2.47	5.40	6.92	4.68	4.96	5.05	47.62
Total	14.33	11.45	10.21	15.57	26.90	24.08	21.95	28.11	36.45	39.38	31.45	21.23	281.35
Average for 60 years (1852–1911)	2.38	1.91	1.70	2.60	4.47	4.01	3.65	4.70	6.07	6.56	5.23	3.53	46.89

* These are from the same observations used in TEXT TABLES 19 to 22, here converted to inches from the "lines" in which rainfall was measured (8 lines = 1 inch). From "Reports of the Virgin Islands Experiment Station, 1911".

† Kings Hill was omitted from the averages for Oct. 1878 to Oct. 1888, inclusive.

for this may also be contained in some observations of the writer: on several occasions during his stay at St. Thomas in June, 1939 when the summit of the island (1800 feet) was visited, he noticed that any large cumulonimbus cloud that had been initiated by forced ascent of the wind over the island would lean to the leeward so that most of the rain falling from it would fall on the ocean surface somewhat to the lee of the island. In other words the orographic influence on the rainfall was not fully enjoyed by the island itself owing to its small size and narrow form. This observation is confirmed (oral communication) by Sergeant Davidovic, the Aerographer stationed at the U. S. Marine Corps Fleet Air Base on St. Thomas in 1939.

In general the annual rainfall does not seem to increase more than about 10 inches between sea level and 1000 feet elevation, but some of the lower stations have as much rain as places high up on the leeward slopes or in high protected valleys (compare Adrian and Cinnamon Bay, or Barracks and Liliendal, *in the same years*) (APPENDIX TABLE 2). In generally rainy years or months the rainfall differences between stations of different elevation are much greater than in generally dry seasons.

At the U. S. Marine Corps station on Lindbergh Bay three rain gages have been set a few hundred yards apart in a line from the water to the foot of the mountain. These gages show a decided increase in rainfall (APPENDIX TABLE 12) as the mountain is approached, although they are all about at the same elevation. This demonstrates how sensitive the rain-producing process is to the topography. For this reason, within the hilly town of Charlotte Amalie, or of Christiansted, the average annual rainfall probably varies considerably (up to 5 inches?) from block to block; hence records taken at different spots in such a town cannot justifiably be combined as if from one station. Likewise different parcels of an estate often have very different rainfall (e.g., Eden, Emmaus, Caroline; Adrian, Susannaberg).

We have not attempted to construct rainfall charts of St. Thomas and St. John owing to the non-homogeneity of the records. Shaw's map of St. Croix (FIGURE 2) is based on a homogeneous though short (10 years) series of 26 records from the flatter parts of the island, which should give a reliable and consistent pattern.

Year to Year Variation

The variability of the mean annual rainfall is of prime economic consequence because in over half the years the actual rainfall is well below the *normal* rainfall,* which is just about sufficient for an annual yield of sugar

* It is characteristic of the frequency distribution of either daily, monthly or annual rainfalls, that the most frequent value (*mode*) is generally much less than the average, and in some cases the zero value is most frequent.

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cane, long the chief crop, and the cane yield suffers accordingly (Dr. Shaw discusses this problem with respect to St. Croix, in paragraphs quoted below). Du Tertre and Oldendorp mention great droughts in 1661 and 1753; the poor crops of 1841, 1864, 1869, 1872 to 1877, 1891, 1892, 1899, 1904, 1923 to 1924 were due to low rainfall (see TEXT TABLES 20 to 23). Contrary to the impression of many residents and travelers, there is no real evidence that the rainfall is slowly and steadily decreasing from century to century (see Forests and Rainfall). The question of cyclic variations has not been scientifically studied here, but results elsewhere generally show long quasi-periodic fluctuations of considerable amplitude in the rainfall. These undoubtedly exist here too but the records are not long enough to reveal any but the shortest "cycles". The average rainfall is so near the critical limit for sugar cane that even the small short-period fluctuations are important. It does not contribute much either to fundamental understanding of the variations nor to practical precautionary measures for the farmers merely to describe the rainfall curve as quasi-periodic. All attempts to forecast the fluctuations by means of extrapolating "cycles" derived from analysis of past records have been failures. Scientific bases for long-range forecasting are being sought in many directions but the solutions offered do not yet give results of practical value and general applicability, however promising the method or enthusiastic the advocates. The most successful results so far are for certain special conditions and places, none of which have been in the West Indies.

Diurnal Variation

The diurnal distribution of the rainfall, as at San Juan, shows a much greater amount of rain by day than by night, judging from Mr. A. Wallöe's observations at Charlotte Amalie, published in the "Sct. Thomae Tidende", 1888. He gives the following figures.

TEXT TABLE 6

NIGHT AND DAY RAINFALL, CHARLOTTE AMALIE, 1888*

Month (1888)	Total	By day	By night
July	38.4	26.8	11.6
August	77.2	55.9	21.3
September	69.0	44.6	24.4

* In lines; 8 lines = 1 inch.

The frequency of rain is no doubt also greater by day but the contrast is probably not so pronounced because the intensity of the day showers is heavier.

At sea the rainfall frequency is a maximum at 6 A.M. with a secondary maximum at about 10 P.M. The amplitude of this daily variation is presumably smaller than the one observed over the islands, where the maximum comes in the afternoon. It is very likely that the sea maximum at 6 A.M. affects the islands, or at least their shoreward margins, causing a secondary maximum at that hour. No hourly observations are available from the islands but the sunrise shower seems to be recognized by the residents as a more or less regular phenomenon. The daily double period in the rainfall is of course reflected in the cloudiness (TEXT TABLE 17) and in the frequency of thunderstorms.

Intensity and Frequency

The rainfall in this low latitude and oceanic situation is entirely of the shower type, and therefore it is of great practical importance to know how frequently showers occur, how long they last, how much rain falls per shower, and what are the average and maximum rates of fall over short periods of time. Unfortunately systematic observations using recording rain gages were begun in the islands only very recently, so we are forced to infer much from the usual rainfall observations which give only monthly totals and numbers of rainy days. The average rainfall per rain day (APPENDIX TABLES 10 and 12; FIGURE 10) indicates some important characteristics.

The "showers" of the winter and spring seasons are characteristically brief and light, often mere sprinkles, from cumulus clouds of small or moderate size and spaced by large intervals of blue sky (cf. TEXT TABLE 9). Sometimes "norther" effects cause a low overcast cloud deck with drizzling rain punctuated by occasional heavier showers, which condition may persist a day or two. However, very heavy rains up to 2 or 3 inches in a day have fallen even in the driest months. In the "rainy season", from May to November, heavier and more enduring showers, with squalls or thunder and lightning at times, are to be expected much more often; at least one shower of some sort then falls almost every day. Heavy rains lasting as much as 6 or 8 hours, even with brief intermissions, are normally very rare, but passage of a hurricane within 50 or 100 miles can cause enormous rainfall totals (over 10 inches) in a day or two from virtually continuous downpours. The high wind during hurricane weather adds greatly to the destructive effect of the rain.

Some significant deductions can be made from the results of the recording rain gages, in spite of the short period they have been in use.

At the Marine Barracks of Bourne Field on St. Thomas a recording rain

gage has been operated since I
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to infer to what extent this
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Any practical interpretatio
Virgin Islands, especially on
that a large proportion of the r
(see TEXT TABLES 9 and 10).
rain gages and they augment
significance for crop growth

gage has been operated since 1935. An analysis of the results (APPENDIX TABLE 12 and FIGURE 10) indicates that the average rainfall per rain day and also per rain hour for each month is proportional to the greatest rainfall during any 24 hours of the corresponding months. This is a very interesting relation because in the absence of recording rain gages at other places we can assume that the "greatest rainfall in 24 hours", which is tabulated by the U. S. Weather Bureau for all its stations, gives a rough basis for estimating the *average* intensity of rainfall per day and per hour.

Since February 1940, the Soil Conservation Service has been tabulating rainfall rates monthly from recording gages at Anna's Hope and Jolly Hill estates on St. Croix. An abstract of the results appears in TEXT TABLES 7 and 8. Although the period of observation is too short to give any definite averages or extremes likely to occur, the figures are already significant. A study of the tables reveals a closer correlation by months between the total rainfall and the maximum intensities than between the total rainfall and the average intensities. This is not surprising because one or two intense showers probably have more effect on the monthly totals than the more numerous lighter showers. There is nevertheless some tendency for the average intensity to be greater in the rainier months than in the drier months. It will be noted, however, that the average intensity in the spring months appears to be as high as or higher than in the autumn months, whereas the total rainfall is usually much greater in the autumn than in the spring. This is a curious fact which we have already suspected from the greater frequency of hail in the late spring and early summer than in the late summer and autumn. Over a period of many years the average intensity of rainfall will actually be greatest in the autumn or late summer because of hurricanes. The important conclusion is that, if hurricanes are excluded, winter and spring showers probably have as great *average* intensity as the autumn rains, but the ***maximum rates*** of rainfall in short periods, as shown in TEXT TABLES 7 and 8, are generally two or three times greater in the "rainy season" than in the winter and spring. It is impossible to infer to what extent this conclusion is justified for all parts of the islands, as the topography may greatly affect the rainfall intensities as well as the totals, but the Bourne Field results (APPENDIX TABLE 12) seem to show similar features to those of Anna's Hope and Jolly Hill estates.

Any practical interpretation of the average rainfalls reported in the Virgin Islands, especially on St. Croix, should take into account the fact that a large proportion of the rain falls in light showers and brief sprinkles (see TEXT TABLES 9 and 10). Many of these light rains are measured in the rain gages and they augment the total rainfall out of proportion to their significance for crop growth and for vegetation because they barely wet

Text Table 7

Rainfall Intensities Measured at
Station SCS No. 18 F. S. A., Jolly Hill Estate, St. Croix, V. I.
(From U. S. Soil Conservation Service)

Month	Total Rainfall, inches	Total Duration, hours*	Average Intensity, in./hr.	Maximum Intensity for Different Intervals				
				5-min.	10-min.	20-min.	60-min.	120-min.
1940								
February	0.90	15.02	0.06	1.00	0.75	0.35	0.13	–
March	0.52	1.92	0.27	–	–	–	–	–
April	1.97	6.42	0.31	2.00	1.50	0.80	0.50	0.28
May	7.10	30.00	0.24	3.50	2.00	1.40	1.10	0.70
June	3.05	8.10	0.38	2.00	1.50	0.90	0.55	0.30
July	2.14	5.07	0.42	5.00	3.50	2.80	1.30	0.65
August	3.05	12.37	0.25	3.00	1.75	0.95	0.30	0.15
September	4.19	12.65	0.33	7.00	5.00	3.40	1.40	0.75
October	7.47	22.45	0.33	4.50	2.75	2.80	1.70	1.05
November	7.15	25.37	0.28	5.00	3.50	2.40	1.45	0.90
December	3.47	20.25	0.17	3.50	2.25	1.60	0.85	0.45
1941								
January	1.97	5.02	0.39	2.00	1.75	0.90	0.40	0.20
February	0.21	0.80	0.26	–	–	–	–	–
March	1.33	1.13	1.17	1.50	1.00	0.50	0.18	–
April	2.28	9.45	0.24	3.75	2.50	1.40	0.56	0.30

* Intensities of less than 0.10 in./hr. are not included.

Text Table 8

Rainfall Intensities Measured at
Station SCS No. 15 F. S. A., Anna's Hope Estate, St. Croix, V. I.
(From U. S. Soil Conservation Service)

Month	Total Rainfall, inches	Total Duration, hours*	Average Intensity, in./hr.	Maximum Intensity for Different Intervals				
				5-min.	10-min.	20-min.	60-min.	120-min.
1940								
January	0.35	2.77	0.13	–	–	–	–	–
February	2.09	17.18	0.12	1.80	1.25	0.75	0.30	0.18
March	0.99	4.92	0.20	1.00	0.75	0.35	0.13	–
April	1.55	4.20	0.37	3.50	1.75	1.20	0.80	0.43
May	2.88	15.05	0.19	2.00	1.50	0.80	0.40	0.25
June	1.56	4.60	0.34	3.00	2.25	1.20	0.40	0.20
July	1.17	4.23	0.28	1.00	0.75	0.35	0.13	–
August	1.75	7.48	0.23	3.00	2.00	0.80	0.30	0.15
September	5.24	6.67	0.82	7.00	5.00	4.20	2.30	1.18
October	8.43	22.05	0.38	4.00	3.00	2.00	0.80	0.50
November	6.05	14.67	0.41	7.00	5.50	3.30	1.10	0.60
December	2.36	14.10	0.17	1.50	1.00	0.45	0.18	–
1941								
January	3.67	12.25	0.30	4.00	2.50	1.60	0.60	0.38
February	0.19	2.50	0.08	–	–	–	–	–
March	1.05	2.83	0.37	1.50	1.00	0.50	0.20	0.15
April	2.48	7.25	0.34	4.00	3.00	2.60	0.92	0.48

* Intensities of less than 0.10 in./hr. are not included.

Evaporation

The actual water loss from the ground by evaporation and by transpiration of plants is probably high, judging from the general weather conditions and from the measures of *evaporating power* of the air made at the Experiment Station (see APPENDIX TABLE 8). Consequently, the roughly 45 inches of measured average annual rainfall in the Virgin Islands is by no means the equivalent for plant growth of 45 inches of measured precipitation in rainier parts of the West Indies or in the southern United States.

Thunderstorms, Squalls, and Hail

Thunderstorms occur, as in Porto Rico, chiefly from July to October, according to the records at Christiansted and Bourne Field (TEXT TABLE 1 and APPENDIX TABLE 12). Schomburgk in 1837 reported that 5 to 10 per cent of the days in a year had thunderstorms, mostly in September and October, which roughly agrees with the Christiansted data, although at Bourne Field more of the storms occur in July and August. Most storms probably occur in the afternoon, as at San Juan. They are apt to be squally and inflict wind damage at times, but lightning damage is usually slight.

Squalls are sometimes associated with heavy showers and probably with most thunderstorms. The familiar downrush of cold air under a thunderstorm or tall cumulonimbus cloud can be so violent as to capsize small boats and damage dwellings, trees, and crops. When the observer is located on the sunny side of the cloud, it may appear white until after the squalls reach him, giving rise to the term "white squall" of the West Indian natives; but when the observer is under or on the shaded side of the cloud, it appears very dark and ominous, so the accompanying gusts are called "black squalls". White squalls are also reported without heavy clouds nearby, but these are merely gusts when the trades are blowing strongly. The West Indian sailor well knows that the squalls are apt to be especially violent and dangerous to boats along a coast which rises to high mountains immediately back of the shore.

Hail is rarely reported and most residents spend a lifetime in the islands without seeing any. There are enough authenticated reports to leave no doubt that it falls at least every few years, even several times in some years in which conditions are favorable for it. Much hail, with cold and rainy weather, occurred in Virgin Gorda in January 1833, according to Schomburgk, who also wrote of hail on the north side of Tortola in November 1829. Knox mentions that hail as big as hen eggs fell in St. Croix on April 13, 1844; and that a Mr. Nissen told him of a hailstorm at St.

the vegetation and the top of the soil and do not sink into it, and so are quickly evaporated by the sun and wind.

TEXT TABLE 9

PERCENTAGES OF DAYS WITH SPECIFIED AMOUNTS OF RAINFALL. CHRISTIANSTED, ST. CROIX, 1852–1907

(From Willaume-Jantzen and Ravn)

Month	0–5 mm (0–0.20")	≧ 20 mm (0.79" or more)	≧ 50 mm (1.97" or more)
January	67	5	0
February	64	3	0
March	66	4	0
April	55	16	2
May	56	10	4
June	46	14	3
July	55	10	2
August	54	11	4
September	45	15	4
October	44	18	7
November	48	12	3
December	52	8	2
Year	54	11	3

TEXT TABLE 10

AVERAGE AND EXTREME NUMBERS OF DAYS WITH RAIN, CHRISTIANSTED, ST. CROIX, 1852–1907

(From Willaume-Jantzen)

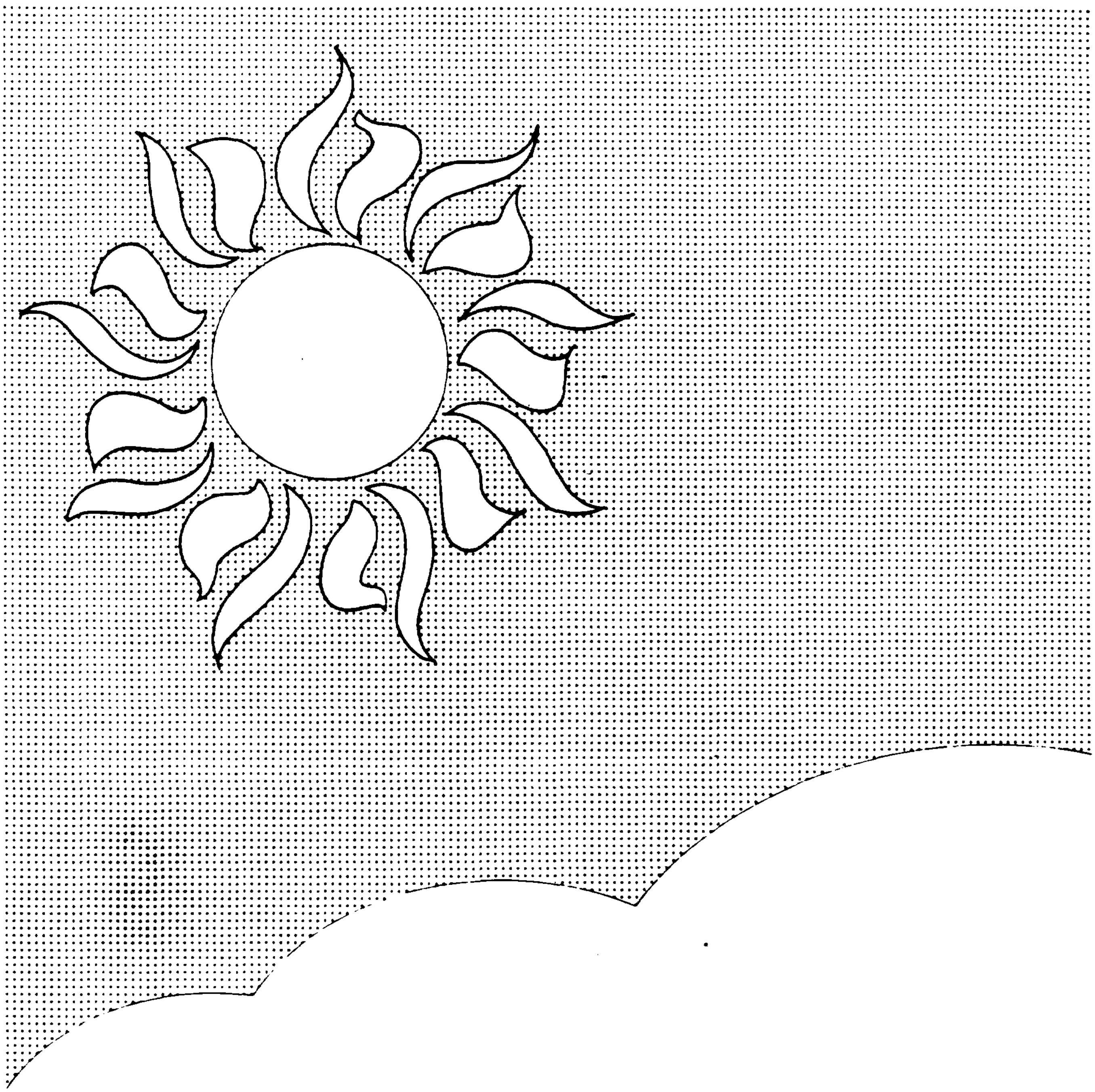
Month	Mean	Highest in any one year	Lowest in any one year
January	11	20	2
February	9	23	1
March	6	14	0
April	7	13	2
May	11	26	3
June	10	20	4
July	11	17	4
August	11	17	4
September	13	19	6
October	12	19	6
November	14	20	4
December	13	19	6
Year	128	177*	84*

* These figures are not sums of the columns above, but are the extreme totals on record for any one year in the period covered by the table.

REFERENCE NO. 5

CLIMATOGRAPHY OF THE UNITED STATES NO. 60

Climate of Puerto Rico and Virgin Islands



noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

REPRINTED JUNE 1982

Due to the small size of the islands and the location of all stations within a few miles of the water, the mean daily range is quite small. It varies from 9.1° at Charlotte Amalie to 15.1°F at Wintberg. For these same reasons extremes of temperature are not as great as they are in Puerto Rico, and relatively few days have temperatures of 90° F or above. Since the extent of land areas is small, the air passage over land is quite short and there is not sufficient time for extreme heating to take place. On St. Croix, Annas Hope has had a temperature as high as 99° F.

During the warmest months, maximum temperatures average about 87° to 89° F, with nighttime temperatures falling to about 74° to 78° F, and a little lower at the higher elevations. In the winter, daily maximum temperatures are generally in the low 80's and nighttime minima in the high 60's or low 70's.

The highest mean maximum temperatures are found in August, while the lowest mean maxima fall either in January or February. The lowest mean minimum temperatures are observed in January and February, and the highest mean minimum temperatures are generally in July or August.

DROUGHT - Drought in the Virgin Islands occurs about as often and is just as damaging as it is in Puerto Rico. None of the three islands has any significant running rivers or streams and only St. Croix has an underground water source in a few sections. Water for irrigation is not available in quantity at any time. Large storage reservoirs do not exist so the Virgin Islands are, to some extent, more at the mercy of "Mother Nature" than is Puerto Rico where there are adequate facilities for water storage.

HAIL - In the U. S. Virgin Islands, hail is even less frequent than in Puerto Rico. In January of 1969 a severe local hailstorm with hailstones up to 1 1/2 inches in diameter occurred. This was the first hailstorm on record in the U. S. Virgin Islands.

Orographic lifting of the moisture laden air over the hilly terrain of these islands is the most frequent cause of rainfall. However, due to the smaller elevations and smaller size of the islands, there is a less marked variation in annual amounts. The larger mean annual totals are between 50 and 60 inches at the higher elevations, and the variation between the greatest and least average value is not as marked as it is in Puerto Rico. Clouds formed by forced ascent of the wind over small and narrow islands, as is the case for St. Thomas and St. Croix, lean to the leeward, so that most of the rain from them falls in the ocean to the lee of the island. Easterly wave passages are important contributors to the rainfall of the Virgin Islands during the months from May through November. Like Puerto Rico, the U. S. Virgin Islands lie in the path of the tropical storms and hurricanes which form over the ocean to the east of the Lesser Antilles. As in Puerto Rico, they are relatively infrequent. While cold frontal passages affect the rainfall regime of the Virgin Islands, the frequency of fronts is less and their intensity is more likely to be diminished and less effective than in Puerto Rico.

Annual rainfall values indicate differences in rainfall from location to location with higher elevations generally receiving greater amounts. On St. Thomas and St. John, on the basis of the limited data available, annual averages of between 40 and 60 inches appear reasonable. On St. Croix there is a more noticeable variation from place to place. This Island has the greatest annual rainfall, in excess of 50 inches in the northwestern corner. There are some indications that stations in a small area along the central portion of the southern coast of St. Croix receive about 40 to 45 inches. A narrow finger of between 25 and 35 inches extends northeast to southwest over the flatlands south of the hills in the western portion of the Island. Annual rainfall averages less than 30 inches in the eastern end of St. Croix, possibly as low as 20 inches.

As in Puerto Rico, there is no sharply defined wet-dry season relationship. Records available for the three islands indicate a relatively wet-relatively dry season distribution similar to that found in the southern portion of Puerto Rico. The relatively dry period extends from about December through June. Occasionally, quite heavy rainfall occurs during the so-called drier months. The driest month of St. Thomas and St. John usually is February or March and the wettest month September or October, as in the southern sections of Puerto Rico. On St. Croix, the month with the heaviest rainfall, on the average, ranges from September through November.

The number of days with measurable rainfall over the Virgin Islands, based on a few known-to-be reliable stations, ranges from a little less than 200 days annually at the higher rainfall stations to less than 100 days annually at the stations with lowest rainfall.

As in Puerto Rico, one of the most striking features of the temperature regime in the U. S. Virgin Islands is the relatively small variation from the coolest to the warmest months, ranging from about 5° to 7°F.

comfort or discomfort, between economic success or failure, or between safe and compatible building design can be a delicate one. Through effective planning and intelligent application of climatic considerations to life in the Caribbean, man can truly say he has found his tropical paradise.

U. S. VIRGIN ISLANDS

Location: The U. S. Virgin Islands are composed of three major islands, together with a number of smaller islands and cays totaling about 50. The three of primary importance are: St. Thomas, where the capital is located; St. Croix, the largest; and St. John, the smallest.

These islands follow Vieques Island and Culebra Island in the path of the Lesser Antilles toward South America. St. Thomas lies some 38 miles east of Puerto Rico and about 1,500 miles southeast of New York. St. John lies a few miles east of St. Thomas and St. Croix is located about 40 miles south of St. Thomas and St. John.

With an area of about 28 square miles, St. Thomas is the second largest of the U. S. Virgin Islands. This island lies between latitudes 18°23'N and 18°18'N and longitudes 65°03'W and 64°50'W. It is about 5 miles from its northernmost to its southernmost points and a little more than 12 miles from its eastern to western extremities.

The smallest of the three principal islands is St. John, with an area of only about 20 square miles. It is also the least populated. St. John lies between latitudes 18°23'N and 18°18'N, and longitudes 64°48'W and 64°40'W. This island extends about 5 miles from its northern to southern-tips and about 8 miles from its easternmost to westernmost points.

Somewhat apart from the others, the largest of the three islands is St. Croix which has an area of 84 square miles. It lies between latitudes 17°47'N and 17°41'N, and longitudes 64°54'W and 64°34'W. The Island extends some 19 miles from east to west and 6 miles from north to south.

Topography: St. Thomas has an extremely irregular coastline and is very hilly with practically no flatland. The highest hills are generally found near the center of the Island, with Crown Mountain at 1,550 feet the highest point. The Island is relatively small and many of the peaks rise above 1,000 feet. This results in rather steep slopes over all the island, so that rainfall runoff is quite rapid and there are no permanent streams or rivers.

Like St. Thomas, St. John has an extremely irregular shoreline and a very hilly topography. It has a number of peaks over 1,000 feet, topped by Bordeaux Mountain at 1,297 feet in the eastern portion of the island. Slopes are quite steep over all of the island, and there are very few areas of flatland. There are no permanent rivers or creeks.

St. Croix is the largest of the three U. S. Virgin Islands. The topography is somewhat different from the other two with a broad expanse of low, relatively flatland running along the southern two-thirds of the Island. A range of hills, ranging in elevation from about 500 feet to more than 1,000 feet, topped by Mount Eagle at 1,165 feet, runs along the northern coast. In the eastern end of St. Croix is found another group of slightly lower hills with a maximum elevation of about 860 feet. The relatively small area covered by hills on St. Croix results in rather steep slopes down to the Caribbean in the north and to the level areas to the south.

Agriculture is not as important in the U. S. Virgin Islands as it is in Puerto Rico. St. Croix is the only one of the U. S. Virgin Islands with any sizable expanse of flatland suitable for farming. Here sugar cane, which was the principal crop, has been abandoned. Subsistence crops are now a minor effort. Some cattle are raised for milk and meat.

In St. Croix, industrial growth has become a significant factor in the island's economy. With the downgrading of agriculture, industrial complexes have been expanded to include the petrochemical industry and refinement of aluminum. Light industrial plants and the manufacture of rum are the other industrial activities in St. Croix and St. Thomas. St. John has no industrial development and remains primarily a National Park.

Tourism is the biggest factor in the Virgin Islands economy. It has, over the past years, undergone a vast increase in the numbers of cruise ships, especially at St. Thomas and St. Croix. Hotel facilities have been increased on both islands.

One of the principal causes of concern in the U. S. Virgin Islands is the short supply of water. Rainfall, while above 40 inches annually over most of the area, is insufficient. This is due partially to a high evaporation rate and the rapid runoff from the steep slopes on St. Thomas and St. John and, to a certain extent, on St. Croix.

In an effort to utilize available water efficiently, most homes and business establishments catch rainwater on the roofs and pipe it to cisterns. The runway at the airport at St. Thomas is also used as a catchment area. On St. Thomas and St. John it is common to see the entire side of a hill cemented to act as a catchment area. Generally, during the drier portion of the year, it is necessary to carry water by barge from Puerto Rico. Installation of a sea-water distillation unit on St. Thomas and St. Croix has helped alleviate the water shortage but water still remains a significant factor in the development of the island's economy.

Rainfall in the U. S. Virgin Islands is of the same nature as that in Puerto Rico, falling most frequently in the form of brief showers. The rainfall-producing mechanisms are essentially the same as in Puerto Rico except in the matter of degree.

REFERENCE NO. 6

TAT-02-F-04642

DRAFT

TUTU WELL SITE
POTABLE WATER ALTERNATIVES REPORT
ANNA'S RETREAT, ST. THOMAS, U.S. VIRGIN ISLANDS

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December 1988

appear to be sufficient land available to increase the cistern volumes laterally. The only way the volume could be increased is by making deeper cisterns. This operation would require the shoring of the existing homes and apartments, therefore, the possibilty of structural damage to these residences.

2.0 SITE DESCRIPTION AND CONDITIONS

2.1 Site Background and Conditions

The Tutu Well site is located at the eastern end of the Island at the Anna's Retreat Section of St. Thomas (see Figure 2-1 page 5). Most of the wells are used for public drinking water supply. The wells appear to be drilled into the Turpentine Run aquifer.

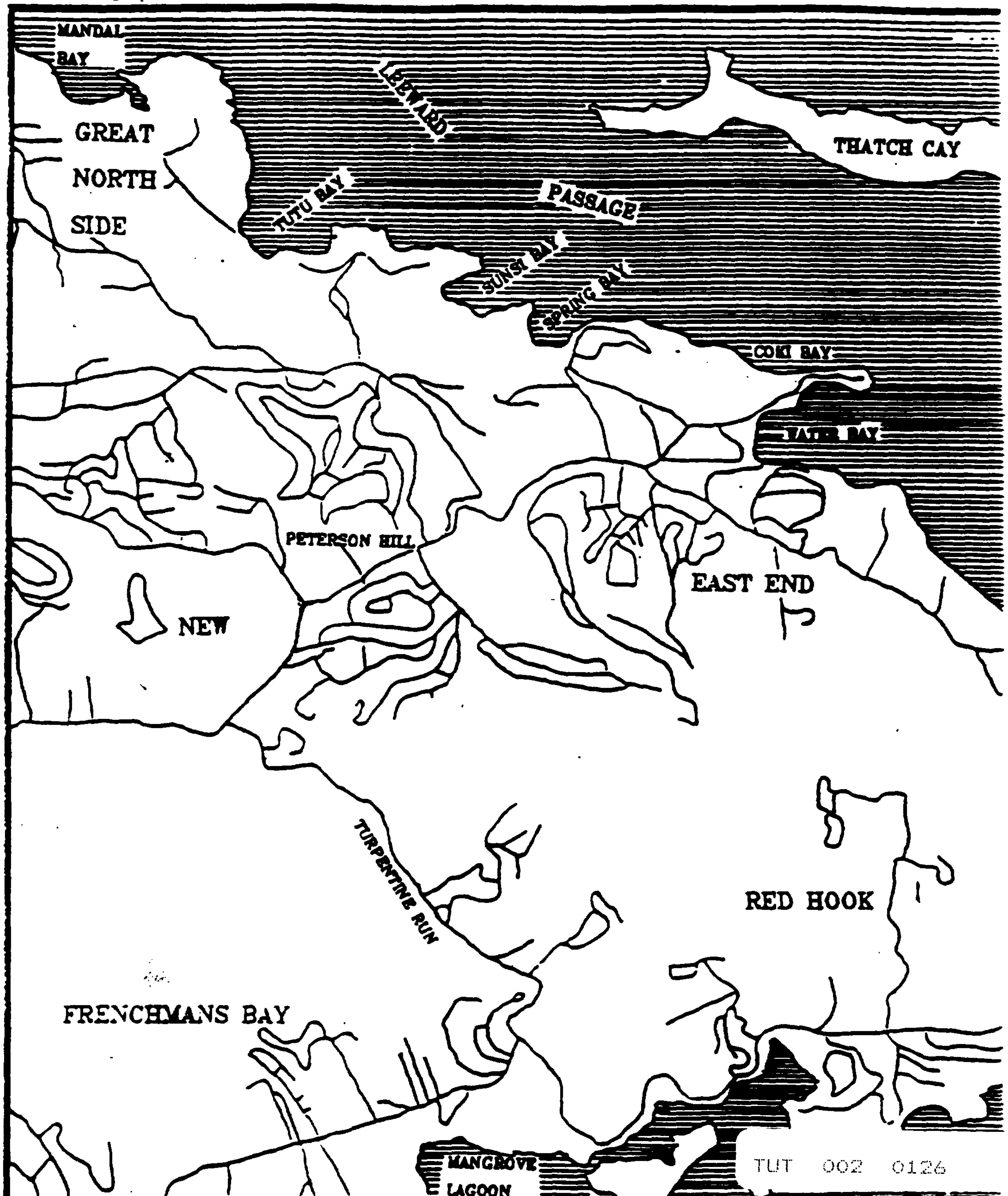
On, or about July 7, 1987, Mr. Eric Tillett, contacted the U.S. Virgin Islands (U.S.V.I.) Department of Planning and Natural Resources (DPNR) regarding an odor emanating from the raw well water on his property located at Anna's Retreat, St. Thomas, U.S.V.I.

On July 16, 1987, the USEPA received a request from the DPNR in St. Thomas, for sampling and analyses of several wells in Tutu. On July 21, the USEPA and its Technical Assistance Team (TAT) contractor, Roy F. Weston, Inc., mobilized to St. Thomas, to perform sampling on the drinking water wells suspected of being contaminated. These wells were also reported to have a strong, unpleasant odor and were found to be contaminated with hazardous substances.

The EPA and its Technical Assistance Team (TAT) in coordination with DPNR, initiated sampling of wells in the affected area in July 1987. The test results showed the presence of high concentrations of gasoline and chlorinated organic compounds. Four wells: Elgin, Four Winds, Harthman, and Virgin Islands Housing Authority (VIHA) were closed down by order of DPNR due to high VOC concentrations.

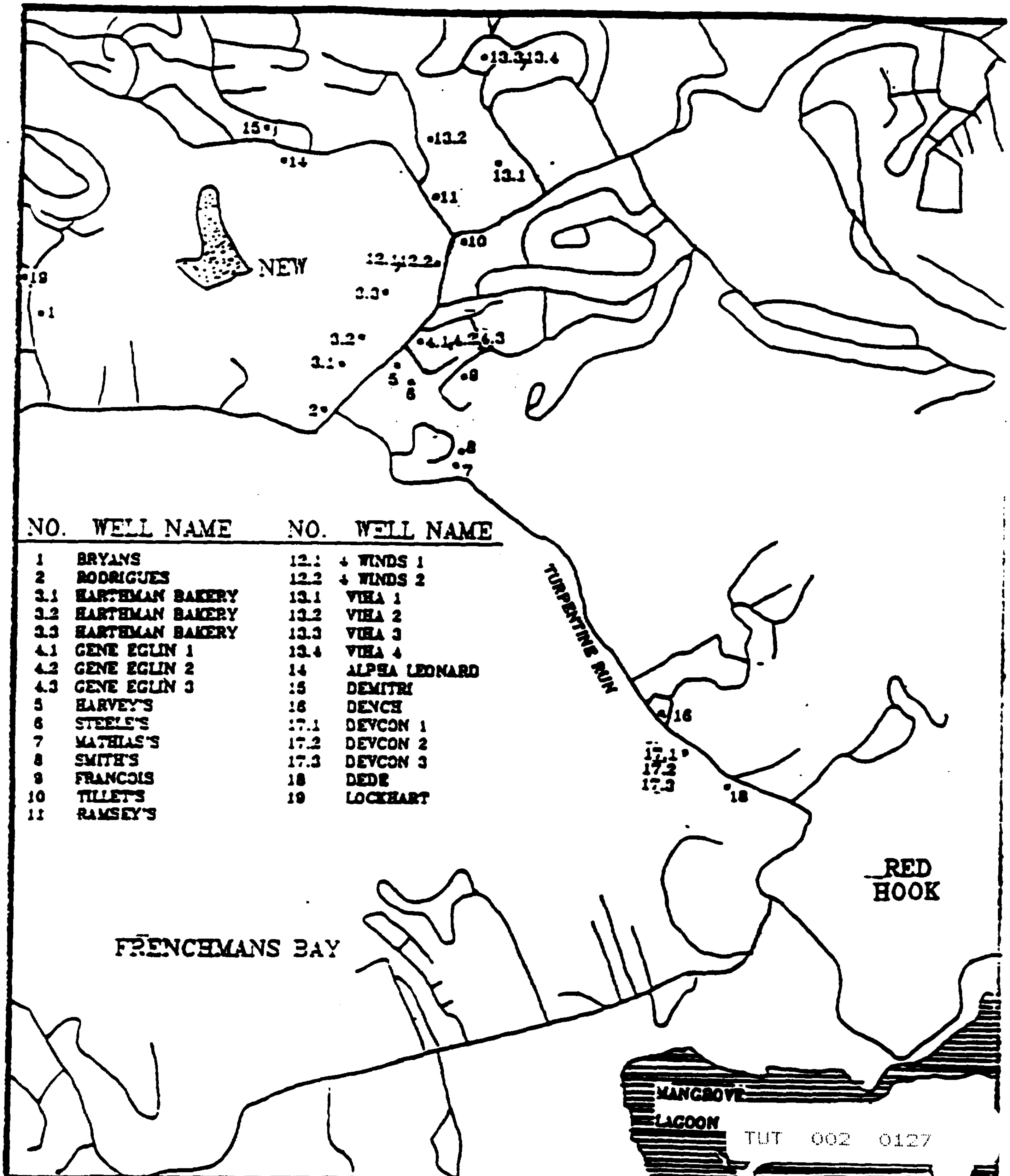
Several of the wells in this area are major commercial well services used for public drinking water supply, therefore, the incident was classified as major, and the DPNR Commissioner requested the EPA to assume the role of Lead Agency. The well locations can be seen in Figure 2-2 page 6.

A Texaco station, located opposite the Tillet Well, is suspected as a possible source of contamination. A Petrotight test conducted on the underground storage tanks at this facility indicated leaks in two of the three tanks. These failures may have contributed



TUT 002 0126

WESTON	SPILL PREVENTION & EMERGENCY RESPONSE DIVISION	EPA PM CARLOS O'NEILL	FIGURE 2-1 SITE LOCATION MAP TUTU ST. THOMAS U.S. VIRGIN ISLANDS
In Association with ICF Technology Inc., C.C. Johnson & Associates, Inc., Resource Applications, Inc., Geo/Resource Consultants, Inc., and Environmental Toxicology International, Inc.		TAT PM R. HAFNER	



NO.	WELL NAME	NO.	WELL NAME
1	BRYANS	12.1	4 WINDS 1
2	RODRIGUES	12.2	4 WINDS 2
3.1	HARTHMAN BAKERY	13.1	VIHA 1
3.2	HARTHMAN BAKERY	13.2	VIHA 2
3.3	HARTHMAN BAKERY	13.3	VIHA 3
4.1	GENE EGLIN 1	13.4	VIHA 4
4.2	GENE EGLIN 2	14	ALPHA LEONARD
4.3	GENE EGLIN 3	15	DEMITRI
5	HARVEY'S	16	DENCH
6	STEELE'S	17.1	DEVCON 1
7	MATHIAS'S	17.2	DEVCON 2
8	SMITH'S	17.3	DEVCON 3
9	FRANCOIS	18	DEDE
10	TILLET'S	19	LOCKHART
11	RAMSEY'S		

TUT 002 0127

WESTON

SPILL PREVENTION & EMERGENCY RESPONSE DIVISION

In Association with ICF Technology Inc., C.C. Johnson & Associates, Inc., Resource Applications, Inc., Geo/Resource Consultants, Inc., and Environmental Toxicology International, Inc.

EPA PM
CARLOS O'NEILL

TAT PM
R. HAFNER

FIGURE 2-2
WELL LOCATION MAP
TUTU ST. THOMAS
U.S. VIRGIN ISLANDS

to the groundwater pollution problem, resulting in the contamination of nearby wells. Another suspected source of contamination is the Tutu Esso gas station. This facility stores waste oil in an underground storage tank. The facility has had problems in the past with leakage from their underground gasoline storage tank and is suspected of using solvents in the mechanic shop. At the time of inspection, the nature of the problem had not been determined. Both the Texaco and Esso gas stations are upgradient from the affected wells which are being supplied with water.

EPA continued its efforts towards the identification of; affected wells in the area, customers which had received water from contaminated wells, and possible alternate water supplies and remedial action alternatives.

A testing program of wells located outside of the known area of contamination was conducted to evaluate those areas as possible alternate water supply sources.

Sampling of cisterns served by the contaminated wells was also performed. EPA directed the Emergency Response Cleanup Services contractor (ERCS) to; clean and disinfect the five (5) cisterns which had tested positive for PCE, modify the existing home plumbing, disconnect the contaminated wells, and dispose of the contaminated water. At EPA's direction, ERCS also contracted a local water hauler to deliver uncontaminated drinking water to the cisterns by tank truck. A well sampling program was established by the EPA to monitor the wells at the Tutu site for a one year period.

Nine potential responsible parties have been identified. These facilities included three gasoline service stations, two vehicle maintenance repair shops, two territorial government agencies, one dry cleaner and one abandoned gasoline service station. EPA has identified Texaco as a viable potentially responsible party, based on the results of a soil/gas survey conducted on the Texaco Property under order from DPNR and under the supervision of EPA. The survey found total hydrocarbon concentrations up to 690 ppm of benzene. EPA is continuing its efforts to identify potential responsible parties.

2.2 Topography and Geology(1)

"St. Thomas is the most northwest island of the U.S. Virgin Islands and the second largest. The island is approximately 14 miles long and 2 to 3 miles wide and has an area of 32 square miles.

The land surface is almost entirely sloping and extend seaward from a central ridge, 800 to 1,200 feet high, running the length of the island. The slopes, which commonly exceed 35 degrees, are dissected by numerous stream courses of steep gradient. The general appearance is a panorama of steep interstream spurs an rounded peaks. Flat inland is confined to the Charlotte Amalie area and a few small alluvial-filled embayments. The only variation in the general topography is in the upper valley of Turpentine Run in eastern St. Thomas. The valley has relatively gentle topography consisting of rolling hills in a basin surrounded by steep slopes and sharp ridges.

The Tutu Formation, the youngest rock exposed on St. Thomas is composed almost entirely of angular debris derived from the Louisenhoj Formation (an older volcanic formation) and minor limestone debris from thin limestone deposited contemporaneously with the Tutu Formation.

The rocks were subsequently tilted to form a northward-dipping homocline. Dips range from 15 to 90 degrees and average about 50 degrees. Locally the formations are overturned.

The permeable zones that these rocks once may have had after deposition have been destroyed by metamorphism or by deposition of minerals in pore spaces. Groundwater movement is now limited to openings along joints and fault zones. The homoclinal structure is cut by sets of faults trending N 45°W, N 55°E and north. Three well-defined joint sets parallel each of the major fault directions. The valleys of the island have similar trends and are apparently the result of selective erosion of rock weakened by faulting and jointing. Prime zones of groundwater availability, therefore, follow the valleys.

Small alluvial deposits ranging from Pleistocene to Holocene in age, lie in the valley of Turpentine Run in east-central St. Thomas and the larger coastal embayments.

The alluvium of Turpentine Run lies in a narrow band seldom more than 200 feet in width along the stream. Maximum thickness of the alluvium is about 40 feet. Most of the alluvium, which is composed of silt, fine sand, and clay and contains discontinuous beds of sand and gravel 2 to 3 feet thick; lies in the Mt. Zion-Tutu area of the upper basin and in the narrow valley from Mariendal to Mangrove Lagoon in the lower basin. The alluvium extends out under the lagoon near the mouth of Turpentine Run. Although composed predominately of fine-grained material, the alluvium readily infiltrates streamflow when the groundwater level is below the base of the stream. As such, the alluvium forms a readily rechargeable aquifer, although it is of small extent and yield.

Some coastal embayments headed by intermittant streams contain small deposits of alluvium similar to that of Turpentine Run. Maximum thickness of these deposits is estimated to be 50 feet, and their areal extent seldom is greater than a few acres (an exception being the Long Bay and Airport areas near Charlotte Amalie). Near the sea, the alluvium interfingers with calcareous sand and at times contains lenses of mangrove swamp deposits. Therefore, the deposits are of minor significance as sources of water".(1)

2.3 Rainfall(1)

"Rain is the only natural source of fresh water to replenish the water resources of the island. Rainfal is seasonal, with a rainy season in late summer and early fall and a secondary wet season usually in May. Nearly half the rain falls during August-November. Rains exceeding 1 inch in 24 hours come six or seven times a year. Four to 15 inches of rain falls in a 4 hour period about once every 2 years in large storms. These rains can occur in any month, but are more like during the hurricane season (August-November). About 50 percent of the time annual rainfall is between 40 50 inches. Less than 10 percent of the time annual rainfall is under 35 inches, which usually means a major deficiency during the normal wet season and drought.

The cumulative departure from average and the 10-year running average of rainfall shows that at this time of writing (1967) the island may be entering a period of deficient rainfall. With the exception of a few years in the late 1940's and early 1950's, rainfall in the past 30 years has been below average. There has been a long-term decline of about 10 inches in annual rainfall since the peak of the surplus rainfall period in the early 1930's. The most severe droughts on record occcurred in 1964 and 1967, when only 27 and 24 inches of rain fell, respectively.

Areal distribution of long-term rainfall, is controlled by topography and the prevailing easterly to northeasterly winds. However, individual storms may or may not show the effects of orographic control or prevailing winds and the areal distribution of the storms can be very irregular".(1) See Figure 2-3, page 10, for average yearly rainfall.

2.4 Sampling Results

The Tutu well site has been sampled repeatedly over the last ten months and found to contain definite contamination. The initial assessment was conducted in July through September of 1987. Subsequent sampling and analysis has proceeded on a monthly basis. The initial assessment considered 26 wells and approximately 50 cisterns. Of these wells and cisterns; 24 wells and 5 cisterns were found to be contaminated. The 5 cisterns were cleaned and disinfected by the ERCS contractor. Subsequent monitoring has been considered for the 24 wells that showed some type of contamination.

Table 2-1 pg. 12, lists the wells included in the current sampling program. Tables 2-2 and 2-3 , pages 13-16, show the volatile organic analysis results of the contaminated wells and give the highest concentration of organic contamination found during the last six months.

The sampling, and most of the preliminary Photovac portable GC screening, was conducted by the U.S. EPA Region II TAT. Drinking water laboratories have performed formal analyses to verify the photovac screening results and to cover the entire spectrum of possible hazardous contaminants.

Although, the concentration of these contaminants fluctuates monthly, it is noteworthy that the major contaminants have been 1,2-trans-dichloroethylene (DCE), trichloroethylene (TCE), tetrachloroethylene (PCE), toluene (TOL), benzene (BEN), tertbutyl methyl ether (TBME) and various metals. Their high concentration in four wells; Tillet, Harvey, Smith and Steele has been evident from the initial assessment. These wells show concentrations of volatile organics (VO) in excess of 1,000 ppb. The major and most consistent contaminant appears to be PCE. The Tillet well has also shown very high DCE and BEN contamination. Four other wells; Francois, Mathias, Four Winds, and Elgin; were confirmed to have >50 ppb VOCs.

The last confirmation analysis conducted during October 1987, included the entire Hazardous Substance List (HSL), (consisting of approximately 150 chemicals). At that time, significant levels of TBME up to 470 ppb, and methylene chloride up to 120,000 ppb were detected. Some samples have also shown traces of vinyl chloride, chloroform, 1,1,1-trichloroethane, bromodichloroethane, xylene, and ethylbenzene.

Finally, the HSL analysis also showed the presence of

TABLE 2-1
CURRENT WELL MONITORING PROGRAM
AND CLASSIFICATION AT TUTU WELL SITE

WELL NAME		CLASSIFICATION	OPEN/CLOSED
1.	Dede	Public	Open
2.	Steele	Private	Closed
3.	Elgin #1	Commercial	Closed
	Elgin #2	Commercial	Closed
	Elgin #3	Commercial	Closed
4.	Four Winds	Commercial	Closed
5.	Smith	Private	Closed
6.	Bryan	Commercial	Open
7.	Harvey	Private	Closed
8.	Tillet	Commercial	Closed
9.	Harthman Estate	Private	Closed
10.	Devcon #1	Commercial	Open
	Devcon #3	Commercial	Open
11.	VIHA #1	Institutional	Closed
	VIHA #3	Institutional	Closed
12.	Dench	Commercial	Pump/No Power
13.	Ramsey	Private	Open
14.	Harthman Crusher	Commercial	Closed
15.	Alpha Leonard	Private	Open
16.	Francois	Private	Open
17.	Demitris	Commercial	Open
18.	Rodriguez Auto	Private	Open
19.	Harthman Bakery	Commercial	Closed
20.	Mathias	Private	Open

Definition of Classifications

Private: Wells which serve one or two houses.

Commercial: Wells that are used to yield water for sale.

Institutional: Wells owned and operated by a non-profit institution or governmental agency.

Public: Wells that are for public use.

REFERENCE NO. 7

FISH AND WILDLIFE SERVICE LIST OF ENDANGERED AND THREATENED WILDLIFE AND PLANTS

(50 CFR 17.11, 17.12; As shown in Code of Federal Regulations, Volume 50, Revised as of October 1, 1983; 48 FR 46057, October 11, 1983; 48 FR 46331, 46336, 46337, 46341, October 12, 1983; 48 FR 49248, October 25, 1983; 48 FR 52742, 52746, November 22, 1983; 49 FR 1058, January 9, 1984; 49 FR 1994, January 17, 1984; 49 FR 2783, 2786, January 23, 1984; 49 FR 6102, February 17, 1984; 49 FR 7334, February 28, 1984; 49 FR 7394, 7397, February 29, 1984; 49 FR 10525, March 20, 1984; 49 FR 14356, April 11, 1984; 49 FR 21058, May 18, 1984; 49 FR 22329, 22334, May 29, 1984; 49 FR 27514, July 5, 1984; 49 FR 28565, July 13, 1984; 49 FR 29234, 29237, July 19, 1984; 49 FR 30201, July 27, 1984; 49 FR 31420, August 7, 1984; 49 FR 33885, 33892, August 27, 1984; 49 FR 34494, 34500, 34504, 34510, August 31, 1984; 49 FR 35954, September 13, 1984; 49 FR 40038, October 12, 1984; 49 FR 43069, October 26, 1984; 49 FR 43968, November 1, 1984; 49 FR 44756, November 9, 1984; 49 FR 45163, November 15, 1984; 49 FR 47400, December 4, 1984; 50 FR 1056, January 9, 1985)

Title 50—Wildlife and Fisheries

CHAPTER I—UNITED STATES FISH AND WILDLIFE SERVICE, DEPARTMENT OF THE INTERIOR

SUBCHAPTER B—TAKING, POSSESSION, TRANSPORTATION, SALE, PURCHASE, BARTER, EXPORTATION, AND IMPORTATION OF WILDLIFE

PART 17—ENDANGERED AND THREATENED WILDLIFE AND PLANTS

Authority: Pub. L. 93-205, 87 Stat. 884; Pub. L. 94-359, 90 Stat. 911; Pub. L. 95-632, 92 Stat. 3751; Pub. L. 96-159, 93 Stat. 1225; Pub. L. 97-304, 96 Stat. 1411 (16 U.S.C. 1531 *et seq.*)

[Amended by 49 FR 21058, May 18, 1984; 49 FR 22329, 22334, May 29, 1984; 49 FR 27514, July 5, 1984; 49 FR 28565, July 13, 1984; 49 FR 29234, 29237, July 19, 1984; 49 FR 30201, July 27, 1984; 49 FR 31420, August 7, 1984; 49 FR 33885, 33892, August 27, 1984; 49 FR 34494, 34500, 34504, 34510, August 31, 1984; 49 FR 35954, September 13, 1984; 49 FR 43968, November 1, 1984; 49 FR 44756, November 9, 1984; 49 FR 45163, November 15, 1984; 49 FR 47400, December 4, 1984; 50 FR 1056, January 9, 1985]

Subpart B — Lists

§17.11 Endangered and threatened wildlife.

(a) The list in this section contains the names of all species of wildlife which have been determined by the Services to be Endangered or Threatened. It also contains the names of species of wildlife treated as Endangered or Threatened because they are sufficiently similar in appearance to Endangered or Threatened species (see §17.50 *et seq.*).

(b) The columns entitled "Common Name," "Scientific Name," and "Vertebrate Population Where Endangered or Threatened" define the species of wildlife within the meaning of the Act. Thus, differently classified geographic populations of the same vertebrate subspecies or species shall be identified by their differing geographic boundaries, even though the other two columns are identical. The term "Entire" means that all populations throughout the present range of a vertebrate species are listed. Although common names are included, they cannot be relied upon for identification of any specimen, since they may vary greatly in local usage. The Services shall use the most recently accepted scientific name. In cases in which confusion might arise, a synonym(s) will be provided in parentheses. The Services shall rely to the extent practicable on the *International Code of Zoological Nomenclature*.

(c) In the "Status" column the following symbols are used: "E" for Endangered, "T" for Threatened, and "E [or T] (S/A)" for similarity of appearance species.

(d) The other data in the list are nonregulatory in nature and are provided for the information of the reader. In the annual revision and compilation of this Title, the following information may be amended without public notice: the spelling of species' names, historical range, footnotes, references to certain other applicable portions of this Title, synonyms, and more current names. In any of these revised entries, neither the species, as defined in paragraph (b) of this section, nor its status may be changed without following the procedures of Part 424 of this Title.

(e) The "Historic Range" indicates the known general distribution of the species or subspecies as reported in the current scientific literature. The present distribution may be greatly reduced from this historic range. This column does not imply any limitation on the application of the prohibitions in the Act or implementing rules. Such prohibitions apply to all individuals of the species, wherever found.

(f)(1) A footnote to the **Federal Register** publication(s) listing or reclassifying a species is indicated under the column "When Listed." Footnote numbers to §§17.11 and 17.12 are in the same numerical sequence, since plants and animals may be listed in the same **Federal Register** document. That document, at least since 1973, includes a statement indicating the basis for the listing, as well as the effective date(s) of said listing.

(2) The "Special Rules" and "Critical Habitat" columns provide a cross reference to other sections in Parts 17, 222, 226, or 227. The "Special Rules" column will also be used to cite the special rules that describe experimental populations and determine if they are essential or nonessential. Separate listing will be made for experimental populations, and the status column will include the following symbols: "XE" for an essential experimental population and "XN" for a nonessential experimental population. The term "NA" (not applicable) appearing in either of these two columns indicates that there are no special rules and/or Critical Habitat for that particular species. However, all other appropriate rules in Parts 17, 217-227, and 402 still apply to that species. In addition, there may be other rules in this Title that relate to such wildlife, e.g., port-of-entry requirements. It is not intended that the references in the "Special Rules" column

Species: Common name	Species: Scientific name	Historic range	Vertebrate population where endangered or threatened	Status	When listed	Critical habitat	Special rules
REPTILES							
Alligator, American	Alligator mississippiensis	Southeastern U.S.A.	Wherever found in wild except those areas where listed as threatened as set forth below	E	1, 11, 51, 60, 111	NA	NA
do	do	do	U.S.A. (FL and certain areas of GA, SC)	T	20, 47, 60, 111	NA	17.42(a)
do	do	do	U.S.A. (LA, TX)	T(S/A)	11, 47, 51, 60, 111	NA	17.42(a)
do	do	do	In captivity wherever found	T(S/A)	11, 47, 51, 111	NA	17.42(a)

[Amended by 48 FR 46336, October 12, 1983]

Common name	Scientific name	Historic range	Vertebrate population where endangered or threatened	Status	When listed	Critical habitat	Special rules
Alligator, Chinese	Alligator sinensis	China	Entire	E	15	NA	NA
Anole, Culebra Island giant	Anolis roosevelti	U.S.A. (Puerto Rico: Culebra Island)	do	E	25	17.95(c)	NA
Boa, Jamaican	Epicrates subflavus	Jamaica	do	E	3	NA	NA
Boa, Mona	Epicrates monensis monensis	U.S.A. (Puerto Rico)	do	T	33	17.95(c)	NA
Boa, Puerto Rican	Epicrates inornatus	do	do	E	2	NA	NA
Boa, Round Island (no common name)	Casarea dussumieri	Indian Ocean: Mauritius	do	E	86	NA	NA
Boa, Round Island (no common name)	Bolyeria multocarinata	Indian Ocean: Mauritius	do	E	86	NA	NA
Boa, Virgin Islands tree	Epicrates monensis granti	U.S. and British Virgin Islands	do	E	2, 86	NA	NA
Caiman, Apaporis River	Caiman crocodilus apaporiensis	Colombia	do	E	15	NA	NA
Caiman, black	Melanosuchus niger	Amazon basin	do	E	15	NA	NA
Caiman, broad-snouted	Caiman latirostris	Brazil, Argentina, Paraguay, Uruguay	do	E	15	NA	NA
Caiman, Yacare	Caiman crocodilus yacare	Bolivia, Argentina, Peru, Brazil	do	E	3	NA	NA
Chuckwalla, San Esteban Island	Sauromalus varius	Mexico	do	E	86	NA	NA
Crocodile, African dwarf	Osteolaemus tetraspis tetraspis	West Africa	do	E	15	NA	NA
Crocodile, African slender-snouted	Crocodylus cataphractus	Western and central Africa	do	E	5	NA	NA
Crocodile, American	Crocodylus acutus	U.S.A. (FL), Mexico, South America, Central America, Caribbean	do	E	10, 87	17.95(c)	NA
Crocodile, Ceylon mugger	Crocodylus palustris kimbula	Sri Lanka	do	E	15	NA	NA
Crocodile, Congo dwarf	Osteolaemus tetraspis osborni	Congo River drainage	do	E	15	NA	NA
Crocodile, Cuban	Crocodylus rhombifer	Cuba	do	E	2	NA	NA
Crocodile, Morelet's	Crocodylus moreletii	Mexico, Belize, Guatemala	do	E	3	NA	NA
Crocodile, mugger	Crocodylus palustris palustris	India, Pakistan, Iran, Bangladesh	do	E	15	NA	NA
Crocodile, Nile	Crocodylus niloticus	Africa	do	E	3	NA	NA
Crocodile, Orinoco	Crocodylus intermedius	South America: Orinoco River Basin	do	E	3	NA	NA
Crocodile, Philippine	Crocodylus novaeguineae mindorensis	Philippine Islands	do	E	15	NA	NA
Crocodile, saltwater (= estuarine)	Crocodylus porosus	Southeast Asia, Australia, Papua New Guinea, Pacific Islands	Entire, except Papua New Guinea	E	97	NA	NA
Crocodile, Siamese	Crocodylus siamensis	Southeast Asia, Malay Peninsula	Entire	E	15	NA	NA
Gavial (= gharial)	Gavialis gangeticus	Pakistan, Burma, Bangladesh, India	do	E	3, 15	NA	NA
Gecko, day	Phelsuma edwardnewtoni	Indian Ocean: Mauritius	[illegible]	[illegible]	3	NA	NA
Gecko, Monito	Sphaerodactylus micropithecus	U.S.A. (Puerto Rico)	do	E	125	17.95(c)	NA
Gecko, Round Island day	Phelsuma guentheri	Indian Ocean: Mauritius	do	E	3	NA	NA
Gecko, Serpent Island	Cyrtodactylus serpensinsula	do	do	T	129	NA	NA
Iguana, Acklins ground	Cyclura rileyi nuchalis	West Indies: Bahamas	do	T	129	NA	NA
Iguana, Allen's Cay	Cyclura cychlura inornata	do	do	T	129	NA	NA
Iguana, Andros Island ground	Cyclura cychlura cychlura	do	do	T	129	NA	NA
Iguana, Anegada ground	Cyclura pinguis	West Indies: British Virgin Islands (Anegada Island)	do	E	3	NA	NA
Iguana, Barrington land	Conolophus pallidus	Ecuador (Galapagos Islands)	do	E	3	NA	NA
Iguana, Cayman Brac ground	Cyclura nubila caymanensis	West Indies: Cayman Islands	do	T	129	NA	NA
Iguana, Cuban ground	Cyclura nubila nubila	Cuba	Entire (excluding population introduced in Puerto Rico)	T	129	NA	NA
Iguana, Exuma Island	Cyclura cychlura figginsi	West Indies: Bahamas	Entire	T	129	NA	NA
Iguana, Fiji banded	Brachylophus fasciatus	Pacific: Fiji, Tonga	do	E	86	NA	NA
Iguana, Fiji crested	Brachylophus vitiensis	Pacific: Fiji	do	E	86	NA	NA
Iguana, Grand Cayman ground	Cyclura nubila lewisi	West Indies: Cayman Islands	do	E	129	NA	NA
Iguana, Jamaican	Cyclura collei	West Indies: Jamaica	do	E	129	NA	NA
Iguana, Mayaguana	Cyclura carinata bartschi	West Indies: Bahamas	do	T	129	NA	NA
Iguana, Mona ground	Cyclura stejnegeri	U.S.A. (Puerto Rico: Mona Island)	do	T	33	17.95(c)	NA
Iguana, Turks and Caicos	Cyclura carinata carinata	West Indies: Turks and Caicos Islands	do	T	129	NA	NA
Iguana, Watling Island ground	Cyclura rileyi rileyi	West Indies: Bahamas	do	E	129	NA	NA
Iguana, White Cay ground	Cyclura rileyi cristata	do	do	T	129	NA	NA
Lizard, blunt-nosed leopard	Gambelia (= Crotaphytus) silus	U.S.A. (California)	do	E	1	NA	NA
Lizard, Coachella Valley fringe-toed	Uma inornata	do	do	T	105	17.95(c)	NA
Lizard, Hierro giant	Gallotia simonyi simonyi	Spain (Canary Islands).	Entire	E	142	NA	NA

[Added by 49 FR 7397, February 29, 1984]

Common name	Scientific name	Historic range	Vertebrate population where endangered or threatened	Status	When listed	Critical habitat	Special rules
Lizard, Ibiza wall	Podarcis pityusensis	Spain (Balearic Islands)	Entire	T	142	NA	NA

[Added by 49 FR 7397, February 29, 1984]

[Sec. 17.11(h)]

REFERENCE NO. 8

NUS CORPORATION TELECON NOTE

CONTROL NO:	DATE: 3/3/89	TIME: 1147

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BETWEEN:	OF:	PHONE:
~~[illegible]~~ Nancy Schlotter	EPA - GW Mgmt.	(212) 264-4124

AND: Diani Trube (NUS)

DISCUSSION:

No aquifers in Virgin Islands have been designated as sole source aquifers. None have been proposed, and no proposals are expected

ACTION ITEMS:

TUT 002 0137

REFERENCE NO. 9

EPA REGION II
SCANNING TRACKING SHEET

DOC ID # 64413

DOC TITLE/SUBJECT:

TUTU WELLS SUPERFUND SITE
TABLE-1
DESCRIPTION OF WELLS AND SEPTEMBER 11, 1987 WATER-LEVEL MEASUREMENTS IN TURPENTINE RUN BASIN, ST. THOMAS, U.S. VIRGIN ISLANDS

THIS DOCUMENT IS OVERSIZED AND CAN BE LOCATED IN THE ADMINISTRATIVE RECORD FILE AT THE

SUPERFUND RECORDS CENTER
290 BROADWAY, 18TH FLOOR
NEW YORK, NY 10007

REFERENCE NO. 10

Uncontrolled Hazardous Waste Site Ranking System

A Users Manual
(HW-10)

Originally Published in
the July 16, 1982, *Federal Register*

United States
Environmental Protection
Agency

1984

TUF 002 0141

TABLE 2

PERMEABILITY OF GEOLOGIC MATERIALS*

Type of Material	Approximate Range of Hydraulic Conductivity	Assigned Value
Clay, compact till, shale; unfractured metamorphic and igneous rocks	$<10^{-7}$ cm/sec	0
Silt, loess, silty clays, silty loams, clay loams; less permeable limestone, dolomites, and sandstone; moderately permeable till	$10^{-5} - 10^{-7}$ cm/sec	1
Fine sand and silty sand; sandy loams; loamy sands; moderately permeable limestone, dolomites, and sandstone (no karst); moderately fractured igneous and metamorphic rocks, some coarse till	$10^{-3} - 10^{-5}$ cm/sec	2
Gravel, sand; highly fractured igneous and metamorphic rocks; permeable basalt and lavas; karst limestone and dolomite	$>10^{-3}$ cm/sec	3

*Derived from:

Davis, S. N., Porosity and Permeability of Natural Materials in Flow-Through Porous Media, R.J.M. DeWest ed., Academic Press, New York, 1969

Freeze, R.A. and J.A. Cherry, Groundwater, Prentice-Hall, Inc., New York, 1979

REFERENCE NO. 11

The Geological Society of America
Memoir 98

CARIBBEAN GEOLOGICAL INVESTIGATIONS

By

H. H. Hess, *Editor*
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1966

the final base map, have good shore-line detail. Mapping on St. John was done on 1:20,000 enlargements of the 1:40,000 U.S. Coast and Geodetic Survey map. Aerial photographs of approximately 1:30,000 scale were useful for some structural interpretations.

Exposures along the shore lines ranged in quality from excellent to very poor. Those inland, except in recent road cuts, were almost invariably very poor. The best ou[illegible] St. Thomas and St. John are steep cliffs, which are in pla[illegible] traverse. More sheltered shore lines are easily walked, but r[illegible] here are much poorer.

Laboratory investigat[illegible] study of several hundred thin sections, X-ray diffraction examination of rock samples and mineral separates, about 300 partial chemical analyses, and numerous mineral determinations by optical examination of crushed samples. About a dozen feldspars were determined by measurement of index of refraction of grains oriented on the universal stage, according to the method of Smith (1960). Approximately 100 additional plagioclase samples were determined by measurements of indices of refraction of unoriented grains. An extensive optical study of the feldspars, completed after this manuscript was first submitted, has been published elsewhere (Donnelly, 1963). Pyroxenes were determined by measurement of n_y and 2V, according to the method of Hess (1949).

SUMMARY OF STRATIGRAPHY OF ST. THOMAS AND ST. JOHN

The rock units of St. Thomas and St. John (Fig. 2) can be divided into three major groups: the Water Island Formation, which consists of keratophyres and spilites; the Virgin Island Group, which consists of andesitic pyroclastic rocks and sediments; and one or more dioritic plutons. The Water Island Formation possibly is late Lower Cretaceous. The Virgin Island Group is probably Albian (although the Hans Lollik Formation could be Eocene), and the diorites are early Tertiary.

The oldest rocks in the Virgin Islands are the keratophyres and spilites of the Water Island Formation. These volcanic rocks are predominantly flows and flow breccias, but keratophyric pyroclastic rocks are widespread. A few of the fine-grained tuffaceous beds contain well-preserved Radiolaria of undetermined age. Noteworthy in the Water Island Formation is the absence of terrigenous sediments. This characteristic, together with their apparently igneous mineralogy, has led the writer to the conclusion that they are probably volcanic rocks which were extruded on a relatively level ocean floor, prior to the existence of a trench or island platform.

In contrast to the postulated abyssal environment for the Water Island volcanic rocks, most of the overlying pyroclastic rocks of the Virgin Island Group were extruded subaerially. Both the volcanic and sedimentary rocks exhibit slump structures, and some megabreccias contain limestone blocks up to 100 feet long. The bulk of the sedimentary rocks in the Virgin Island

Group are coarse wackes consisting almost entirely of slightly weathered debris derived from the andesitic pyroclastic rocks. The deposition of this group may have accompanied the formation of the initial island platform and trench.

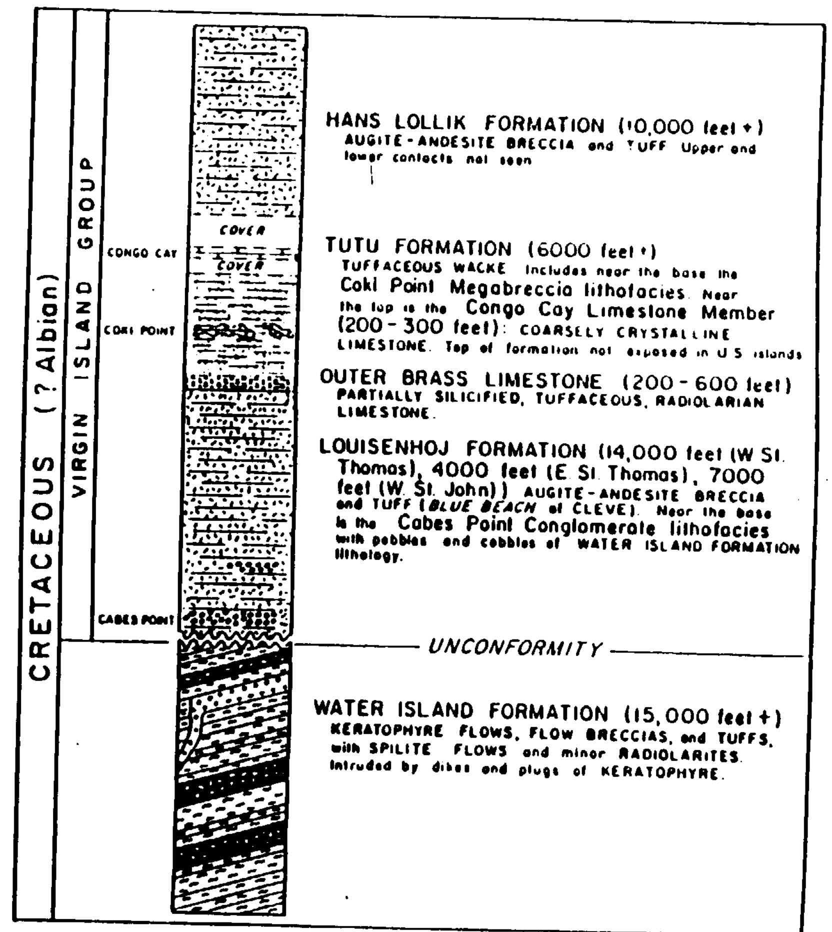

FIGURE 2. Stratigraphic section for St. Thomas and St. John, Virgin Islands

Folding after deposition of the Virgin Island Group resulted largely from differential vertical movement and produced average dips of 10°, ranging from 15° to 90°. The associated strike-slip faults have horizontal offsets of less than 1 mile. Although contact metamorphic effects resulting from the emplacement of dioritic plutons are extensive, the western two thirds of St Thomas and the southern third of St. John are essentially unmetamorphosed.

WATER ISLAND FORMATION

GENERAL STATEMENT

The Water Island Formation of possible late Lower Cretaceous age consists almost entirely of keratophyre, spilite, and radiolarian tuff. The exposed thickness of this formation is 15,000 feet, based on projection of the highest and lowest horizons seen. A reasonable correction for lenticularity might lower the true thickness of the exposed section to 8000 or 10,000 feet. Water Island, in the harbor of Charlotte Amalie, St. Thomas, has been selected as the type locality because of the great variety of rock types there and the general excellence of exposures, although excellent exposures crop out extensively along the south shores of St. Thomas and St. John.

"Keratophyre", as used here, is an extrusive or hypabyssal intrusive volcanic rock consisting prodiminantly of albite and quartz, with chlorite, micaceous minerals, and iron oxides. Nearly all of the Virgin Islands keratophyres contain considerable free quartz, commonly as conspicuous phenocrysts. Those with quartz phenocrysts could be called "quartz keratophyre" but many aphanitic rocks here called "keratophyre" are chemically identical to the so called "quartz keratophyres" and the simplest term is preferred for all these rocks. A striking feature of keratophyres is the absence of phenocrysts (or pseudomorphs) of pyroxene, amphibole, and mica. Keratophyric flows and crystal tuffs are sodic, with a very low potassium content, but some apparently vitric tuffs are slightly more potassic. Keratophyre intrusive rocks have a higher potassium content an' commonly contain secondary monoclinic K feldspar.

"Spilite" is a greenish seemingly altered extrusive or hypabyssal intrusive rock, consisting of chlorite and albite, with variable amounts of epidote, prehnite, and calcite, Fresh phenocrysts of clinopyroxene are generally present; amphibole and olivine were not seen in the Virgin Islands spilites. Amygdules are abundant and commonly contain most of the calcium content of the rocks as epidote, calcite, or prehnite, with quartz and chlorite. These spilites contain about the same amount of Na_2O as the augite andesites of the Louisenjoj Formation, and about 0.5 per cent more than Virgin Islands diabase dikes. Included with the spilites here is a partially albitized augite andesite which occurs near the top of the formation.

The name spilite has been applied in the past to many diverse rock types, some of which may be low-grade regionally metamorphosed andesites or basalts. Other spilites appear to have been unusually hydrous mafic intrusive rocks, and many are deuterically altered basalts or andesites. However, there is an impressive body of evidence that many so-called spilites, notably certain Ordovician, Devonian, and Cretaceous geosynclinal spilites, have characteristics which can be best explained by assuming an essentially magmatic origin for these rocks. It is to this latter group of rocks that the Water Island Formation spilites belong.

Such spilites may be thought of as rocks which have formed by albitization of andesites. However, this process is believed to occur during a late stage in the solidification of a hydrous mafic magma and is not caused by later metamorphism. Given a certain combination of physical and chemical conditions, spilitization of mafic extrusive rocks is inevitable. Hence the term, applied in an admittedly restrictive genetic (hence subjective) sense, is a useful one and should be retained. The author admits that low-grade metamorphism may obliterate the mineralogical criteria necessary for the recognition of spilitization. Chemical analysis of a large and carefully selected suite of specimens might reveal whether or not the metamorphic rocks in question had been originally spilitized, but such analysis might also fail to do so, and the term should be applied with care to such rock suites.

KERATOPHYRES

Introductory statement. Keratophyre comprises about four fifths of the Water Island Formation. Most keratophyre occurs as flows and flow breccias, with minor tuffs, both crystalline and vitric (the latter always devitrified) and, rarely, volcanic breccias. Keratophyric intrusive rocks are not uncommon, they occur as both dikes and plugs, commonly with very well developed columnar jointing.

Keratophyric flows are generally tens of feet in thickness. Few thick flows are completely exposed from top to base; those which are well exposed are striking only for their textural uniformity. Baking and chilling phenomena are absent. Flow banding, usually somewhat contorted, is seen locally (Pl. 3, fig. 4). Contacts between flow units are commonly difficult to identify as such, and attitudes of the flows are not always easily ascertained.

One thick keratophyre flow near the base of the section, on Ram Head, St. John, shows good field and petrographic evidence of vertical differentiation. The flow is about 165 feet thick, and near the center is reddish gray, grading to greenish gray downward and upward. Petrographic differences will be discussed later. The color change observed in the field would appear to be related to a differential degree of oxidation of iron within the flow, which is probably related to relative concentration of volatiles in the flow center during cooling.

Keratophyre flow breccias, occurring as discrete beds, are probably more common than flows in the keratophyre sequence but are difficult to distinguish from flows. The matrix of the flow breccias can frequently be distinguished from the fragments only by careful scrutiny of the outcrop; the patina of weathering which covers most keratophyres effectively obscures the fine details necessary to recognize these rocks. Fragments in flow breccias are subangular to subrounded. The matrix is almost identical to the fragments in polished section; however, the matrix weathers more rapidly, and in outcrop a flow breccia will appear rougher in gross texture than a flow. A few flow breccias consist of both kertophyre and spilite fragments. One such occurrence (sample GSJ-2, near the west end of Great St. James Island) is a 100-foot-thick bed of keratophyre and spilite rubble with a few limestone fragments set in an apparently igneous matrix. The minor recrystallization of the limestone suggests a low temperature of extrusion. No conglomerates were identified within the Water Island Formation, although many flow breccias have rounded as well as angular fragments and, when weathered, resemble conglomerates. [illegible] (sample ST-274, Lisenlund, St. Thomas) would undoubtedly [illegible] a conglomerate by most field geologists, but unweathered specimens found a short distance eastward along the strike show the igneous matrix very clearly.

Tuffs and volcanic breccias form minor but distinct units in the formation. Tuffs (grain size less than 32 mm) are much more common than breccias and occur as beds only 1 or 2 feet in thickness. None of the tuff units could be demonstrated to have a horizontal extent greater than about half a mile. Grading is visible in the tuff beds, although this grading is commonly interrupted by diastems representing the action of water currents on the sea bottom. Slump structures, generally in the form of contorted bedding, are uncommon. Many tuff beds are silicified, although the original pyroclastic groundmass is recognizable in thin section. Apparently the originally vitric groundmass of many tuffs has altered to fine-grained mica minerals; muscovite is the most widespread, and celadonite and stilpnomelane have been recognized.

One of the best exposures of a keratophyre breccia is on the east shore of Lameshur Bay, St. John (sample SJ-7). Here a bed several tens of feet thick consists of angular fragments of keratophyre a few mm to 5 cm in a reddish, hematitic matrix (Pl. 4, fig. 4). The hematitic matrix contrasts with the more neutral colors of most other keratophyre flows and tuffs in which hematite is generally subordinate to magnetite.

Dikes and shallow plutons of keratophyre occur throughout the formation, but are most conspicuous in the hills southwest of Charlotte Amalie, St. Thomas (Haypiece Hill, Grambokola Hill, Sara Hill, Cabritaberg), in the vicinity of Nazareth Bay, St. Thomas, and in the vicinity of Hoffman and Mt. Zion, St. Thomas. (Mt Zion itself, however, is underlain by another type of intrusive rock.) These bodies commonly exhibit columnar jointing perpendicular to the cooling surface, and examination of the joints provides a means of reconstructing the shape of the intrusive body.

The hills around the Submarine Base on St. Thomas (Cabritaberg, Grambokola, Haypiece, and Sara hills) are underlain by one or two intrusive bodies known collectively as the Submarine Base Pluton. The accompanying map and sections (Fig. 3) show that the form of the intrusive body is irregular. The pattern of joints around Haypiece Hill strongly suggests the presence of an intrusive funnel beneath this hill. The joint pattern beneath eastern Sara Hill, on the other hand, would appear to suggest that the floor of the intrusive body is subhorizontal, irregular, and shallowly dipping here. The intrusive-extrusive contact near a probable vent at the southern end of

Grambokola Hill is moderately steep. On Cabritaberg Hill the columnar joints are nearly horizontal or shallowly dipping toward the southern end of the intrusive body, but are nearly vertical approximately 300 feet north of the southern contact. An outcrop of extrusive rock, evidently occurring

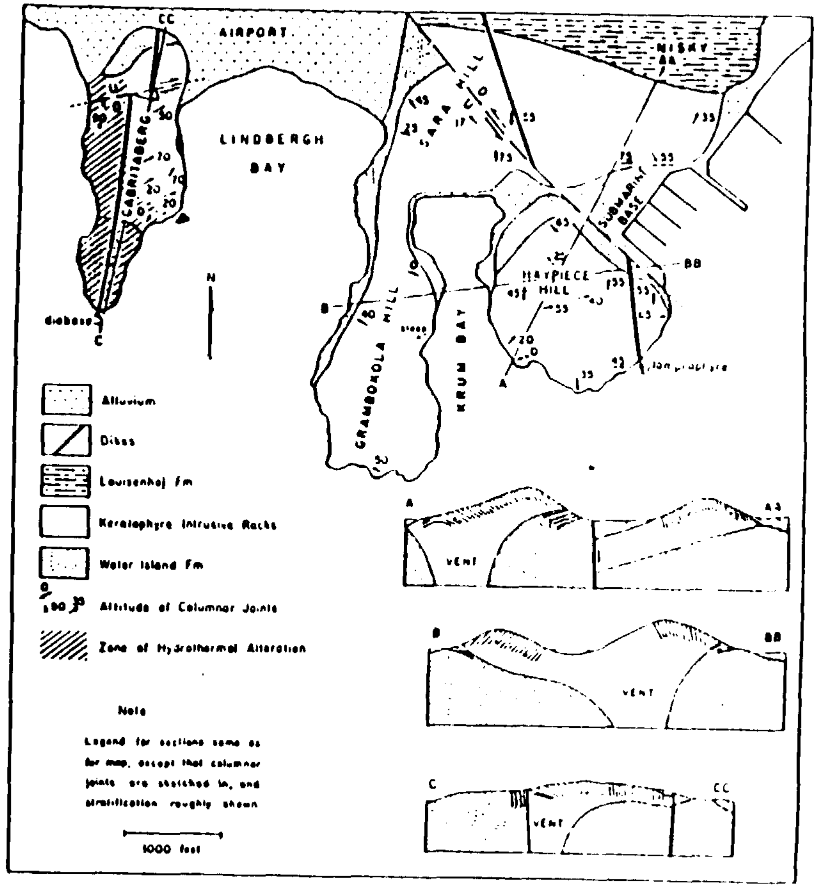

FIGURE 3. Map and cross sections of the Submarine Base pluton, St. Thomas. Refer to Plate I for location.

just underneath the intrusive body, can be seen along the shore just south of the Caribbean Hotel. Here the intrusive body was probably fed through a steep conduit at its southern end, and spread northward as a roughly conformable sheet. It is not known whether or not this intrusive body connects with the other one at shallow depth.

The occurrence of intrusive keratophyre in moderately large bodies toward the top of the section may reflect a subtle upward change in lithology:

ture optics), and rare biotitic mica and a mafic mineral which has altered completely to a fine grained, very red substance. This could be either iddingsite, bowlingite, or some other clay mineral or combination of minerals. The glass fragments have diffuse outlines and could be shards. In no case, however, has the degree of preservation revealed the outlines of the original glass fragments. The appearance of these beds in thin section is very similar to the slightly devitrified tuffaceous beds found in explosive rhyolitic suites, but their explosive origin is not established by petrographic evidence.

STRATIGRAPHIC VARIATIONS

The Water Island Formation is remarkably uniform, consisting throughout of about one fifth spilite and the remainder keratophyre. The lower portion of the formation, seen best at Ram Head, St. John, and on Great St. James Island, consists dominantly of thick keratophyre flows with intercalated spilites. Breccias and pyroclastic rocks are minor and form only very thin units with a limited lateral extent. The upper portion of the formation, seen best in the vicinity of Charlotte Amalie, St. Thomas, and on Water Island itself differs principally in the greater percentage of pyroclastic units. Around the intrusive bodies of Haypiece Hill, Grambokola Hill, and Cabritaberg, the formation is dominantly pyroclastic, with only a few thin keratophyric flows. On Flag Hill, stratigraphically slightly lower than these pyroclastic rocks, a strikingly thick pyroclastic unit is intercalated in a dominantly flow sequence. No mineralogical distinctions between the lower and upper portions of the formation can be seen except that near the top of the formation there is one occurrence of oligoclase and albite with high-temperature optics, and there are three occurrences of albite with optics which deviate significantly from the low-temperature state and which have been called quasi low-temperature optics (Donnelly, 1963).

ENVIRONMENT

The most striking feature of the Water Island Formation is the complete absence of terrigenous sediment: the entire exposed thickness consists of volcanic rocks only slightly reworked locally by water. The second important feature of this unit is that most of the volcanic rocks, except for the uppermost 5 per cent of the formation, are flows. The pyroclastic rocks themselves consist entirely of relatively equant, angular fragments, and shards or pumiceous fragments are not seen. The quiescent eruption of apparently hydrated magmas must indicate that these magmas were erupted under a confining pressure of superincumbent sea water approximately equivalent to that of the deep-sea bottom, which is sufficient to prevent the explosive expansion of a magmatic gas phase. Hydrated magmas erupted in this environment will experience separation of volatiles if the

partial pressure of these volatiles exceeds that of the sea water (about 500 atm at 15,000 feet). The expansion of these volatiles, however, will be in the order of a few times, not many thousand times, as would be the case if the magmas were erupted subaerially or in shallow water. Abyssal pyroclastic rocks will not be formed by explosion but by relatively quiet expansion of volatiles and sudden chilling by sea water. Dispersal of pyroclastic fragments will probably be effected by slow-moving bottom currents, or convective currents initiated by the release of heat into the sea water. The absence of terrigenous sedimentary rocks indicates that there were no emergent islands which could have served as the source of weathered detritus. Slump structures or other evidences of deposition on slopes are present but are not abundant; in contrast, near the top of the formation there are several striking occurrences of evenly layered pyroclastic keratophyre with no bedding disturbances. Evidently this formation accumulated not only in abyssal depths but also on rather flat sea bottom. The appearance of slightly more explosive eruptives only at the very top of the Formation shows that the sea bottom may have been subsiding during the greater part of the accumulation but that subsidence was not rapid enough to maintain a constant water level at the eruptive center of the accumulated volcanic deposits. Alternatively, regional uplift near the end of Water Island time could have been responsible for the apparent shallowing of water.

VIRGIN ISLAND GROUP

LOUISENHOJ FORMATION

Introductory statement. Unconformably overlying the Water Island Formation and cropping out on about half the land area of St. Thomas and St. John is the Louisenhoj (Lōō ē' zan hoi) Formation, named for excellent exposures in road cuts in the vicinity of Louisenhoj, just north of Charlotte Amalie, St. Thomas. This thick sequence is predominantly augite andesite and varies in mode of deposition from pyroclastic to epiclastic. The maximum apparent thickness traversed is about 13,000 feet, but a reasonable correction for lenticularity might reduce this computed thickness by a third or more. Cleve (1871) called this rock type "Blue Beach" and this name has persisted: all of the natives of the Virgin Islands are familiar with "Blue Bitch" or "Blue Bit."

The formation is thickest and almost entirely pyroclastic (locally reworked tuff beds are considered essentially pyroclastic) in western St. Thomas. In eastern St. Thomas the formation is much thinner (1000 feet) and is composed almost entirely of coarse slumped and reworked pyroclastic debris, probably originating from a small subaerial cone. In western St. John the formation is thicker (7000 feet minimum) and consists predominantly of coarse cone debris. Figure 6 shows an interpretation of the conditions which resulted in this distribution of rock types and thicknesses. Evidence for the

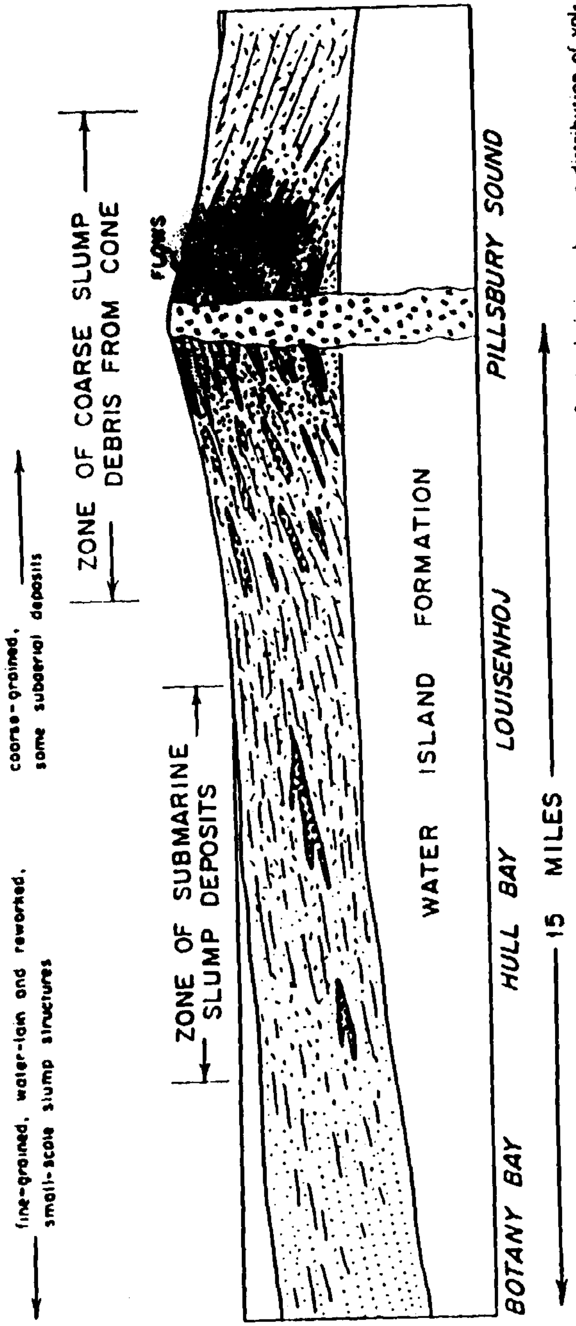

FIGURE 6. Hypothetical east-west cross section through St. Thomas and western St. John during Louisenhoj time, showing distribution of volcanic facies around a subaerial cone.

postulated Pillsbury Sound eruptive center is based on the coarseness of volcanic ejecta in nearby western St. John and eastern St. Thomas, on the presence in Pillsbury Sound of a dioritic pluton, and on the necessity of finding the nearest reasonable source for the lithic framents in the Louisenhoj Formation of western St. Thomas. In western St. Thomas (15 miles from the presumed eruptive center) occasional angular blocks 6 inches in diameter are found in the ash beds, which themselves range from fine tuff to fragments about 1 inch long.

The coarse cone debris is most striking in western St. John and eastern St. Thomas. In western St. John 4-foot blocks of what must have been subaerially deposited ash from the slopes of the cones are found mixed in coarse conglomeratic beds. Near Mandal in eastern St. Thomas large fragments of what may have been a subaerial andesite flow are seen in breccias of debris eroded from the cone. At one locality fragments of flow up to 2 feet long rest in a matrix of finer material. Many of these fragments broke apart just prior to cessation of transport, and their broken outlines can be matched in outcrop. This is the only probable flow material identified in this formation.

At the type locality the formation consists dominantly of beds of coarse andesitic tuff which, like most of the tuff seen, was apparently water-laid. The beds are typically 6–12 feet thick and have fair grading with the coarsest material (rarely coarser than about 3 inches; a few blocks to 1 foot) near the base. These beds commonly show laminar slumping (Figs. 7, 8). The most striking feature of this slumping is the abundance of "pull aparts" and the frequent interruptions and reversals of the grading. This laminar slumping is a very characteristic feature of the Louisenhoj Formation and apparently formed as follows: an ash fall was deposited underwater (Fig. 7A) on a slope and developed fair grading, interrupted occasionally by a large angular block which depressed the bedding below it. The fine ash on top became cohesive more rapidly than did the coarser ash below. The less cohesive, coarser material below slumped (Fig. 7B), carrying on it and enveloping within it fragments of the more cohesive, finer-grained material above. The flow was rarely rapid enough to become turbulent; the pulled-apart beds have nearly all retained an orientation parallel to the bedding. During this process of slump the grading lost its original arrangement, and the coarsest material is commonly found somewhat above the base of the unit. Additional evidence for deposition on a slope is the nearly ubiquitous slump structures seen in fine-grained tuffs in the formation.

Purely pyroclastic beds are not always easily distinguished from tuff beds which have slumped and from beds which have been more or less reworked by water currents. Coarser pyroclastic rocks usually exhibit the fragment angularity, the uniformity of lithologies, and the apparently igneous matrix which one associates with ash deposits, whereas finer ash beds resemble volcanic wacke. The over-all aspect of this formation suggests aerial transport and subaqueous deposition of pyroclastic debris. Transporta-

Cabes Point Conglomerate lithofacies. Near the base of the formation in the vicinity of Cruz Bay, St. John, and Cabes Point, Pearson Gardens, and Bunker Hill, St. Thomas, conglomerates are interbedded with andesitic pyroclastic and epiclastic rocks. These conglomerates consist almost entirely of well-rounded keratophyre cobbles and pebbles derived from the underlying Water Island Formation. At Cruz Bay, however, these conglomerates are more or less mixed with andesitic debris, suggesting that subaerial erosion of the cone deposits and that of the underlying keratophyre beds were simultaneous. At Cabes Point the conglomerate is composed of well-rounded and fairly well-sorted keratophyre and spilite cobbles and pebbles. These conglomerate beds appear to have been deposited in shallow water, and were not products of turbidity-current deposition. They are well sorted, are not graded, and have relatively little matrix. Their presence indicates subaerial erosion, transport, and deposition of older rocks during early Louisenhoj time.

Water Island-Louisenhoj contact. There are few places where the contact between the Water Island and Louisenhoj Formations is well exposed. In St. John there is one excellent exposure of the contact along the west shore of Monte Bay, and there are poor exposures at Klein Bay. The exposure on Monte Bay shows a conglomerate of the Louisenhoj overlying a spilite bed. The spilite is quite fresh at the contact, and the overlying conglomerate contains a wide assortment of Water Island lithologies including, however, very few rocks identifiable with the underlying spilite. At Calvary Bay, St. John, there is an exposure of a conglomerate of the Louisenhoj Formation overlying keratophyre.

On St. Thomas the contact itself is poorly exposed, but an extensive exposure of Louisenhoj beds above the contact at the headlands between Brewer's Bay and the airport is of great interest because of the extent of apparently contemporaneous weathering displayed here. The Louisenhoj beds here consist dominantly of subaerially, varicolored andesitic ash interbedded with conglomeratic Water Island detritus. Some of the ash units are brick red and consist solely of albite, hematite, and a little illite (X-ray diffraction). The albitized plagioclase phenocrysts evidently withstood the weathering almost perfectly, but the entire mafic part of the rock has been converted to oxide. Other units consist of varicolored fragments ranging from deep red to green, evidently reflecting differential susceptibility to weathering. Still other units consist of greenish or grayish fragments in a uniformly purplish matrix. The basal subaerially weathered unit is less than 100 feet thick and was found at only this one locality. The color of the beds somewhat resembles that of the weathered hydrothermally altered rocks (discussed in a following section), but the latter grade into whitish unweathered rock within a few feet of the surface and are mineralogically quite distinct. The extent of this weathering is completely unlike any recent weathering of any rock types in these islands and undoubtedly reflects weathering contemporaneous with original deposition.

Another occurrence of contemporaneous weathering is poorly exposed at Wintberg Hill, St. Thomas. The poor natural exposures, which are of lightly metamorphosed rock, were originally thought to be of hydrothermally altered rock. However, recent (1963) excavations for road construction revealed the originally weathered nature of these rocks.

Mineralogy of mafic fragments. The principal minerals found in mafic fragments are plagioclase, clinopyroxene, chlorite, and pumpellyite, and also matrix and opaque minerals.

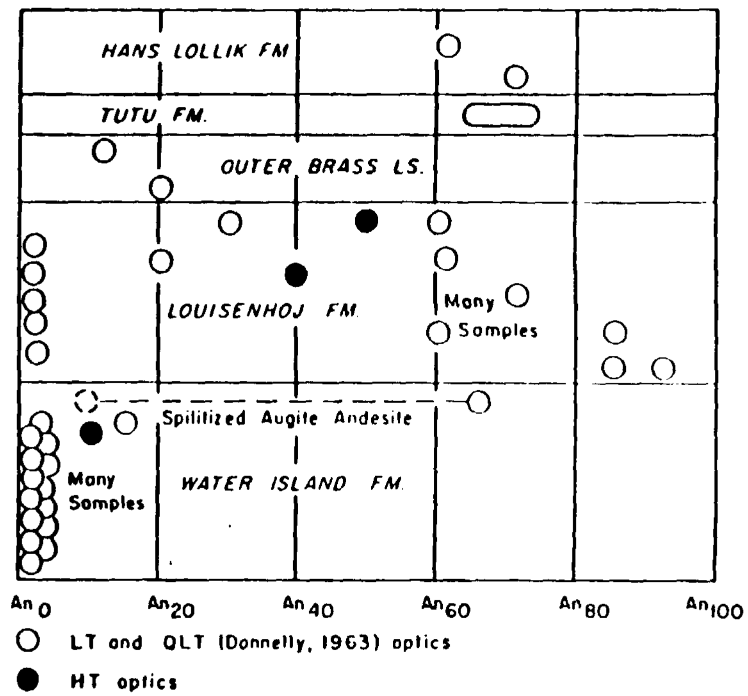

FIGURE 10. Compositions of plagioclases arranged according to stratigraphic position

PLAGIOCLASE: Most phenocrysts of the Louisenhoj andesites are labradorite, about An_{60} (Fig. 10). Near the base of the formation many pyroclastic rocks contain a distinctly more calcic plagioclase (An_{85} to about An_{92}). Some of these pyroclastic rocks contain both bytownitic and labradoritic fragments, but a few contain only bytownitic (or anorthitic) fragments. The feldspars are sharply euhedral and slightly zoned. They show abundant simple twinning and some albite twinning. Groundmass plagioclases and plagioclases in the matrix of coarse pyroclastic rocks are very fine-grained and cloudy. Many are distinctly more sodic than the phenocrysts and range in calcium content down to An_{20}. In many lapilli tuffs, the only feldspar found is albite (An_5);

composition of the more siliceous differentiates. The experiments of Yoder and Tilley (1962) show clearly that at water pressures greater than about 1000 bars, material of basaltic composition should be converted to a mixture of hornblende and plagioclase at subliquidus temperatures. As the temperature rises the material will begin to melt, with the plagioclase being consumed first. The first liquids produced will be highly felsic and siliceous. The compositional trend of liquids produced at successively higher temperatures has not been experimentally determined, but a comparison with the analogous sequence in anhydrous cases (generation of basalt) suggests that hornblende will take the place of diopside as the dominant mafic phase being consumed during the greater part of the melting. The hydrous liquid might, therefore, be more enriched in Si than would comparable liquids coexisting with diopside in the anhydrous case. The extent to which residual hornblende might control the composition of the liquids will not be easily evaluated until these hornblendes can be collected and analyzed, but this consideration might prove to be pivotal.

The quantity of keratophyric magmas generated is perhaps the only really serious objection to the hypothesis of generation of this entire suite from the upper mantle. The quantity of siliceous rocks is unknown, but geological inference (exposed area of Water Island Formation, which is about 80 per cent keratophyre) combined with geophysical information (seismic refraction and gravity) suggest that the Water Island Formation is a prism about 5 km thick, extending perhaps 40 km in an east-west direction, but quite possibly thinning to the east, and extending perhaps 20 km in a north-south direction. This volume—4000 cu km, or 3200 cu km of keratophyre—is probably a maximum, because possible thinning to the east and to the south was ignored in the calculation. If fusion of 10 per cent of the upper mantle might yield a keratophyric liquid, then 32,000 cu km of upper mantle were fused during this igneous episode. If the depth of fusion was 10 km and the east-west horizontal extent of fusion 40 km, then the horizontal dimension of the fused zone in a north-south direction must have been 80 km. These figures may be off by an order of magnitude or more, but they emphasize one problem: the generation here of siliceous magma from the upper mantle may require the partial fusion of more material than can directly underlie the vent, unless the fusion extended to great depth. The explanation for this seeming paradox is as follows: During the orogenic process compression and thickening of hydrated Caribbean crust and upper mantle carried this material into the orogen from a considerable distance perpendicular to the axis of depression. The orogenic magmatic process then can be compared to a mill to which is fed fresh, hydrated upper mantle, and from which two products, magma and mafic residuum, are removed, the first through ascent and eruption and the second through gradual displacement downward and eventually laterally. The amount of keratophyre erupted might have required lateral shortening of about 80 km in this area. The quantity of siliceous igneous rock seen here is far in excess of any that has been recorded in similar orogenic zones, and

the Virgin Islands may be an extreme example of a process which has occurred to a lesser extent in many places at many times. Clearly our knowledge of the composition of upper mantle is too limited at this time to assess this problem further.

The writer (Donnelly, 1964) also pointed out that the generation of a second, strengthless phase (aqueous, or hydrated silicate melt) during orogenic thickening would have profound structural implications. The volume in which this phase was generated would become essentially strengthless, and the structural process would be expected to change from a relatively mild thickening to a more violent movement along an extensive shear. The consequences of this movement would be that the island platform would be raised to an emergent level, and possibly an adjoining oceanic trench would be formed. The effect on the generation of igneous melts would be that the rate of depression of mantle material (and the rate of heating) should be increased greatly. After this profound structural episode, the generation of magma will be relatively rapid, and the proportion of mafic to felsic magma high. The restriction of abundant siliceous magmas to the early stages of orogenic evolution is consistent with this idea.

In conclusion, the following points seem well established: (1) Two types of chemically uniform magmas were generated throughout the span of geologic history of these islands. (2) There has been interaction of erupted magmas with the environment in the case of alkali exchange in extrusive keratophyres. Other possible exchanges have not been established, except that a few samples of highly metamorphosed keratophyres have been impoverished in alkalies. (3) The siliceous magmas represent ternary (Q-Ab-Or) melts derived by partial fusion in a dominantly sodic environment, and most probably, in an environment with considerable calcium. The later behavior of this presumed calcium remains one of the important anomalies. This parent material, for diverse reasons including geophysical and chemical evidence, is considered to be upper mantle. (4) The mafic magmas are chemically similar to so-called high-alumina basalts typical of orogenic regions generally. The high magnesium of the spilites results from its generation from a material largely depleted in iron by abstraction of keratophyre. (5) The increase in aluminum with time and the higher normative Ab/Q ratio of the later quartz-andesine porphyries of the second group may indicate generation at increasing depth with time. (6) Crystal settling and assimilation of wall rock were probably of little importance in the generation or differentiation of this suite.

SUMMARY OF GEOLOGIC AND TECTONIC HISTORY OF THE NORTHERN VIRGIN ISLANDS

The tectonic evolution of the Puerto Rico-Virgin Islands area has already been discussed by the writer (Donnelly, 1964). The following account summarizing the geologic history of the northern Virgin Islands elucidates these ideas but introduces no new concepts. The major east-west fault deduced largely from gravity evidence was not recognized at the time that paper was prepared; however, its existence requires no modification of the ideas presented.

The keratophyres and spilites of the Water Island Formation were extruded on a relatively flat sea bottom, as indicated by lack of terrigenous detrital sediment and paucity of slump structures in most tuffaceous units. A major east-west high-angle fault inferred from gravity data was probably the locus of eruption of these magmas as well as most of the later magmas. Movements along this fault simultaneous with eruption led to accumulation of the Water Island rocks in a basin with a sharply defined northern edge. There is some evidence of shallowing of the water level toward the end of Water Island time in the greater proportion of tuffaceous keratophyres at the very top of the section. The end of Water Island time was marked by abrupt emergence, possibly in part along the major east-west fault noted previously. This movement, as well as subsequent movements along this fault, was of an opposite sense to the original movement: the northern side went down. Overlying basal Louisenhoj beds were deposited subaerially and weathered to form a brick-red soil completely unlike any that are forming at the present time. Intercalated conglomerates of predominantly keratophyric clasts which are especially abundant near the base of the Louisenhoj show that there was a rather persistent emergent source area of older rocks exposed at this time. Slow subsidence after early Louisenhoj time is reflected in the gradual diminution in abundance of conglomeratic units, the finer grain size of the pyroclastic deposits and their reworked equivalents, and the increasingly excellent grading of the tuff beds toward the top of the formation. The overlying Outer Brass Limestone represents almost complete volcanic quiescence and subsidence below the level of effective wave erosion of the older rock units.

The beginning of Tutu time was the beginning of renewed differential vertical movement, with newly created or rejuvenated steep slopes shedding wackes into water of unknown depth. Emergence of part of the source area is seen in the abundance of partially weathered Louisenhoj fragments among the detrital component of the Tutu Formation and in the intercalated blocks of fossiliferous limestone of the Coki Point Megabreccia lithofacies. A brief period of near-emergence is seen in the Congo Cay Limestone Member. The recrystallization of this unit is too extensive to have preserved any of the diagnostic petrographic criteria which might have revealed something of its environment of deposition, but its massiveness and nearly pure calcitic composition shows that it must have been a bank deposit of nearly pure skeletal debris.

Renewed vulcanism after Tutu time is seen in the thick augite andesite pyroclastic rocks of the Hans Lollik Formation. Mineralogically this andesite appears to be identical to that of the Louisenhoj Formation.

Post-Hans Lollik Formation history is obscure in the American islands

and has been treated in more detail by Helsley (1960 thesis) in the British Virgin Islands. A date of Middle Eocene near the top of the Tortola Formation (which includes the Hans Lollik Formation, called by Helsley a member, in the British islands) establishes the age of the upper part of the Virgin Islands Group. The large batholith in the British islands intrudes the Tortola Formation and is apparently contemporaneous with the nonfossiliferous Necker Formation.

Horizontal forces of any orientation or sense cannot be shown to have played an important role at any stage during the evolution of this area. Nearly all the structural relationships observed, as well as the physical stratigraphic character of the rock units, can be more easily explained on the basis of differential vertical movements. Many fault planes across which such movements occurred may have continued to be the loci of fault displacements from Cretaceous to early Tertiary time, and even to the present.[4]

The problem of the generation of the magmas is inextricably linked with that of the structural evolution of the arc. The generation of all of the magmas is considered to have occurred as a result of the more or less partial fusion of hydrated upper mantle material, identical to that presently found beneath the Caribbean Sea at depths between 5 and 15 or 20 km below the sea floor. The large volume of siliceous keratophyre, and to a lesser extent, the volume of later mafic rocks, requires the fusion of upper mantle over a horizontal extent considerably greater than the present dimensions of the outcropping rock units. If the fusion was limited to the hydrated 10 to 15 km of upper mantle, then the only adequate explanation for the volume of magma erupted is that horizontal movements transported adjacent, unfused mantle into the orogen, where it was depressed, heated, partially fused, and then its refractory residuum slowly displaced downward and laterally.

The evolution of this portion of the West Indies is basically the response of juxtaposed, physically contrasting plates of crust and upper mantle to an applied horizontal force. Failure along the join between these plates resulted in thickening and downwarping in the initial stages (Water Island time), followed by compressive failure, the formation of a major reverse fault system, and rapid uplift, which formed an emergent island platform (Louisenhoj time) and, most probably, an adjoining oceanic trench. Further application of compressive forces caused further thickening and continued emergence of the island platform. There is no evidence in the Virgin Islands that submergence of any magnitude ever occurred after Water Island time. Magma was generated by the partial fusion of hydrated upper mantle; the proportion of siliceous and mafic magmas at any time reflects the rate of deformation and the rate of temperature rise.

The eastern Greater Antilles is a unique exhibit of the salient features

[4] See footnote 2, page 140.

of the earth's island arcs. This area has never been blanketed with the thick terrigenous sediments which have modified and later guided the structural evolution of most orogenic regions; it represents instead the direct interaction of oceanic crust and orogenic forces. The failure of these rocks to have been metamorphosed and their subsequent exhumation in a nearly pristine condition are probably the result of a lucky geological accident—the development of an extensive strike-slip fault system south of the island platform along which were resolved the bulk of the post-Eocene deformative forces. Within the island platform, the dominant tectonic forces have been differential vertical movements caused by thickening at depth. Although none of the structural or petrologic conclusions derived from this study can necessarily be applied to any other specific area, nevertheless certain observations cannot fail to raise serious questions concerning long-standing geological hypotheses which have not been seriously questioned in recent years.

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S T T H O M A S
CHARLOTTE AMALIE
AIRPORT
HASSEL IS
WATER IS
BUCK IS

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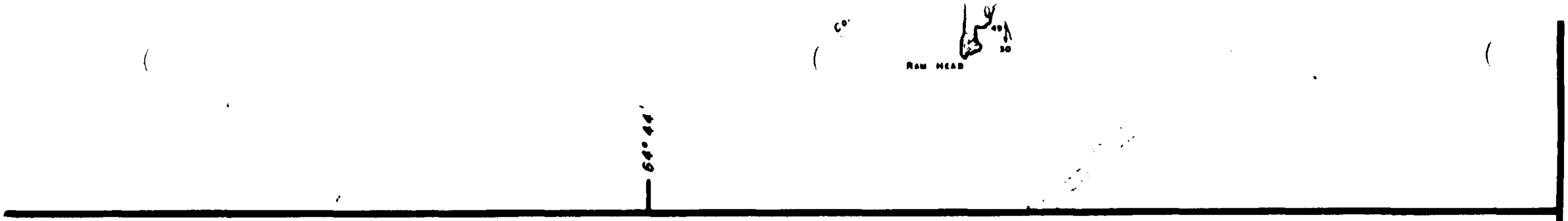


LEGEND

Quaternary		Alluvium
U. Cretaceous L. Tertiary		Dikes and Plugs: qa = quartz-andesine porphyry; ah = andesine-hornblende porphyry
Cretaceous (Albian ?)		Dioritic Rocks
Cretaceous (Albian ?)	Virgin Island Group — Khl	Hans Lollik Fm.: Augite andesite volcanic breccia and tuff
Cretaceous (Albian ?)	Virgin Island Group — Kt	Tutu Fm: Volcanic wacke. X-cp outcrop of Coki Point Megabreccia Ktcc — Congo Cay Ls. Member
Cretaceous (Albian ?)	Virgin Island Group	Outer Brass Ls.: Thin-bedded, siliceous ls.
Cretaceous (Albian ?)	Virgin Island Group — Kl	Louisenhoj Fm.: Augite andesite volcanic breccia and tuff, with minor conglomerate

? UNCONFORMITY

Lower Cretaceous		Quartz keratophyre dikes and plugs
Lower Cretaceous	Kwi	Water Island Fm.: Quartz keratophyre flows, flow breccias, and tuffs; radiolarites; spilite flows

	Contact
U D	Fault, showing displacement
40 90	Attitude of bedding
40 90	Attitude of fault
40 90	Attitude of intrusive contact

MAPPED BY THOMAS W DONNELLY (1956-1957)
SOUTHWEST TORTOLA BY C E HELSLEY (1958)

REFERENCE NO. 12

ISSN 0500-4780

CLIMATOLOGICAL DATA
ANNUAL SUMMARY
PUERTO RICO AND VIRGIN ISLANDS
1987

VOLUME 33 NUMBER 13

DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

"I CERTIFY THAT THIS IS AN OFFICIAL PUBLICATION OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION AND IS COMPILED FROM INFORMATION RECEIVED AT THE NATIONAL CLIMATIC DATA CENTER, ASHEVILLE NORTH CAROLINA" 28801

Kenneth D Hadeen

DIRECTOR
NATIONAL CLIMATIC DATA CENTER

noaa

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE

NATIONAL CLIMATIC DATA CENTER ASHEVILLE NORTH CAROLINA

TOTAL PRECIPITATION AND DEPARTURES FROM NORMAL (INCHES)

STATION	JUL		AUG		SEP		OCT		NOV		DEC		ANNUAL	
	PRECIP	DEPARTURE	PRECIP	DEPARTURE	PRECIP	DEPARTURE	PRECIP	DEPARTURE	PRECIP	DEPARTURE	PRECIP	DEPARTURE	PRECIP	DEPARTURE
VIRGIN ISLANDS														
ST THOMAS 01														
DOROTHEA AES	1.82		2.72		2.57		4.53		18.47		4.43		70.17	
ESTATE FORT MYLNER	2.04		2.76		.40		4.32		17.37		5.65		67.66	
ESTATE HOPE	1.88		2.96		2.90		4.57		12.91		4.27			
RED HOOK BAY	1.22		1.69		1.66		3.97		11.49		2.32		41.37	
TRUMAN FLD FAA AP	.99		2.41		1.42		4.35		10.36		2.99		42.84	
WINTBERG	.93		1.53		1.43		3.53		10.43		4.13		50.08	
--DIVISIONAL DATA------->	1.40	-1.85	2.22	-2.38	1.50	-4.60	4.14	-1.27	13.62	8.51	3.90	.12	53.97	10.23
ST CROIX 02														
ALEX HAMILTON FLD FAA	1.22	-2.14	1.63	-2.84	2.79	-2.84	2.65	-2.60	13.25	8.23	4.94	.96	M 50.10	
ANNALY	2.28		1.80		2.09		2.80		15.03		3.52		58.16	
ANNAS HOPE	1.80	-1.22	1.25	-3.12	1.50	-4.53	4.10	-.97	11.45	5.86	M			
BETH UPPER NEW WORKS	1.92		1.32		2.02		M 2.55		15.27		4.62		M 48.89	
CHRISTIANSTED FORT	2.28		.86		1.43		3.78		15.48		3.73		55.51	
COTTON VALLEY 2	2.50		M		M		3.86		10.17		2.39			
EAST HILL	1.46		1.13		1.45		5.13		13.80		3.19		54.89	
ESTATE THE SIGHT	2.20		1.81		1.23		4.86		14.51		2.96		58.10	
FOUNTAIN	3.00		1.91		1.50		3.00		15.23		5.50		61.67	
FREDERIKSTED 1 SE	2.31		2.09		2.92		2.52		15.76		3.74		56.75	
GRANARD	1.57		1.45		1.18		3.17		M		M			
HAM BLUFF L-H STN	1.95		1.62		1.42		M 2.33		16.95		2.96		M 59.02	
MONTPELLIER	2.55		1.38		2.10		4.63		13.78		4.42		58.78	
--DIVISIONAL DATA------->	2.08	-1.17	1.52	-3.08	1.80	-4.30	3.68	-1.73	14.22	9.11	3.82	.04	55.21	11.47
ST JOHN 03														
CANEEL BAY PLANTATION	1.74		2.15		2.23		5.07		12.86		3.90		48.22	
CATHERINEBURG	2.02		2.20		1.22		5.27		13.08		M 4.42		M 49.47	
CORAL BAY	1.74		M		3.65		3.56		11.52		4.56			
CRUZ BAY	1.59	-2.11	2.27	-2.02	2.42	-3.55	3.75	-1.37	8.54	4.03	M			
EAST END	2.10		1.88		2.08		3.08		10.39		3.67		40.62	
LAMESHUR BAY	1.65		1.90		M		M 3.08		10.64		4.04			
--DIVISIONAL DATA------->	1.81	-1.44	2.08	-2.52	2.32	-3.78	4.15	-1.26	11.17	6.06	4.04	.26	44.96	1.22

Norm. ann. 43.74

SEE REFERENCE NOTES FOLLOWING STATION INDEX

AVERAGE TEMPERATURES AND DEPARTURES FROM NORMAL (°F)

PUERTO RICO AND VIRGIN ISLANDS 1987

STATION	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANNUAL	
	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE	TEMPERATURE	DEPARTURE
OUTLYING ISLANDS 07																										
MONA ISLAND 2	M75.7		75.9		76.3		79.8		80.4		M		83.2		84.4		83.4		M		M		M79.7		M	
VIEQUES ISLAND #2	76.4		75.6		76.5		78.7		M79.5		79.1		80.0		81.7		81.9		80.8		79.0		78.1		M78.9	
--DIVISIONAL DATA------->	75.7		75.9		76.3		79.8		80.4				83.2		84.4		83.4						79.7			
VIRGIN ISLANDS																										
ST THOMAS 01																										
DOROTHEA AES	M		75.6		75.6		78.6		78.7		M79.9		M81.4		82.5		82.2		81.4		78.9		76.5		M	
RED HOOK BAY	M		M		M		M		M		M		M		M		M		M		M		M		M	
TRUMAN FLD FAA AP	78.8		79.1		78.9		81.7		81.4		82.4		83.8		85.1		85.1		83.9		82.3		81.0		82.0	
--DIVISIONAL DATA------->	78.3	1.7	77.8	1.2	77.5	.3	80.2	1.8	80.1	.3	81.2	-.2	82.6	.8	83.8	1.9	83.7	2.3	82.7	1.8	80.6	1.3	78.8	1.3	80.6	1.2
ST CROIX 02																										
ALEX HAMILTON FLD FAA	M78.3		77.8		77.9		81.3		80.6		82.6		83.9		M84.7		84.1		83.4		82.2		81.0		M81.5	
ANNALY	M		M		M		M		M		M		M		M		82.1		M		M		M		M	
BETH UPPER NEW WORKS	M		M		M71.1		M		M		M		M		M		M		M		M		M78.5		M	
CHRISTIANSTED FORT	M77.8		76.8		M		M		M		M		M		M		M84.3		82.8		M80.6		79.4		M	
--DIVISIONAL DATA------->	78.1	1.5	77.3	.7	74.5	-2.7	81.3	2.9	80.6	.8	82.6	1.2	83.9	2.1	84.7	2.8	83.5	2.1	83.1	2.2	81.4	2.1	79.6	2.1	80.9	1.5
ST JOHN 03																										
CATHERINEBURG	M74.3		M75.9		M75.1		M78.3		M77.7		M78.4		M78.9		M80.6		M81.9		M79.6		M77.3		M76.2		M77.9	
CRUZ BAY	M77.7		77.2		77.7		M81.0		M81.3		M82.7		M83.2		M84.5		83.8		M83.2		81.8		M		M	
--DIVISIONAL DATA------->	76.0	-.6	76.6	.0	76.4	-.8	79.7	1.3	79.5	-.3	80.6	-.8	81.1	-.7	82.6	.7	82.9	1.5	81.4	.5	79.6	.3	76.2	-1.3	79.4	0

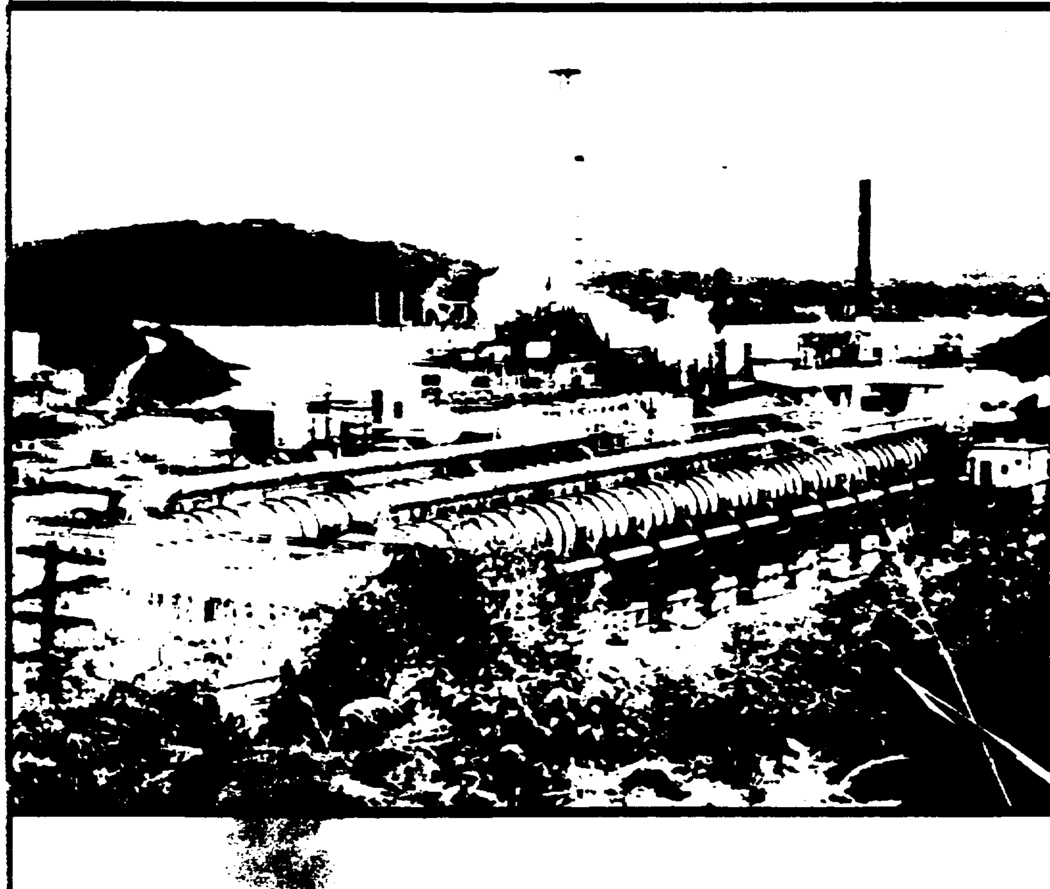
SEE REFERENCE NOTES FOLLOWING STATION INDEX

REFERENCE NO. 13

ESTIMATED WATER USE IN ST. THOMAS, U.S. VIRGIN ISLANDS, JULY 1983 - JUNE 1984

By

Heriberto Torres-Sierra and Rafael Dacosta



DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

OPEN-FILE DATA REPORT 84-721

Prepared in cooperation with the
CARIBBEAN RESEARCH INSTITUTE
COLLEGE OF THE VIRGIN ISLANDS
ST. THOMAS, U.S. VIRGIN ISLANDS

ESTIMATED WATER USE IN ST. THOMAS, U.S. VIRGIN ISLANDS, JULY 1983 - JUNE 1984

By

Heriberto Torres-Sierra and Rafael Dacosta

INTRODUCTION

Water use data (withdrawal and return amounts) has always been the most difficult element to define in the hydrologic cycle. The need to determine the amount of water used to meet public, commercial and domestic needs among other uses is essential where the available supply is inadequate. In St. Thomas, U.S. Virgin Islands, where streamflow occurs mostly during periods of intense rainstorms and ground-water resources are limited (Jordan and Cosner, 1973), water-use information is critical.

In 1983, the U.S. Geological Survey, Water Resources Division, in cooperation with the Water Resources Research Institute of the College of the Virgin Islands, began a generalized inventory of water use in St. Thomas.

St. Thomas is located about 20 miles east of Puerto Rico (fig. 1). The island's population increased from 16,000 in 1960 to more than 47,500 in 1984, paralleled with an increase in water production to meet the public water-supply demand (fig. 2).

The water demands have increased also in response to tourism development. Although the production of water increased with the installation of a large-scale seawater desalination plant by the Government of the U.S. Virgin Islands, the demand has not been satisfied. Only about 40 percent of the water produced is accounted for, mostly due to losses from leakage in the distribution system installed in 1949 (Priede-Sedgwick, Inc., 1979). Other losses are due to unauthorized connections, faulty meters, and uncontrolled public faucets (fig. 3).

WATER SOURCES AND USES

The principal sources and uses of water in St. Thomas are shown in fig. 4. Seawater, rainfall collected from residential roof-top catchments, and ground water are the main water sources in the island. Thermoelectric-power generation, public-water supply, and domestic and commercial self-supply are the principal uses.

Seawater is used indirectly as the source of condenser-cooling water by the Virgin Islands Water and Power Authority (WAPA). The waste heat from the Island thermoelectric facility (fig. 5a) is used by the seawater-desalination plant (fig. 5b). Desalinated water from storage tanks (fig. 5c) is distributed to the urban areas in Charlotte Amalie (fig. 5d), by the Virgin Islands Public Works Department (VIPWD). Areas outside the public-water supply distribution system, such as the Donoe housing project at New, (fig. 5e) can be classified as self-supplied users. These obtain their water supply from rainfall catchments, wells, or from commercial water haulers (fig. 5f).

The main urban area of Charlotte Amalie is also served by a seawater system. This system supplies water for fire fighting and flushing of toilets and open drains. Areas outside the seawater system depend on "gray water" (wastewater from other household uses) as their source of water for flushing toilets or irrigation. Where aquifers yield significant water to wells (10 gal/min or more) these are also tapped as a source of water, even if saline, as feed for reverse osmosis units or for flushing.

Bottled water produced locally or imported is an important drinking water source. Bottled water costs approximately $1.25 per gallon. In 1979 importation of bottled water was estimated at 1,600 gal/d (Peebles, 1979). There are no reliable figures for current imports.

Public-Water Supply

Production of desalinated water during the study period averaged 2.4 million gallons per day (Mgal/d). Only about 0.9 Mgal/d (38 percent) was accounted (revenues from sales) by the VIPWD. About 1.5 Mgal/d was unaccounted for as previously indicated. A recent investigation showed that leakage in the distribution system represents 30 to 40 percent of the total losses (CH2M Hill Southeast, 1983).

The production of desalinated water for public supply increased to a peak of about 2.4 Mgal/d in 1975, declining thereafter to less than 0.6 Mgal/d in 1980. Since 1981, WAPA has installed three new desalination units with a total rated capacity of 3.1 Mgal/d. At present only two units are being operated. Full production capacity will be required when the East End Transmission System becomes operational (fig. 6). This distribution system was constructed in 1977 but has not been utilized.

Water pumped to the seawater distribution-system averages 1.0 Mgal/d. Only about 0.35 Mgal/d of this amount is accounted for at the public sewage treatment plant serving Charlotte Amalie. The remainder may be lost through leaks in the seawater-distribution system. However, various storm drains in Charlotte Amalie are continuously flushed to the ocean by taps from the seawater-distribution system. Discharge from two of these taps were measured and had an average flow of 0.08 Mgal/d each. Five of these taps would account for ½ of the unaccounted flow..

The cost of potable water to WAPA from the desalination units is about $9.00 per thousand gallons ($9.00/kgal). This does not include amortization costs of the desalination units (Ajayi and Gómez, 1983). The actual costs charged by VIPWD to consumers connected to the distribution system is $14/kgal (VIPWD personal communication, 1984).

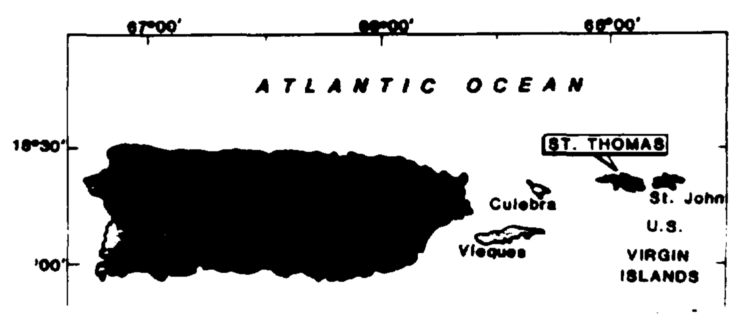
Thermoelectric-Power Generation

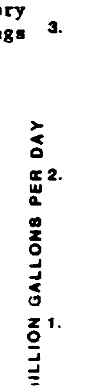
Thermoelectric-Power Generation is the largest single water use category in St. Thomas. Total use was about 67 Mgal/d. This was essentially seawater, except about one percent freshwater obtained directly from the desalination plant for boiler feed.

Domestic Self-Supplied - Rainfall

About two-thirds of the population in St. Thomas is not served by the potable public water supply distribution system, and thus classified as domestic self-supplied. Rainwater collected from rooftop catchment systems and stored in cisterns, and withdrawals from ground water are the sources for domestic self-supply. Estimated water use for this category was about 0.75 Mgal/d. Of this amount, 0.60 Mgal/d (80 percent) was supplied from rainfall. This indicates that rooftop catchments are a major source of water for most private homes especially in the more humid areas of the island (fig. 7).

Virgin Islands law requires all dwellings, apartments and hotels to have a minimum cistern storage of 10 gallons for each square foot of roof area for one story buildings, and 15 gallons for each square foot of roof area for two or more story buildings. All other buildings





are required to have cisterns with a minimum useable capacity of 4½ gallons per square foot of roof area except churches and warehouses, which are not required to conform to this standard (Jordan and Cosner, 1973). A comparison of yields between rooftop-rainfall catchment at a high rainfall (Dorothea), and at a low rainfall area (Red Hook), was made using data from July 1983 to June 1984. The comparison was made for a family of four using 25 gallons per capita per day (25 gpcd) with a roof area of 1,000 ft² and an initially full cistern (10,000 gal). The family would have required the services of a water hauler only once if they lived in the Dorothea area, and twice if they lived in the Red Hook area. Rainfall could have supplied about 50 percent of the total water needs in the Dorothea area, but only 31 percent at Red Hook.

The cost of water produced by household roof-top cistern systems is estimated at $17 to $19/kgal (CH2M Hill Southeast, 1983). The major cost is associated with construction of a cistern.

Domestic Self-Supplied - Ground Water

Ground water withdrawn for domestic self-supplied use was about 0.15 Mgal/d. Ground-water withdrawals by the Virgin Islands Housing Authority (VIHA) were estimated at 0.10 Mgal/d. An additional 0.05 Mgal/d was used by other domestic self-supplied users.

Ground water for domestic use is available in nearly all parts of the island. There are only a few areas where yields to wells are large enough to warrant the development of public supplies. In their study, Jordan and Cosner divided the island into five ground-water areas according to their potential yield and water quality (fig. 8). The potential yield and water quality of these areas are limited by excessive depth to water, seawater intrusion, waste-water contamination, and contamination from seawater mains.

Commercial Self-Supplied

Condominiums and hotels used about 2.0 Mgal/d of saline water. This is used principally for cooling, flushing toilets, and swimming pools. Small desalination plants produce about 0.1 Mgal/d freshwater.

About 0.2 Mgal/d of the commercial water-use is ground water. This is used mostly for flushing toilets. In some areas, where the ground water is of good quality, the waste water is used for irrigation of lawns (Mahogany Run). However, most of the commercial facilities are located near the coast and pump saline-ground water.

Water haulers supplied an estimated 0.07 Mgal/d of desalinated water from the VIPWD standpipes to commercial users. The average price of water delivered by water haulers is $55/kgal (Ajayi and Gómez-Gómez, 1983). An estimated amount of 0.05 Mgal/d was obtained from rooftop rainfall catchments.

Public Waste-Water Treatment

There are seven public waste-water treatment facilities in St. Thomas (fig. 9). The airport plant, serving Charlotte Amalie, discharges about 0.5 Mgal/d to the ocean. Instantaneous flow rates measured in June 1984 ranged from 0.16 to 1.4 Mgal/d (fig. 10). Specific conductance measurements indicated that about 70 percent of the effluent was seawater.

The other six waste-water treatment plants serve mostly public-housing projects. These discharge about 0.20 Mgal/d to streams and the ocean.

ACKNOWLEDGMENTS

We would like to acknowledge the following Virgin Islands Government Agency employees for their cooperation:

Virgin Islands Public Works Department: [illegible]

Virgin Islands Water and Power Authority: [illegible]

Virgin Islands Housing Authority: [illegible]

We also wish to thank the [illegible] of the St. Thomas hotels and [illegible] for their [illegible] cooperation.

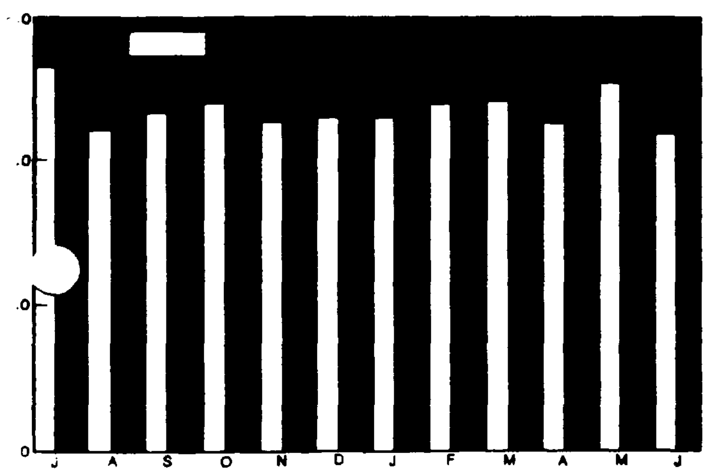


FIGURE 3. Comparison of the quantity of water distributed ... by Virgin Islands Public Works Department.

SOURCE, DISTRIB

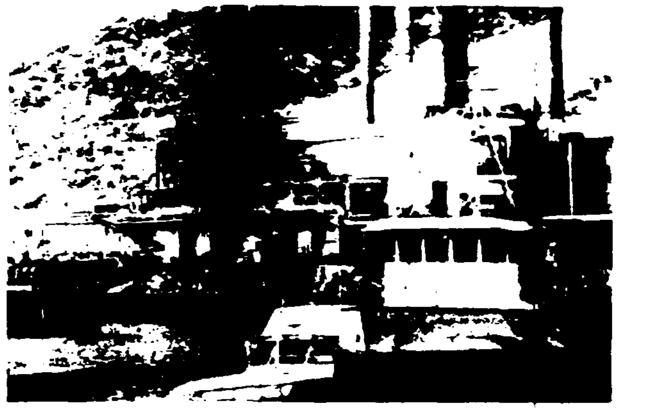


FIGURE 6c. Seawater intake at the Thermoelectric Power Plant at Krum Bay (Sub Base).

FIGURE 6d. Domestic and commercial users at Charlotte Amalie area.

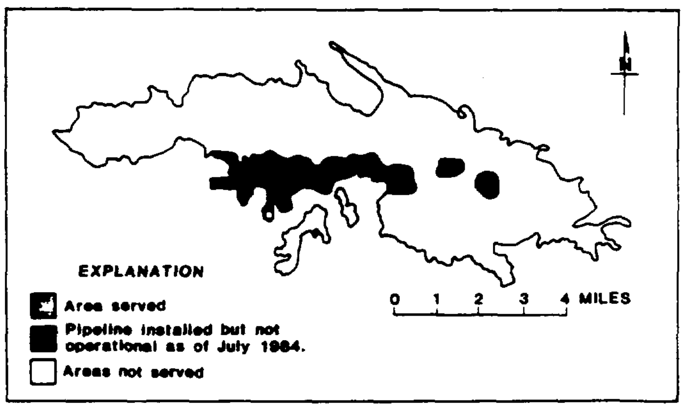
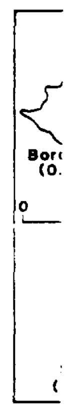


FIGURE 8. Areas served by the fresh-water distribution system.



FIGU
p.

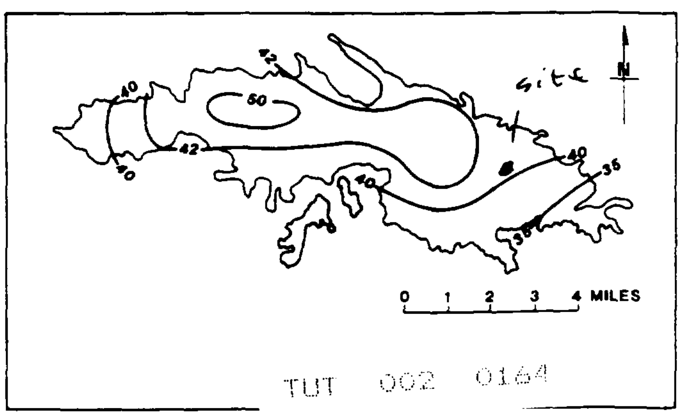
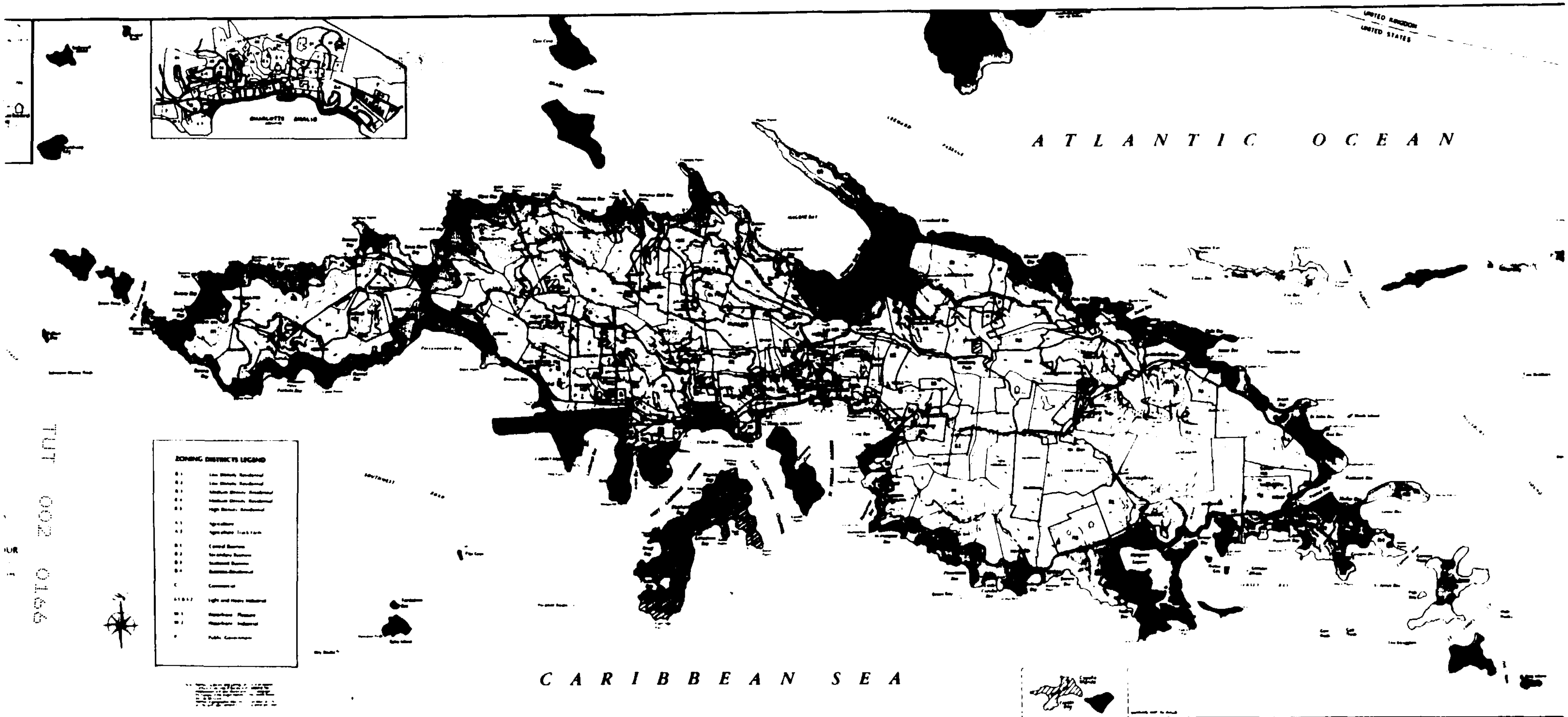


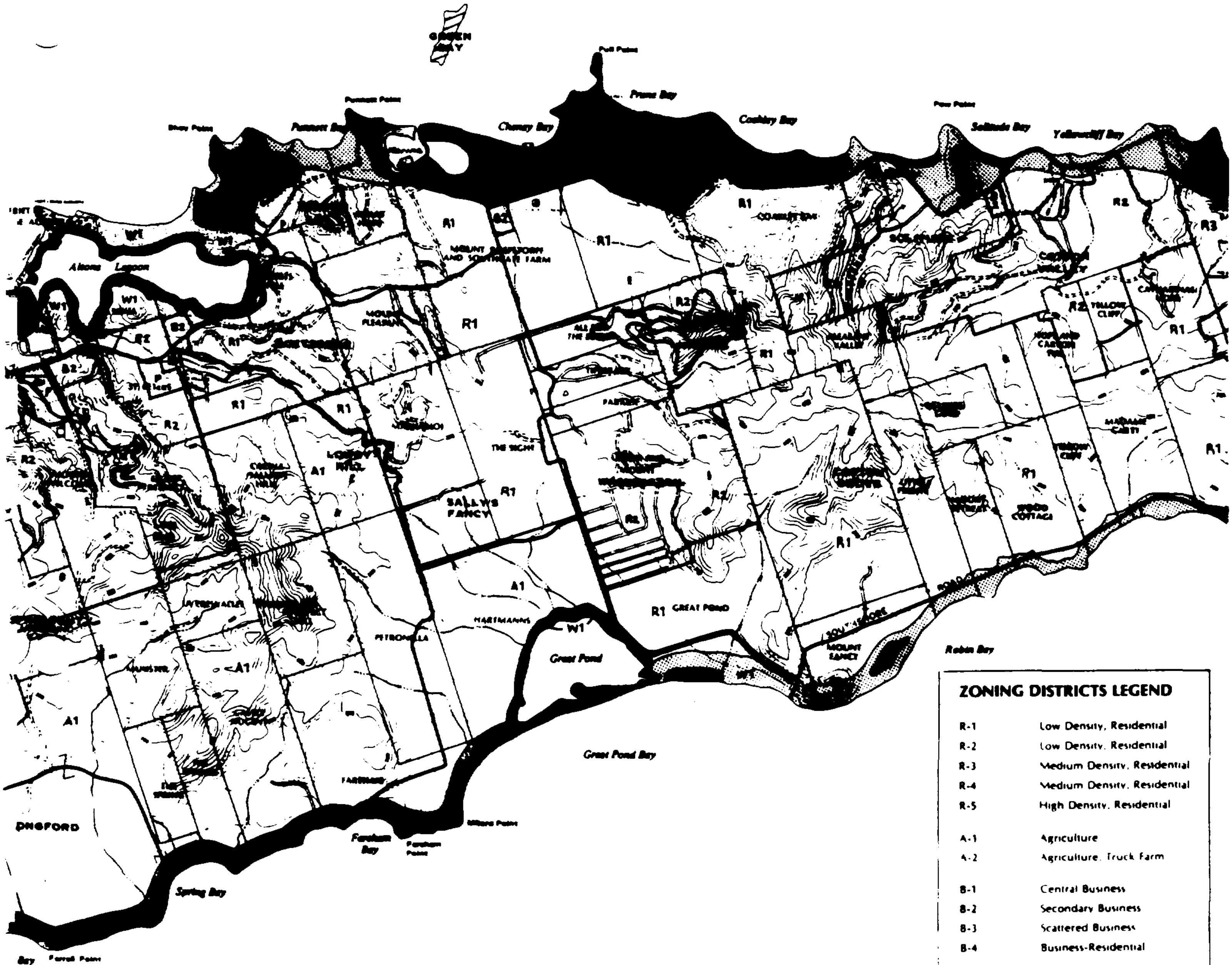
FIGURE 7. Average-annual rainfall, in inches. (Prepared by R.J. Calvesbert, (NWS) NOAA.)

REFERENCE NO. 14



U.S. Virgin Islands
Dept. of Planning and Natural Resources
Coastal Zone Management Program

Preparation of this map was financed in part under the Coastal Zone Management Act of 1972, administered by the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration.



ZONING DISTRICTS LEGEND

R-1	Low Density, Residential
R-2	Low Density, Residential
R-3	Medium Density, Residential
R-4	Medium Density, Residential
R-5	High Density, Residential
A-1	Agriculture
A-2	Agriculture, Truck Farm
B-1	Central Business
B-2	Secondary Business
B-3	Scattered Business
B-4	Business-Residential
C	Commercial
I-1 & I-2	Light and Heavy Industrial
W-1	Waterfront - Pleasure
W-2	Waterfront - Industrial
P	Public/Government

COASTAL LAND AND WATER USE PLAN

- Preservation
- Conservation Recreation, Traditional Uses
- Protection, Residential Low Density
- Residential, Medium Density
- Residential, High Density
- Water Dependent & Related Commercial Marine Facilities
- Water Dependent & Related Industrial Marine Facilities
- Commercial
- Industrial
- Excluded Federal Land

REFERENCE NO. 15

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II

DATE: JAN 06 1988

SUBJECT: Preliminary Assessment and Confirmation of Authorization of CERCLA Removal Action Monies for the TUTU Well Site, Anna's Retreat, Saint Thomas, U.S. Virgin Islands - ACTION MEMORANDUM

FROM: Carlos E. O'Neill Bruce Sprague (for)
On-Scene Coordinator

TO: Stephen D. Luftig, Director
Emergency and Remedial Response Division

THRU: George H. Zachos, Acting Chief
Response and Prevention Branch

I. EXECUTIVE SUMMARY

On July 15, 1987, Mr. Allan Smith, Commissioner of the Department of Planning and Natural Resources (DPNR), U.S. Virgin Islands, verbally requested that the U.S. Environmental Protection Agency (EPA) provide analytical support in the sampling of one well which was reported to exhibit a strong unpleasant odor. This well is a major source of commercially provided potable water supply for the eastern portion of St. Thomas. The well is located on the eastern part of the island in the Tutu Section of Anna's Retreat. This verbal request was followed by an additional request for EPA to assume the role of Lead Agency after sampling results indicated that several commercial wells were found to be contaminated with hazardous substances. This verbal request was followed by a formal request in writing by DPNR on August 10, 1987.

In July and August of 1987, EPA confirmed by sampling and analysis, the contamination of groundwater with volatile organic compounds. A major contaminant in the groundwater is tetrachloroethylene (TCE). The EPA 10-Day Health Advisory Level of 175 ppb was exceeded in three (3) of twenty four (24) wells sampled, with two of the three contaminated wells being private residential wells. The concentrations found ranged from 240 to 7,600 ppb with seven (7) additional wells being below the EPA 10-Day Health Advisory, but above the U.S. Virgin Island's interim maximum permissible concentration levels set on September 1, 1987, by DPNR for volatile organics in drinking water in the Turpentine Run Aquifer (50 ppb for a single compound or 100 ppb for total volatile organic compounds). Three of the previously mentioned seven wells were residential wells.

This Action Memorandum will document funding authorized for Phase I of the Tutu Well Site CERCLA Removal Action. Phase I addresses only residences having contaminated drinking water wells with volatile organic compounds above levels established by the U.S.V.I.'s interim maximum permissible concentration levels for potable water. This action did not include wells where water is used primarily for commercial, business, industrial and/or trade purposes. It also did not include wells contaminated solely by gasoline or gasoline by-products which are not hazardous substances within the definition of Section 101(14) of CERCLA. This action includes the decontamination and cleaning of residential cisterns contaminated by hazardous substances, the modification of plumbing, the delivery of water by tank trucks as a temporary alternate water supply, and a well water monitoring program. The total project ceiling authorized for a 52-week period is $100,000 of which $40,000 is estimated for mitigation contracting; $45,000 for TAT's extramural costs; and $15,000 for EPA's intramural costs.

This memorandum will confirm your prior verbal authorization of Trust Fund monies, issued to the Chief, Incident Response and Prevention Section on September 1, 1987, to initiate the removal action at the subject site, and subsequently revised to the current project ceiling of $100,000.

II. BACKGROUND

A. Historical Information

A request for EPA analytical support for one well in the Tutu Section of St. Thomas was made verbally on July 15, 1987 from DPNR. On July 31, 1987, a verbal request for EPA to assume the role of Lead Agency was made, and this was followed by a written confirmation of the request, dated August 10, 1987 (received by the Emergency and Remedial Response Division on August 19, 1987). The initial request was based on a report that one well was reported to have a strong odor, characteristic of a petroleum product. This well is a major source of commercially provided potable water for the eastern portion of the island. EPA's preliminary investigation commenced on July 21, 1987, with a field reconnaissance and sampling of this one well and six additional wells identified in the immediate area. Several of these wells are also major water suppliers of public drinking water to the eastern part of the island.

Laboratory results from this survey indicated that the initial well was highly contaminated with gasoline and chlorinated organics, and the additional six wells contained elevated levels of chlorinated volatile organic compounds. Based on these results, DPNR declared that an imminent health threat existed, which could affect approximately 20,000 people living in St. Thomas.

In addition, an indefinite number of tourists who vacation in St. Thomas were at risk since these commercial wells supply water to major hotels and restaurants. DPNR issued orders to close these seven commercial wells to protect public health.

✓Subsequent to this action, EPA expanded their sampling plan due to the threat of greater contamination to drinking water wells in the area. EPA along with DPNR, identified other wells within the Tutu Water/Turpentine Run Aquifer which may be impacted by the hazardous substances identified to be present in the groundwater. A second round of groundwater well sampling took place on August 10 and 11, 1987, which included a total of twenty-four (24) wells identified in the Tutu Section of Anna's Retreat. All twenty-four wells were sampled and analyzed for volatile organic compounds. Following these results, DPNR closed the five private wells which service two three-family homes and one apartment building housing twelve studio units.

B. <u>Site Setting/Description</u>

The contaminated wells are located in the Tutu Section of Anna's Retreat, St. Thomas, U.S. Virgin Islands. The five (5) private wells recently ordered closed are located in the Tutu residential area. At the present time, the affected area is not serviced by any public water supply. EPA sampled a total of twenty-four (24) wells in the Tutu area and found five private wells and eight (8) commercial wells seriously contaminated with up to 7,600 ppb of PCE. (See map attached).

C. <u>Quantity and Type of Substance Present</u>

EPA sampled and analyzed for suspected volatile organic compounds on Ju[illegible]2 and August 10, 1987. Listed below are the maximum concentrations of the hazardous substances identified in the drinking water wells:

TUT 002 0171

Contaminant	Maximum Concentration Found (ppb)	Statutory Source of Hazardous Substances under CERCLA
Tetrachloroethylene	7,600	Clean Water Act Section 307(a)
Trichloroethylene	61	Clean Water Act Section 307(a)
Benzene	1,400	Clean Water Act Section 307(a)

The results of the sampling are contained in Tables I and II. PCE contamination ranged from non-detectable to seven thousand-six hundred parts per billion (7,600 ppb). Sampling results adequately document 3 wells with contamination above EPA's 175 ppb PCE 10-Day Health Advisory Level and eight (8) wells above the DPNR's interim standards for maximum contaminant levels of volatile organic compounds in drinking water.

III. THREAT

A. Threat of Public Exposure

Direct contact with PCE may cause eye and nose irritation along with dry scaly and fissured dermatitis. Acute exposure through absorption, inhalation or ingestion, may cause central nervous system depression, hepatic injury and anesthetic death. PCE has been found to be carcinogenic.

This is a case of actual contamination in excess of the EPA 175 ppb PCE 10-Day Health Advisory Level for a three-family house and one apartment building housing twelve studio units. In the other three family apartment dwellings, the well contamination exceeded the interim DPNR drinking water standard of 50 ppb for any single volatile organic constituent. In addition to the exposure via consumption of the water, or eating food prepared with this water, showering with water contaminated with volatile organics can contaminate the air to significantly unhealthy levels.

The location, direction and dimensions of the plume are affected by variations in water table depth, rate of pumping of the wells, duration and intensity of rainfall, and intermittent releases of chemicals from one or more sources, all of which are unknown at this time. Given the above variables which affect contaminant strengths in any well within the plume may vary randomly.

On September 2, 1987, DPNR issued three (3) orders to close wells and issued two (2) advisory letters to homeowners not to use well water for drinking, bathing and washing.

B. Evidence of Extent of Release

Investigation, sampling and analyses by EPA have identified contaminated groundwater, as described above, and containing contaminates, as described in Tables I and II.

C. Previous Actions to Abate Threat

No mitigative action was taken by any Potentially Responsible Party prior to EPA's recent activities.

D. Current Actions to Abate Threat

√ EPA has commenced an investigation of the Tutu Water/Turpentine Run Aquifer by establishing a cooperative agreement with the U.S. Geologic Survey to define the characteristics of this aquifer and to determine the extent of contamination. EPA and DPNR have also completed Aquifer and a monthly well monitoring program is being developed.

√ DPNR has issued a total of ten (10) orders/advisories to well owners to close sixteen (16) wells.

A local dry-cleaner has been identified as using and storing PCE. Handling, storage and disposal practices from this facility are unknown at this time. DPNR has proposed to issue an advisory to local dry cleaning establishments instructing them to properly store and hold all waste for proper disposal by an industrial waste hauler. √DPNR with the assistance of EPA is conducting an assessment of at least nine (9) facilities identified to be potential sources of hazardous waste and/or substance releases in the Tutu area.

EPA has cleaned the homeowner's cisterns that have been contaminated by hazardous substances from the groundwater, modified the existing home plumbing to terminate well connections, and intends to continue to deliver clean water via tank trucks on a regular basis, and establish a surveillance program for all wells in the area by a monthly groundwater monitoring program. This Phase I, short-term removal action will mitigate the threat to public health by providing a temporary alternate source of water for affected consumers.

IV. ENFORCEMENT

The contaminant plume is generally believed by both DPNR and EPA, to have its source from past and present improper handling and disposal practices of organic solvents, possibly from dry cleaners and auto repair shops operating in the area. This site has been referred to the Site Compliance Branch for enforcement action. An attorney and enforcement project officer have been assigned to this case. EPA issued Request for Information letters to all Potentially Responsible Parties.

V. PROPOSED PROJECT

A. Objective of the Phase I Removal Action

The primary objective of the Phase I of the removal action is the mitigation of the threat to public health by providing a safe potable water supply to the affected residences.

Two three-family homes and one apartment complex housing twelve studio units were identified as being dependent on groundwater from their own private wells. Their respective wells were ordered closed-down by DPNR for exceeding interim drinking water standards.

To reach the objective of providing a safe interim drinking water supply and protect the health of the public at risk, the following removal action was initiated. Water storage cisterns, which received contaminated groundwater from affected wells, were cleaned and sanitized. Cisterns were filled with clean, safe, drinking water. Water tank trucks from local water haulers will be providing water for the affected cisterns on a regular basis. Plumbing modification was made to disconnect water lines from the contaminated wells which provide groundwater to the cisterns.

An attempt to connect well water directly to toilets for flushing will be made, if physically and economically feasible. A well surveillance program will be implemented involving all the wells in the Turpentine Run Aquifer, thru monthly sampling and monitoring.

The longer term, Phase II objective will require the provision of a permanent alternate water supply in lieu of the temporary trucking of water to the threatened consumers within the plume area. Upon completion of an analysis of the alternatives for permanent water supply to these residences, a recommendation will be made for Phase II.

B. Project Estimated Costs

Water consumption per person per day on the average is thirty (30) gallons. It is estimated that the one apartment building has twelve studio units with the average of two people per unit. The two other private homes are three-family dwellings with the average of ten people in each. The cisterns in the three family houses are small and, therefore, a supply of water must be delivered every two or three weeks, respectively. The delivery period is currently estimated to be one year or when a permanent alternate water supply can be provided, whichever occurs first.

PROJECT COST (PHASE I)

Cisterns Clean-Up:

Provide labor, material and equipment including one vacuum truck, pressure water spray guns, water tank truck, etc., to drain and dispose contaminated water and to clean and sanitize identified cisterns	$13,000
Modification of plumbing including Labor and Materials	$ 5,035
Refill cisterns with clean and safe drinking water	$ 2,665
Provide cisterns with clean and safe drinking water on regular basis according to a pre-approved schedule	$15,000
Contingency (10%)	$ 4,300
Total Mitigation Cost	$40,000

Extramural TAT Cost

TAT Monitoring and sampling program
(Including travel and per diem).................. $35,000

TAT Technical and administrative
support (including travel and per diem).......... $10,000

Total TAT Cost $45,000

Intramural EPA Cost

(Including travel and per diem)..................$15,000

ESTIMATED TOTAL PROJECT COST..........$100,000

This figure represents the estimated total for Phase I. It could be reduced significantly, if a reliable and permanent alternate water supply is found sooner than the proposed 52-weeks delivery period; might be increased, depending upon the identification of new drinking water wells found to be contaminated with hazardous substances within the affected area.

C. Project Schedule

Project initiation of cistern clean-up and safe water delivery has already been implemented based on verbal funding authorization. Safe water delivery period is currently estimated not to exceed one year or when a permanent alternate water supply can be provided, whichever occurs first.

V. RECOMMENDATIONS

Conditions at the Tutu Well Site meet the requirements of Section 300.65 of the National Contingency Plan (NCP) for a CERCLA/SARA removal action. EPA has determined that there is a threat to public health at the site (Section 300.65(b)(1). This determination was based on:

1) Human exposure to unacceptably high levels of acutely toxic substances (Section 300.65(b)(2)(i), and

2) Contamination of drinking water supply (Section 300.65 (b)(2)(ii).

The resident population at risk currently relies on private well water as their source of potable water.

This removal action complies with Section 104(b)(2) of CERCLA, as amended by SARA, in that it is consistent with the efficient performance of long-term remedial measures, by providing an interim supply of potable water to the public until a permanent water supply can be secured.

This is a written confirmation of the initial and revised verbal approval of up to $100,000 for the total project ceiling established on September 1, 1987, by the Director of the Emergency and Remedial Response Division to the OSC for the CERCLA removal action at the Tutu Well Site. The mitigation contracting ceiling is estimated at $40,000, with an additional $45,000 for TAT costs, and $15,000 for EPA costs.

Your authority to authorize these funds is pursuant to Deputy Administrator Alvin Alm's memorandum of Delegation Number 14-1A dated April 15, 1984, and Richard Dewling's Redelegation Order R-11-1200.6 of August 29, 1984.

APPROVAL: Stephen D. Luftig DATE: 1/6/88

DISAPPROVAL: ______________________ DATE: ______________

cc: (after approval is obtained)

C. Daggett, 2RA
R. Salkie, 2ERR-DD
S. Luftig, 2ERR
G. Zachos, 2ERR-RP
B. Sprague, 2ERR-RP
J. Czapor, 2ERRD-SC
G. Pavlou, 2ERRD-NYCRA
J. Marshall, 2OEP
P. Gelabert, 2CFO
R. Gherardi, 2OPM-FIN
T. Sullivan, PM-214F (EXPRESS MAIL)
T. Fields, WH-548B
P. McKechnie, 2IG

PHOTOVAC SAMPLING RESULTS
TUTU WELL SITE
ST. THOMAS, U.S. VIRGIN ISLANDS

SAMPLE LOCATION	SAMPLE NUMBER	DATE SAMPLED	DATE ANALYZED	SOURCE	BEN	TCE	PCE	TOL	DCE	GCMS
HARTHMAN CRUSH	87-473	07/22/87	07/30/87	IW	0	7	102	6	0	.T.
HARTHMAN BAKERY	87-474	07/22/87	07/30/87	IW	0	0	3	6	0	.T.
4 WINDS WELL#1	87-475	07/22/87	07/30/87	CW	7	19	64	6	0	.T.
4 WINDS WELL#1	87-476	07/22/87	07/30/87	CW	7	19	61	6	0	.T.
TILLET	87-477	07/22/87	07/30/87	CW	633	65	200	48	35	.T.
VIHA	87-478	07/22/87	07/30/87	IW	15	9	36	6	0	.T.
EGLIN	87-479	07/22/87	07/30/87	CW	3	16	58	6	0	.T.
TILLET	87-480	07/22/87	07/30/87	CW	6950	711	2040	492	327	.T.
FIELD BLANK	87-481	07/22/87	07/30/87	NA	0	0	0	6	0	.T.

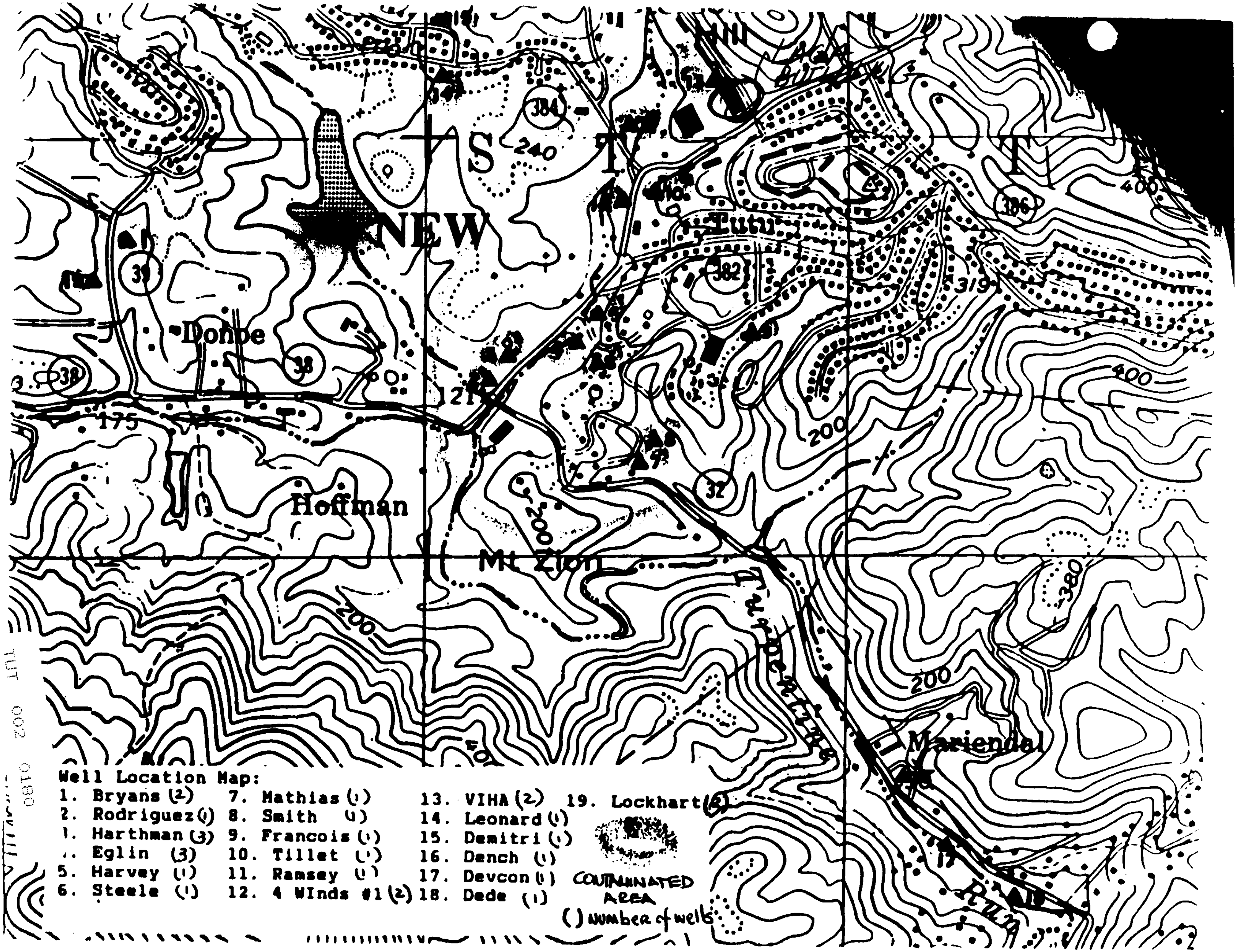
TABLE I

WELL SAMPLING RESULTS
TUTU WELL SITE
ST. THOMAS, U.S. VIRGIN ISLANDS

[illegible]LE [illegible]TION	SAMPLE NUMBER	DATE SAMPLED	DATE ANALYZED	SOURCE	BEN	TCE	PCE	TOL	DCE	GCMS
4 WINDS #1	001A	08/10/87	08/13/87	CW	2	21	72	1	213	.T.
EGLIN WELL #1	002A	08/10/87	08/13/87	CW	0	11	38	0	63	.T.
EGLIN WELL #2	003A	08/10/87	08/13/87	CW	0	13	43	0	74	.T.
EGLIN WELL #3	004A	08/10/87	08/13/87	CW	0	16	57	0	66	.T.
HARTHMAN BAKERY	005A	08/10/87	08/13/87	IW	0	0	3	0	1	.T.
HARTHMAN CRUSH	006A	08/10/87	08/13/87	IW	0	3	26	0	12	.T.
HARTHMAN ESTATE	007A	08/10/87	08/13/87	PW	0	0	1	0	0	.T.
RODRIGUEZ AUTO	008A	08/10/87	08/13/87	IW	0	0	1	0	0	.T.
BRYAN	009A	08/10/87	08/13/87	CW	0	0	0	0	0	.T.
ALPHA, LEONARD	010A	08/10/87	08/13/87	PW	0	0	1	0	0	.T.
SMITH, LUCITA	011A	08/10/87	08/13/87	PW	0	17	120	1	81	.T.
DEVCON #3	012A	08/10/87	08/13/87	CW	0	0	0	0	0	.T.
DEVCON #1	013A	08/10/87	08/13/87	CW	0	0	0	0	0	.T.
DEDE	014A	08/10/87	08/13/87	NA	0	0	0	0	0	.T.
DEMITRI	020A	08/10/87	08/13/87	CW	0	0	2	0	0	.T.
VIHA WELL #3	021A	08/10/87	08/13/87	IW	0	0	0	0	7	.T.
VIHA WELL #1	022A	08/10/87	08/13/87	IW	0	3	10	1	12	.T.
RAMSEY	030A	08/10/87	08/13/87	IW	0	0	7	0	1	.T.
STEEL	031A	08/10/87	08/13/87	PW	0	20	270	0	61	.T.
HARVEY	032A	08/10/87	08/13/87	PW	0	61	7600	1	56	.T.
MATHIAS	033A	08/10/87	08/13/87	PW	0	4	66	1	9	.T.
FRANCOIS	034A	08/10/87	08/13/87	PW	0	28	120	0	140	.T.
DENCH	035A	08/10/87	08/13/87	PW	0	0	0	0	0	.T.
TILLET	036A	08/10/87	08/13/87	CW	1300	0	240	56	570	.T.
TILLET DUP	037A	08/10/87	08/13/87	CW	1400	36	120	33	620	.T.
FIELD BLANK	040A	08/10/87	08/13/87	NA	0	0	0	0	0	.T.

TABLE II

TUT 002 0179



NEW
Donoe
Hoffman
Mt Zion
Tutu
Mariendal
240
175
200
380
400
Well Location Map:
1. Bryans (2)
2. Rodriguez (1)
3. Harthman (3)
4. Eglin (3)
5. Harvey (1)
6. Steele (1)
7. Mathias (1)
8. Smith (1)
9. Francois (1)
10. Tillet (1)
11. Ramsey (1)
12. 4 WInds #1 (2)
13. VIHA (2)
14. Leonard (1)
15. Demitri (1)
16. Dench (1)
17. Devcon (1)
18. Dede (1)
19. Lockhart (2)
CONTAMINATED AREA
( ) number of wells

REFERENCE NO. 16

U. S. Geological Survey
Water Resources Division

Caribbean District
Open - File Report

A SURVEY OF THE WATER RESOURCES OF ST. THOMAS, VIRGIN ISLANDS

UNITED STATES DEPARTMENT OF THE INTERIOR

IN COOPERATION WITH THE

GOVERNMENT OF THE VIRGIN ISLANDS OF THE UNITED STATES

ABSTRACT

St. Thomas, with an area of 32 square miles, is the second largest of the Virgin Islands of the United States. The island is mountainous, and slopes commonly exceed 35 degrees along a central ridge 800 to 1,200 feet high running the length of the island. The general appearance is a panorama of numerous steep interstream spurs and rounded peaks.

The island is made up of rocks of Cretaceous age, mostly volcanic flows and breccias. A thin limestone and tuffaceous wacke complete the sequence of major rock types. All the rocks have been tilted and dip about 50 degrees north.

Water in Charlotte Amalie, the capital, is supplied by sea-water desalting and water barged from Puerto Rico and is augmented by hillside rain catchments and individual roof catchments. Rainwater augmented by water hauling and a few wells is the source of water for the rural areas.

Streamflow is meager--2 to 8 percent of the annual rainfall--and is predominantly storm runoff. Runoff after rainstorms seldom exceeds 5 percent of the rainfall. Runoff is rapid, however, and flash floods occasionally occur.

Test drilling has shown that water can be obtained from fractured volcanic rocks in nearly all parts of the island. Wells will yield, generally, less than 1,000 gpd (gallons per day). In the upper Turpentine Run Valley and the Lovenlund Valley, short-term yields of individual wells are as great as 100 gallons per minute. Estimates of potential yield from these areas are 300,000 and 100,000 gpd, respectively. Two smaller areas--Long Bay and Lindberg Bay on the outskirts of Charlotte Amalie have estimated ground-water yields of 70,000 and 30,000 gpd, respectively. Fully developed, the surface- and ground-water resources of the island could yield [illegible].3 million gallons of water per day.

Ground water is slightly saline, commonly containing more than 1,000 milligrams per liter dissolved solids. The principal source of the minerals is bulk fallout of sea- and land-derived dust from the atmosphere. Solution of minerals from the rocks of the aquifers is the second largest contributor. Nitrate and some of the bicarbonate content of the water is probably derived from vegetation and animal and human wastes.

Surface water is similar in mineral content to ground water during base flow.

Caribbean District
Open-File Report

UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey

A SURVEY OF THE WATER RESOURCES OF ST. THOMAS, VIRGIN ISLANDS

by
D. G. Jordan and O. J. Cosner

Prepared in cooperation with the
Government of the Virgin Islands
of the United States

1973

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LOCATION AND GENERAL SETTING

Location

The Virgin Islands, forming part of the Antilles Island Arch separating the Caribbean Sea from the Atlantic Ocean, are about 1,400 miles southeast of New York and almost 1,000 miles east southeast of Miami. St. Thomas, the northwesternmost island, lies about 50 miles east of Puerto Rico (fig. 1).

St. Thomas is the second largest of the more than 50 islands and cays constituting the Virgin Islands of the United States. The island is approximately 14 miles long and 2 to 3 miles wide and has an area of 32 square miles. Lying within a few miles of the coast are nearly 40 smaller islands, ranging in area from slightly less than a square mile to a few hundred square feet.

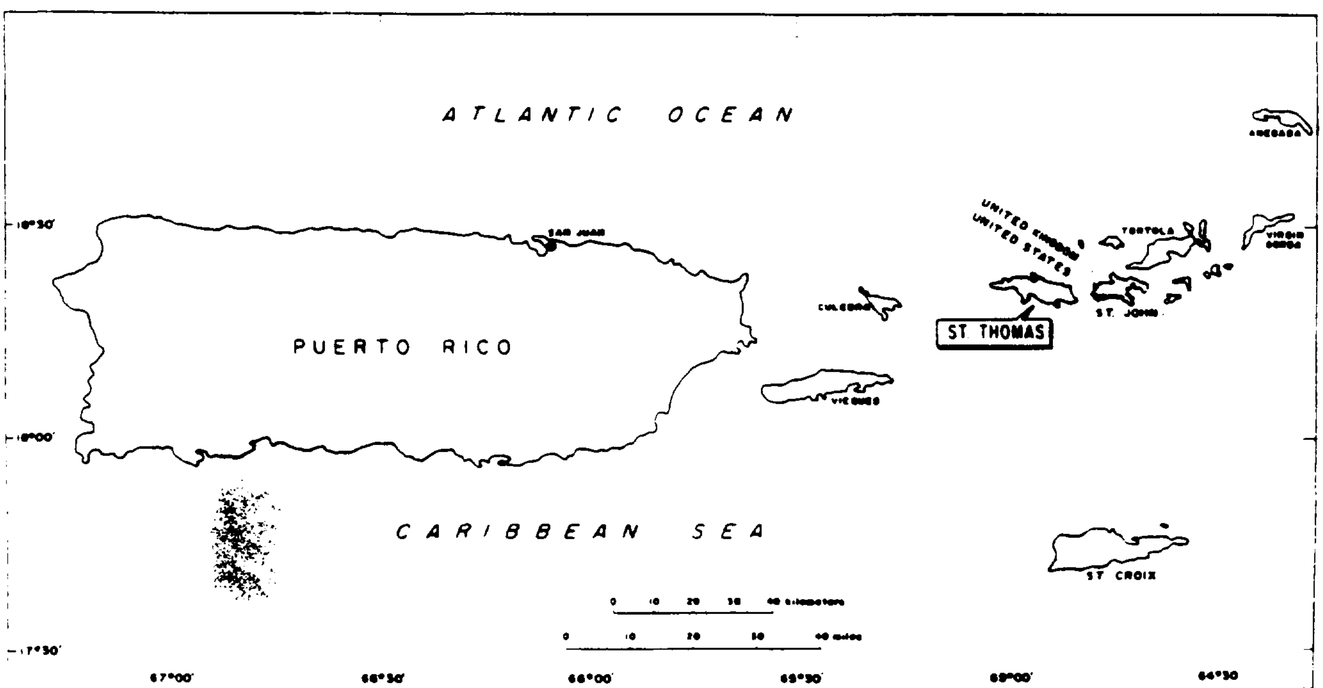


Figure 1.--Location of the Virgin Islands of the United States.

Population

St. Thomas has about 17,000 permanent residents and a transient population of tourist and imported laborers of about 8,000. The majority of the population is urban--about 20,000 people live in Charlotte Amalie, the only city and also the seat of government of the Virgin Islands. The permanent population is increasing rapidly and is expected to double by 1980 (unpublished data, V.I. Planning Board, 1964).

Topography

The land surface is almost entirely sloping and extends seaward from a central ridge, 800 to 1,200 feet high, running the length of the island. The slopes, which commonly exceed 35 degrees, are dissected by numerous stream courses of steep gradient. The general appearance is a panorama of steep interstream spurs and rounded peaks. Flat land is confined to the Charlotte Amalie area and a few small alluvial-filled embayments. The only variation in the general topography is in the upper valley of Turpentine Run in eastern St. Thomas. The valley has relatively gentle topography consisting of rolling hills in a basin surrounded by steep slopes and sharp ridges.

Land Cover and Use

At one time almost all the land, including that characterized by steep slopes, was under cultivation, primarily for grazing or growing sugarcane or cotton. Agriculture, however, has declined almost to extinction. A few square miles of land are still devoted to grazing in the eastern part of the island, and about 10 acres are used for truck gardening in the north central part. The remainder has been allowed to revert to brush and secondary forest.

Now, land use is changing rapidly, much of it brought on by the jetliner and its rapid mass transportation. Increasing population, in part caused by development of the island as a retirement haven and by tourism, results in more land being used for urban and suburban development. The increase in population not only makes new demands upon the water supply, but also the changes in land use could very well affect the available quantity and quality of the water resources.

Climate

The average annual rainfall is about 45 inches and the average temperature is only 80°F, but the prevailing impression of the climate is one of dryness, especially in the winter. This is especially true of the east end of the island, where, because of orographic effects, rainfall is only about 80 percent of that elsewhere.

Rain is seasonal, nearly half falling between August and November. February and March are the driest months and September and October the wettest. Most of the rain occurs as short, intense showers lasting but a few minutes. Rains exceeding 1 inch, with accompanying overcast, cloudy skies, come but six or seven times a year. Thus, there are few days when the sun does not shine.

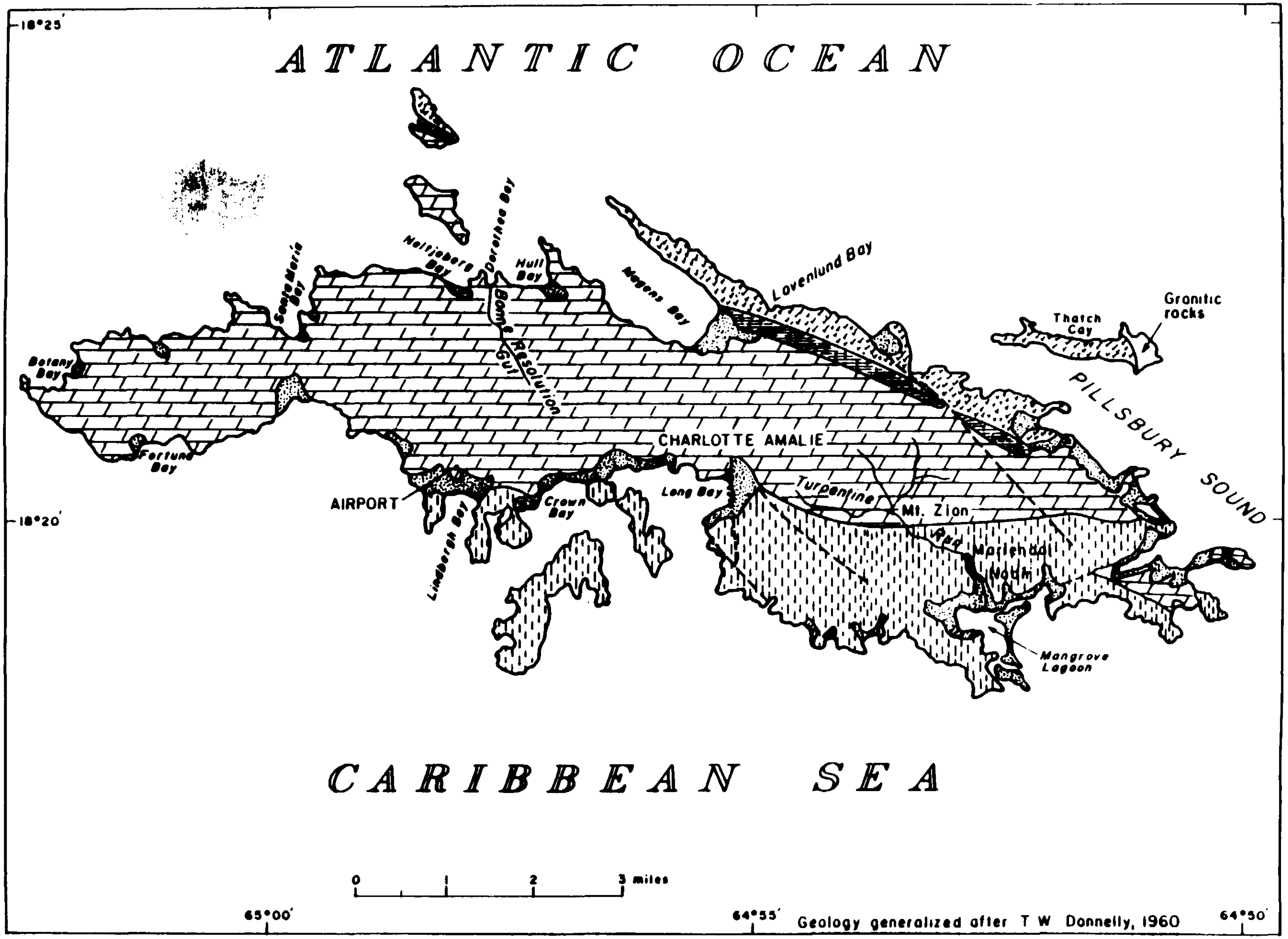
Although major rains are rare, their volume is noteworthy. The greatest rainfall of record was 18.0 inches September 13-14, 1928, during a hurricane. The last great rain in recent years was 10.6 inches May 8, 1960, the result of a stationary tropical depression.

The island lies in the path of hurricanes and occasionally receives heavy rains and high winds from passing storms. The incidence of direct hits is low--damaging storms having a frequency of about one every 33 years. The last hurricane to cause extensive damage was in September 1928.

The direct rays of the sun are very hot, but air temperature is modified by the almost constant trade wind. Air temperature (table 1) ranges from a mean low of 72.0°F in February to a mean high of 87.8°F in August. The highest daily temperature of record was 95°F and the low, 63°F.

The prevailing wind direction is from the east. Northeast and southeast winds are relatively common, but west winds are rare. Monthly average wind velocity during 1953-58 at Harry S. Truman Airport is given in table 1. A wind rose for the same period is shown in figure 2.

Relative humidity is high owing to the proximity of the sea. At Harry S. Truman Airport during 1953-58 relative humidity was highest, averaging 81 percent,in the early morning hours, and lowest, averaging 66 percent, in the early afternoon. Average daily humidity is given in table 1.



Geology generalized after T W Donnelly, 1960

EXPLANATION

Pleistocene (?) and Holocene

ALLUVIUM - Silt, clay, and thin, discontinuous beds of sand and gravel. Includes beach sand. Estimated maximum thickness 50 ft.

TUTU FORMATION - Tuffaceous conglomeratic mixture derived from older rocks. Contains some limestone, especially near the top. Maximum thickness greater than 6,000 ft.

OUTER BRASS LIMESTONE - Thin-bedded siliceous limestone and a few thin beds of tuff. Estimated maximum thickness 600 ft.

LOUISENHOJ FORMATION - Water-laid tuff, breccia, and a few thin beds of limestone. Maximum thickness known 13,000 ft.

WATER ISLAND FORMATION - Lava flows, flow breccia, and water-laid tuff intruded by dikes and plugs. Maximum thickness greater than 15,000 ft.

Contact

Inferred fault, dotted where concealed

Figure 3.--Geology of St. Thomas.

Geology

The general geology of St. Thomas (fig. 3) has been studied for many years, but only recently have the geologic formations been named and described in detail (Donnelly, 1960, 1966). The names of geologic formations used in this report are after Donnelly. The names have not been adopted by the U.S. Geological Survey.

The volcanic and sedimentary rocks of St. Thomas are of Cretaceous (and older?) age. The oldest rocks, those of the Water Island Formation of Donnelly (1960) are predominantly lava flows and flow breccias deposited at great depth on the sea floor. Uplift and subareal erosion followed deposition.

The Louisenhoj Formation overlying the Water Island Formation was extruded from a volcanic center probably sited in what is now Pillsbury Sound between St. Thomas and St. John. Near the presumed location of the volcanic orifice the rocks are mostly very coarse reworked cone debris. Farther from the orifice, coarse material lessens and tuffs predominate. Near the base of the Louisenhoj Formation is a conglomerate composed chiefly of rock from the Water Island Formation.

The Outer Brass Limestone was deposited on the flanks of the Louisenhoj volcanic cone during a period of volcanic quiescence. It consists of 200 to 600 feet of thin-bedded graphitic silicified radiolarian limestone and a small amount of included tuffaceous material.

The Tutu Formation, the youngest rock exposed on St. Thomas proper, is composed almost entirely of angular debris derived from the Louisenhoj Formation and minor limestone debris from thin limestone deposited contemporaneously with the Tutu Formation.

The rocks were subsequently tilted to form a northward-dipping homocline. Dips range from 15 to 90 degrees and average about 50 degrees. Locally the formations are overturned.

The permeable zones that these rocks once may have had after deposition have been destroyed by metamorphism or by deposition of minerals in pore spaces. Ground-water movement is now limited to openings along joints and fault zones. The homoclinal structure is cut by sets of faults trending N 45° W, N 55° E and north. Three well-defined joint sets parallel each of the major fault directions. The valleys of the island have similar trends and are apparently the result of selective erosion of rock weakened by faulting and jointing. Prime zones of ground-water availability, therefore, follow the valleys.

Small alluvial deposits ranging from Pleistocene (?) to Holocene in age lie in the valley of Turpentine Run in east-central St. Thomas and the larger coastal embayments.

The alluvium of Turpentine Run lies in a narrow band seldom more than 200 feet in width along the stream. Maximum thickness of the alluvium is about 40 feet. Most of this alluvium, which is composed of silt, fine sand, and clay and contains discontinuous beds of sand and gravel 2 to 3 feet thick, lies in the Mt. Zion-Tutu area of the upper basin and in the narrow valley from Mariendal to Mangrove Lagoon in the lower basin. The alluvium extends out under the lagoon near the mouth of Turpentine Run. Although composed predominately of fine-grained material, the alluvium readily infiltrates streamflow when the ground-water level is below the base of the stream. As such, the alluvium forms a readily rechargeable aquifer, although it is of small extent and yield.

Some coastal embayments headed by intermittant streams contain small deposits of alluvium similar to that of Turpentine Run. Maximum thickness of these deposits is estimated to be 50 feet, and their areal extent seldom is greater than a few acres (an exception being the Long Bay and Airport areas near Charlotte Amalie). Near the sea, the alluvium interfingers with calcareous sand and at times contains lenses of mangrove-swamp deposits. Therefore, the deposits are of minor significance as sources of water.

OCCURRENCE AND MOVEMENT OF WATER

Water moves through a cyclic pattern--the hydrologic cycle--in which there are three storage areas: the sea, the land, and the atmosphere. On the land, surface water and ground water depend on: (1) the amount, intensity, and areal extent of the rainstorms; (2) the slope of the land; (3) the moisture content of the soil and vegetal cover; (4) the infiltration capacity of the soil and underlying rocks; and (5) the size, number, and interconnection of openings in the aquifer.

Rainfall

Rain is the only natural source of fresh water to replenish the water resources of the island.

Rainfall is seasonal, with the rainy season in late summer and early fall and a secondary wet season usually in May. Nearly half the rain falls during August-November (fig. 4). Rains exceeding 1 inch in 24 hours come six or seven times a year. Four to 15 inches of rain falls in a 48-hour period about once every 2 years in large storms. These rains can occur in any month but are more likely during the hurricane season (August-November). About half the time annual rainfall is between 40 and 50 inches (fig. 5). Less than 10 percent of the time annual rainfall is less than 35 inches, which usually means a major deficiency during the normal wet season and drought.

The cumulative departure from average and the 10-year running average of rainfall shown in figure 6 shows that at this time of writing (1967) the island may be entering a period of deficient rainfall. With the exception of a few years in the late 1940's and early 1950's, rainfall in the past 30 years has been below average. There has been a long-term decline of about 10 inches in annual rainfall since the peak of the surplus rainfall period in the early 1930's. The most severe droughts of record occurred in 1964 and 1967, when but 27 and 24 inches of rain fell, respectively.

Areal distribution of long-term rainfall, shown in figure 7 (see letter "a"), is controlled by topography and the prevailing easterly to northeasterly winds. However, individual storms may or may not show the effects of orographic control or prevailing winds and the areal distribution of the storms can be very irregular (fig. 7--letters "b" to "f").

Soil Moisture

The soil zone over most of St. Thomas is not more than 1 foot thick. Where of sufficient thickness it has, however, the unique property of absorbing large volumes of water--as much as 12 inches in 24 hours (R. Scott, SCS, oral commun., 1963). Examination of the soil zone when dry shows it to be coarsely granular, owing to clumping of clay and silt particles. Prolonged saturation is necessary before the granules break down. As a result, the soil has a high permeability until well saturated, but, once saturated, it becomes poorly permeable and retains water in the pore spaces between particles and rejects any excess.

Observations during rainstorms indicate that the typical soil zone will absorb about 2 inches of water before some water is rejected or moves to the underlying bedrock. Fully saturated, the soil will probably retain 3 inches of water per foot of depth.

The capacity of the soil to hold large volumes of water, together with infrequent major rainstorms and a high evapotranspiration rate, seriously reduces ground-water recharge and storm runoff.

Evapotranspiration

Most of the water trapped in the soil zone returns to the atmosphere by evaporation or transpiration by plants (evapotranspiration). On St. Thomas this process is active throughout the year, and 90 to 95 percent of the rainfall is returned to the atmosphere. The tendecy of the soil to granulate is also conducive to evaporation. As water is evaporated from the surface of a saturated tight soil, the soil again becomes granular and exposes the soil at depth to the circulation of air. Consequently, further rapid evaporation of soil moisture results.

Transpiration is a major means of water loss from the soil zone and also from the upper part of the aquifer, if the water table is near the land surface. Grasses and shallow-rooted plants can transpire water only from the upper few feet of the soil zone, but many kinds of trees, such as deep-rooted false tamarind, transpire water from depths of more than 20 feet.

The effects of evapotranspiration may be seen in the channel of Bonne Resolution Gut below the gaging station. The gut flows in a predominantly bedrock channel a few feet wide for about 1,500 feet before reaching the alluviated embayment at Dorothea Bay. Base flow of the stream, when less than 10,000 gpd (gallons per day), disappears in this reach. The loss is attributed principally to transpiration by the dense growth of brush and

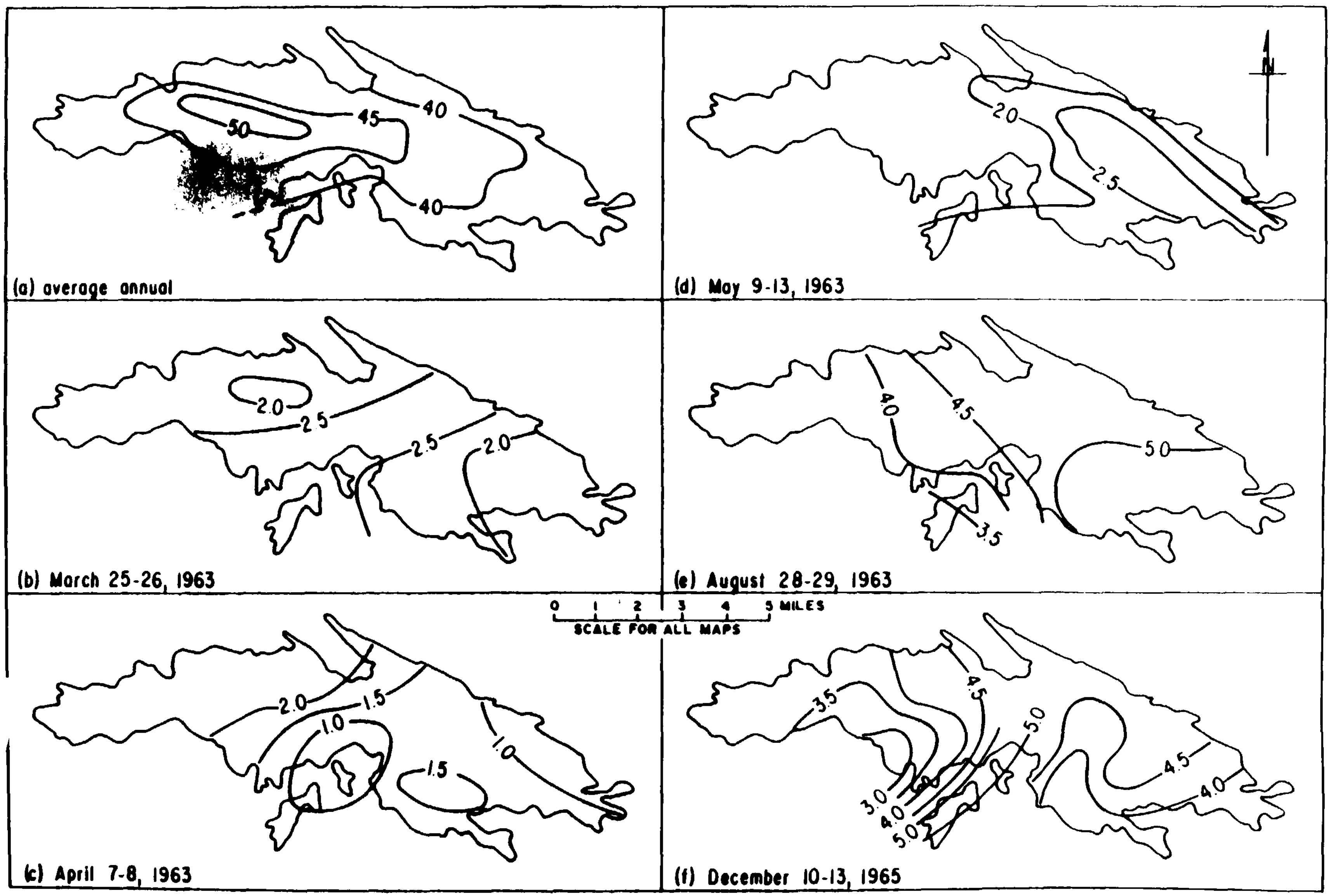


Figure 7.--Isohyetals in inches of the long-term distribution of rainfall (a) and of individual rainstorms (b-f) on St. Thomas.

trees bordering the stream. From the appearance of the vegetation in a dry period, only the vegetation in a strip about 100 feet wide with a total area of about 3 acres benefits from the stream. A minimum water loss of 10,000 gpd, 3.6 million gallons annually, would indicate an evapotranspiration rate of 1.2 million gallons per acre per year, or 44 inches.

Bowden (1968) computed monthly potential evaporation and soil-moisture deficiency at six stations on St. Croix using the method devised by C. W. Thornthwaite. Potential evaporation ranged from 58 to 69 inches and averaged 62 inches per year. Actual evapotranspiration (derived from potential evapotranspiration and change in soil moisture) ranged from 41 to 46 inches and averaged 43 inches per year. Bowden's data shows a soil-moisture deficiency 9 to 11 months of the year at the different stations. Surplus soil moisture occurred only in the months of September to November. The authors believe that conditions are similar in St. Thomas.

Streamflow

The 5 to 10 percent of rainfall not returned to the atmosphere by evapotranspiration from the soil zone either recharges the ground-water reservoir or runs off to the sea. Annual runoff in a time of average rainfall ranges from about 2 to 8 percent of the rainfall.

Most stream channels on St. Thomas are dry and carry only storm runoff. Only two streams on the island have perennial reaches. In these reaches, about one-half to three-fourths of the flow is storm runoff, and the remainder is base flow (ground-water outflow to the streams).

From 0.5 to 2 inches of water annually reaches the sea as storm runoff. The amount of storm runoff varies from basin to basin, depending upon topography, soil moisture, exposure, and vegetation. Base flow of the streams with perennial reaches, while often equal in volume to storm runoff, seldom reaches the sea. The flow usually infiltrates into alluvial deposits in the lower reaches of the streams.

Ground Water

From 0.5 inch to as much as 5 inches of the rainfall annually infiltrates the soil and rocks to reach the ground-water reservoir. Water in the ground-water reservoir or aquifer moves by gravity toward the sea. Where the water table is intercepted by the land surface, water is discharged as a spring or as base flow to a stream. Where it is near the land surface, such as along stream channels and in coastal embayments, large volumes of water are transpired by plants whose roots tap the ground-water reservoir. The transpiration by plants directly from the water table is so great that only minute quantities of ground water ever reach the sea, either as streamflow or as seepage directly through the soil and rocks.

Fresh- Salt-Water Interface

Fresh water in the aquifers along the coast is in contact with salt water in a dynamic system. So long as water levels grade seaward, fresh water will discharge to the sea at the shore. During times of ground-water recharge, the fresh-water lens thickens, displacing the underlying, heavier, salt water downward and seaward. During times of no recharge, the fresh-water lens thins, as ground water discharges to sea. Salt water, which moves into the normally fresh zone of water during times of no recharge, is not entirely flushed out by fresh water when recharge occurs. Some remains behind, where it mixes with influxing fresh water. The interface zone of brackish water is thick where fluctuations in the size of the fresh-water lens are large.

In some coastal areas, where the fresh-water lens is thin because of lack of rainfall or unfavorable topographic or geologic factors, the underlying interface zone may extend inland several hundred feet at depths of but a few feet below the water table.

The balance between salt water and fresh water in coastal aquifers is delicate and can easily be disrupted by man's quest for water. Salt-water encroachment can readily result by removing more water from the fresh-water lens than is being replaced by recharge or by pumping a well at an excessive rate, in which case the fresh-water head is lowered, and movement of salt water upward or horizontally into the fresh-water zone is induced.

WATER SOURCES

Fresh water has always been in critical supply in St. Thomas. Rain collected on roofs and stored in cisterns is still the source of water for most rural and urban domestic supplies. Before 1960 hillside rain catchments and a few dug wells were the major source of water for public supplies. Since then, desalted water has become the major source of water for public supplies, and water barged from Puerto Rico is a close second.

Charlotte Amalie

Charlotte Amalie has a dual public water system. Fresh water is used for drinking and general household needs, and salt water is used for sanitary and fire-control purposes. The fresh-water supply, obtained from salt-water distillation plants, hillside rain catchments, and a well, is supplemented by water barged from Puerto Rico. Potable water use and the sources of the water in figure 8 not only show the increasing demand for water but also the shift in sources of the water. In the late 1950's, with the exception of 1957, a drought year, catchments were the major source of water. Barged water became the major source of supply in the early 1960's, but by the late 1960's, desalted water became the principal source of supply.

Nearly all buildings, both private and public, in Charlotte Amalie have roof catchments and cisterns. In 1926, before the establishment of a public water system, about 200 private and 17 public dug wells were in use in the urban area. Since then most of the wells have been abandoned because of sewage and salt-water contamination. Some of the salty water was drawn into the wells from the sea as a result of overpumping, and some of it entered the wells from leaky salt-water pipes. A few of the wells are still pumped occasionally for nondrinking domestic supplies and for construction purposes. In recent years, wells have been dug in eastern Charlotte Amalie for a supplemental water supply for the [illegible] public-housing projects. Several other wells have been dug in the same general area for water for nondrinking domestic use.

Since 1926, 18 public hillside rain catchments have been constructed. Of these, 14 are connected to the urban water-distribution system. Water is hauled from the remaining four catchments by individual users or by water haulers. The total area of the public catchments is estimated to be 24 acres, and the storage is estimated to be 14 million gallons. Reliable figures are not available on the amount of water used from any of the catchments, but total yield is estimated to be 50,000 gpd. In addition to the public catchments, four privately owned catchments are in the urban area.

A gallery well at the airport was an important source of water in the 1950's. It reportedly yielded 13,000 gpd. An attempt to increase production resulted in salt-water encroachment, ruining the well as a source of potable water.

In 1962 the first desalting plant, with a capacity of 250,000 gpd, was put into production. In 1966 a plant of 1 million gpd was put into production, and, by 1967, the start was made on a 2.5 million gpd desalting plant.

The demand for water has increased six-fold since 1960 and shows little indication of leveling off. In 1962 and again in 1966, when desalting plants were put on line, water demand increased almost overnight to absorb the increase in production. Water barging, considered a stopgap measure, has had to be continued to meet the demand.

The desalting plants reportedly will produce water at an average cost of about $1.00 per 1,000 gallons when operating at maximum efficiency. The cost of barged water from Puerto Rico depends upon equipment used, but in 1967 averaged about $3.50 per 1,000 gallons. Water is sold to the consumer at a cost of 50 cents per ton, about $2.00 per 1,000 gallons. The difference between production cost and delivery cost is absorbed by the Virgin Islands Government.

Rural St. Thomas

Rooftop catchments and cisterns are still the major source of water for rural St. Thomas. During prolonged dry periods, rain water is supplemented by water hauled from public-supply points in Charlotte Amalie. Small ponds have been constructed, tapping storm runoff for irrigation water for truck gardening and drinking water for stock. Since 1962 several private wells have been drilled

Observations indicate that wind velocity and roof configuration are major factors in the recovery of rainfall from residential structures. High wind will blow rain off a pitched roof oriented parallel to the wind, whereas a rain shadow in proportion to the degree of roof pitch will occur on the lee side of a roof oriented perpendicular to the wind. A V-shaped roof will be affected in the same manner, although probably to a lesser degree. The most efficient is probably a flat roof with a low lip around the edge. Water cannot blow off the roof, nor is a rain shadow created, and the lip converts the roof into a temporary storage container during high-intensity rains. Rainfall recovery on flat roofs is probably greater than that measured from the hillside catchments, whereas recovery on pitch roofs is probably 10 to 20 percent less, depending on orientation and steepness of pitch.

Figure 25 shows an estimate of the annual costs of collecting rainwater and of cistern storage for a small home. Cistern cost, amortized over a 20-year period at 5 percent per year (interest costs not included), is estimated to range from $5.00 per cubic foot for 10 percent storage to $2.50 per cubic foot for 100 percent storage of the total annual recovered rainfall. Rainfall recovery was estimated to be 70 percent of an annual rainfall of 40 inches over 1,000 square feet of roof. Recovery under these conditions would yield 48 gpd. It was assumed that water loss due to insufficient storage would be made up by water purchased from water haulers at costs of 10, 20, or 30 dollars per 1,000 gallons. The figure shows that, using these criteria, the optimum cistern storage would be about 20 percent of expected annual recovery, or about 3.5 gallons per square foot of catchment. Average yield from rainfall alone would be about 40 gpd. Annual water cost would range from $130 to $196 annually, or $7.45 per 1,000 gallons to $11.20 per 1,000 gallons. Annual cost of 100 percent cistern storage would be $294 or $16.80 per 1,000 gallons.

Ground Water

Ground water is available in nearly all parts of the island in sufficient quantity to be of importance to the water supply. In general, yields of wells are sufficient only for individual domestic supplies. There are, however, a few areas where yields to wells are large enough to warrant

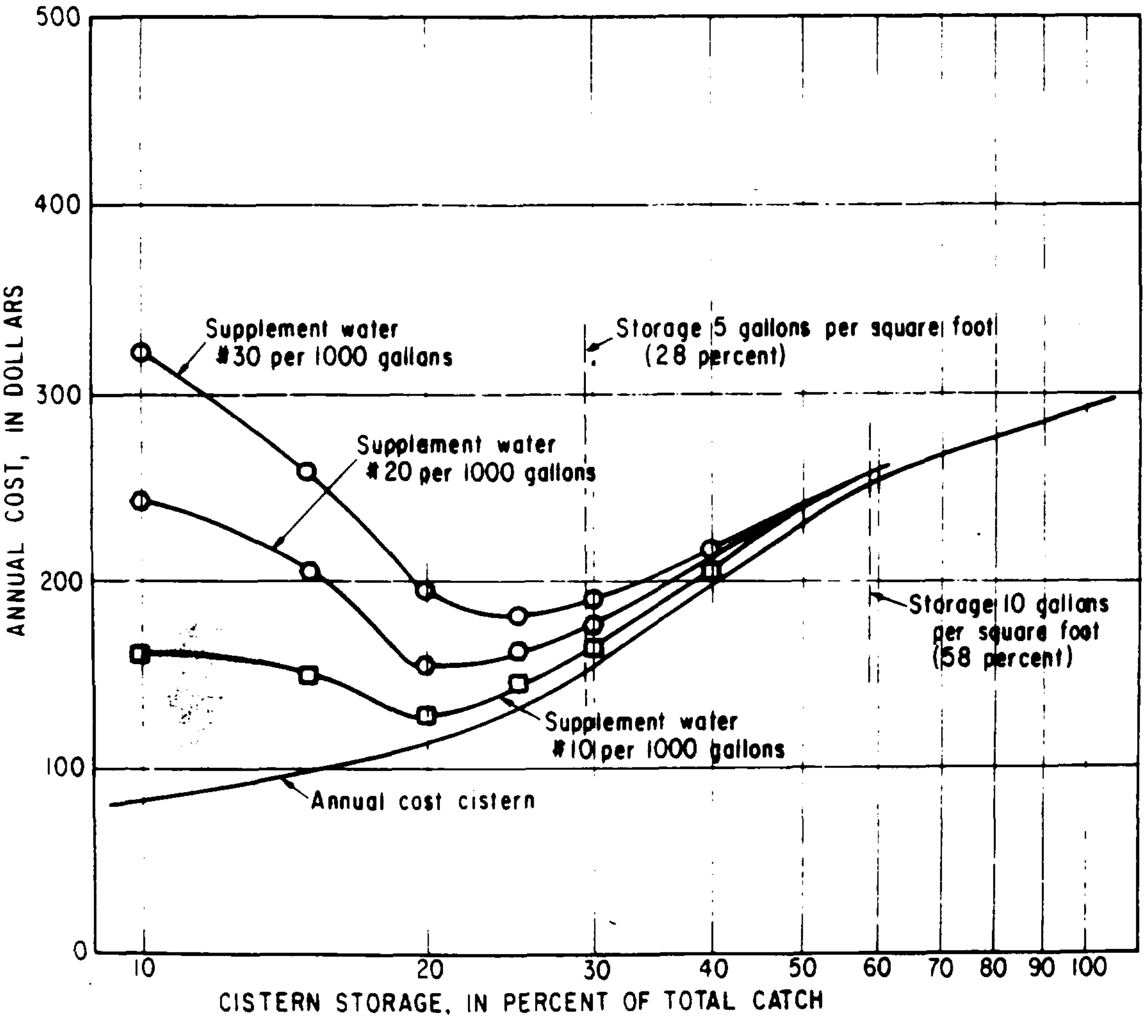


Figure 25.--Annual cost of water from a roof catchment of 1,000 square feet with a maximum yield of 48 gallons per day.

Table 4.--Scale of values for determining ground-water potential from physical criteria and examples for selected wells

Rainfall		Topography		Exposure		Drainage area		Potential	
Inches	Value		Value		Value	Acres	Value	Sum of values	Long term yield, gpd
< 40	0	Crest of ridge	0	North or south slope	0	< 100	1	4 or less	< 500
40-45	1	General slope	1	South slope North slope	1 2	101-200	2	5-6	500-1,000
45-50	2	Central valley on general slope	2	Sheltered interior valley	2	201-300	4	7-8	1,000-5,000
> 50	3	Large valley on alluvial flat	3			301-400	6	9-10	5,000-10,000
						> 400	8	11 or greater	10,000 +
Examples									
Well 3	2		2		2		1	7	1,000-5,000
Well 10	1		1		1		1	4	500
Well 22	1		2		2		2	7	1,000-5,000
Well 20	1		3		2		6	12	10,000
Well 16	1		4		2		6	13	10,000

the development of public supplies for local use. The water, as a whole, is of poor quality, being slightly mineralized, but can still be considered potable. It can be blended with cistern water, yielding a mixed water of more acceptable potability. Householders who have wells generally prefer a dual system, using the well water for washing, lawn watering, and sanitary purposes and rain water for drinking and cooking.

Ground-Water Potential

The ground-water potential of an area can in large part be determined by the average annual rainfall, topography, and exposure to solar radiation. In general, areas receiving less than 40 inches of rainfall have a low ground-water potential. The southern slopes of the island, where, because of solar radiation, evapotranspiration is high and recharge is low, generally have less ground-water potential and yield more highly mineralized water than the north slopes. Topography is important in that on the flatter slopes ground-water recharge is favored.

A crude scale based on rainfall, topography, exposure, and drainage-basin area was developed for estimating ground-water potential of the rocks of the island (table 4). The different features are assigned values ranging from 0 to 8. The sum of these values is a number from which an estimate of the long-term yield of a well can be obtained. A deep well will generally yield more water than a shallow well in the same location. For the purpose of the scale, a well depth of about 200 feet is assumed with the water level in the well at 50 feet below land surface. Little water is yielded from depths of more than 200 feet below the water table.

It is emphasized that even though conditions appear favorable for obtaining a ground-water supply, there is always a possibility no water will be obtained as a well may not penetrate water-bearing strata.

Water in Consolidated Rocks

The permeable zones of the consolidated rocks consist of open joints and fractures. Near the land surface the joints are open--the result of weathering and release of pressure. Joint openings, however, narrow rapidly with depth, and generally at depths of a few hundred feet they are too narrow to transmit significant quantities of water.

All the bedrock formations are broken by faults--fractures along which movement has taken place. In some faults, earth movement has crushed the rock to gravel-size breccia, whereas in others the rock has been reduced to a flourlike substance called fault gouge. Brecciated fault zones not sealed by mineral deposits or fault gouge can be very permeable and often extend to depths of hundreds of feet.

The orientation of many of the valleys and bays evidently is controlled by a fault and joint system along which erosion has occurred. Valleys, therefore, are often indicators of zones of an extensive jointing or fracturing system that may contain ground water.

The yield to wells drilled in the bedrock is small--generally less than 1,000 gpd. Many wells will yield 5 to 10 gpm (gallons per minute) for about 10 hours. After that they yield at a much reduced rate as a result of removal of water from storage in the immediate vicinity of the well. Once water in local storage is removed, the yield to the well is reduced to the general yield of the aquifer. For example, well 17 near Wintberg reportedly yielded 12 gpm (17,000 gpd) for a 24-hour pumping period when first drilled. However, almost daily use over the past 5 years has shown that the long-term yield of the well is about 250 gallons per day.

The consolidated rocks are permeable as a result of interconnected open fractures along joints and faults, which tend to be linear. However, permeability may vary significantly along a lineation.

One example of possible linear permeability is the north-south fault in eastern Charlotte Amalie. Permeability, as determined from pumping tests of wells, ranged from about 1 to 9 gpd per ft^2 (gallons per day per square foot) east and west of the fault. Immediately along the fault zone in the vicinity of the race track, however, permeability ranged from about 70 to 150 gpd per ft^2. Southward along the fault permeability was 1 gpd per ft^2.

The effective porosity, or storage capacity, of the consolidated rock also is related to open interconnected fractures and joints. Effective porosity in the upper Turpentine Run basin is estimated to be 4 percent based upon changes in the ground-water level in response to rainfall. Effective porosity of the rocks in most of the island is estimated to be 1 percent or less.

Water in Unconsolidated Rock

Water-bearing unconsolidated deposits are present only in Turpentine Run Valley and in coastal embayments. These deposits consist of two different lithologic types, which have a variety of water-bearing characteristics. They can be divided into (1) a bouldery silt and clay alluvium, which contains lenses and beds of sand and gravel, and (2) beach deposits, predominantly coral sand and occasional interbedded zones of coral, beach rock, and organic silt and clay. In the coastal embayments, alluvial and beach deposits may interfinger.

The alluvial deposits are predominantly fine grained, and, although they have a high porosity, they have a low permeability and will yield water only slowly to wells. Water in these deposits is with few exceptions under water-table conditions. Sand and gravel beds and lenses in the alluvium are rare. Where present, however, they will yield water readily and act as a large collector system into which water from the less permeable alluvium will percolate. Occasionally the water in the sand and gravel beds is under artesian pressure because they are confined by the less permeable overlying alluvium.

The beach deposits, principally medium to coarse coral sand, have a moderate to high permeability and porosity and will yield water readily to wells. The moderate to high permeability of the beach deposits is often detrimental in that salt-water encroachment can easily occur.

Water Table

Ground water in St. Thomas is assumed to be under water-table conditions--that is, the water surface is unconfined, open to the atmosphere, and free to rise and fall. Sufficient data are not available to show contours of the surface of the water table throughout the island. In general, the water table roughly parallels the topography. The depth to the water table is a few feet below land surface in the coastal embayments but may be as much as 120 feet below land surface near the crest of the central ridge.

The water table responds to changes in the quantity of water stored in the ground-water reservoirs. The water table rises when recharge from rainfall or streamflow exceeds the discharge; it declines when discharge to springs, streams, or the sea, evapotranspiration from the water table, and withdrawal of water from wells exceed recharge.

Water-table fluctuations

The hydrograph of well 1 in figure 26 is typical of the water-level fluctuations in the rock aquifer of the south coast. Recharge follows the infrequent heavy rainstorm or smaller storms in a wet period. The overall low storage capacity of the rock causes a rapid rise in water levels, but the steep hydraulic gradients result in rapid losses and almost as rapid declines.

Figure 27 is the hydrograph of well 24 tapping the alluvium and weathered bedrock in the lower Turpentine Run Valley, and figure 28 is the hydrograph of well 21 in the alluvium of the upper basin. Recharge is received every time storm water runs off in the stream and water levels rise. Between times of storm runoff, ground-water levels are partly maintained by the infiltration of base flow from the stream when flow is present.

The hydrograph of well 19 in figure 29 shows the pattern of water-level fluctuations of the rock aquifer in upper Turpentine Run basin. The pattern is similar to that of the rock aquifer of the north coast and larger valleys on the south coast. Here, greater permeability and storage capacity and generally thicker soil and alluvium result in a slower but more prolonged response to recharge and a slower discharge. The "troughs" in the hydrograph during early 1965 were caused by pumpage (averaging 18,000 gpd) from a nearby well.

Recharge

The bedrock aquifer is principally recharged by infiltration of rain on the land surface. Streamflow and storm runoff locally recharge the alluvium, which may, in turn, contribute water to the bedrock aquifer in the major valleys and alluviated coastal embayments.

Rainfall, vegetation, evaporation, surficial deposits, and exposure to solar radiation are the main factors affecting recharge to the aquifers.

Leaky-salt water and sewage mains in Charlotte Amalie and effluent from sewage plants in the Turpentine Run basin also contribute water to the aquifers as does effluent from septic tanks throughout the island. Recharge from these sources is detrimental as it is a potential source of pollution.

The bedrock aquifer is recharged infrequently and only after a heavy rain or series of lesser rains. The amount depends on the antecedent rainfall and the degree to which soil moisture has been depleted by evapotranspiration since the last rain. Extensive brush cover and the granular nature of the soil cause rapid evapotranspiration. Conversely, the granular nature of the soil will allow water to pass through the soil zone without the soil being completely saturated--saturation being required only along the conduits between the soil granules. This reduces the water needed to satisfy soil-moisture requirements before recharge can take place. Even then, under dry conditions, a major rainstorm of 2 inches or more, or the equivalent in lesser rains, is necessary to initiate recharge to the bedrock aquifer. The amount of rainfall necessary for recharge varies from one part of the island to another. On the north slope 1 inch of rain may cause recharge, whereas on the south slope, under dry conditions, 3 inches or more may be necessary for recharge.

The fluctuation of ground-water levels indicates that recharge to the aquifers on the south-facing slopes is less frequent than on the north-facing slopes. Less frequent recharge on the south slopes is attributed to the greater solar radiation received by these slopes, which results in increased evapotranspiration and a greater soil-moisture deficiency. Consequently, a greater volume of water is necessary to overcome the soil-moisture deficiency before recharge takes place.

Where the surficial deposits (saprolite or alluvium) are thick, ranging from 2 to 15 feet, as on the north slope in the vicinity of Dorothea, in upper Turpentine Run basin, and in the alluvial embayments, such as at Long Bay and the Harry S. Truman Airport, water is retained in the surficial deposits and takes a much longer time to reach the bedrock aquifer. Peak recharge to the bedrock aquifer may lag as much as a month behind the rainfall. In some places little recharge reaches the bedrock aquifer--as most is discharged to springs or streams directly from the saprolite or alluvium, as has been observed in the vicinity of Dorothea on the north slope.

Runoff from major rainstorms is the principal recharge to the aquifers of the coastal embayments and is an important source of recharge to the alluvium of Turpentine Run. Base flow of Turpentine Run and Bonne Resolution Gut at Dorothea Bay, when present, also contributes recharge to the unconsolidated aquifers in their respective basins.

For convenience of discussion, the island has been divided into five ground-water areas as shown in figure 30. Estimates of yield in these areas are given in table 5.

Table 5.--Estimated yield of ground-water areas. (See fig. 30)

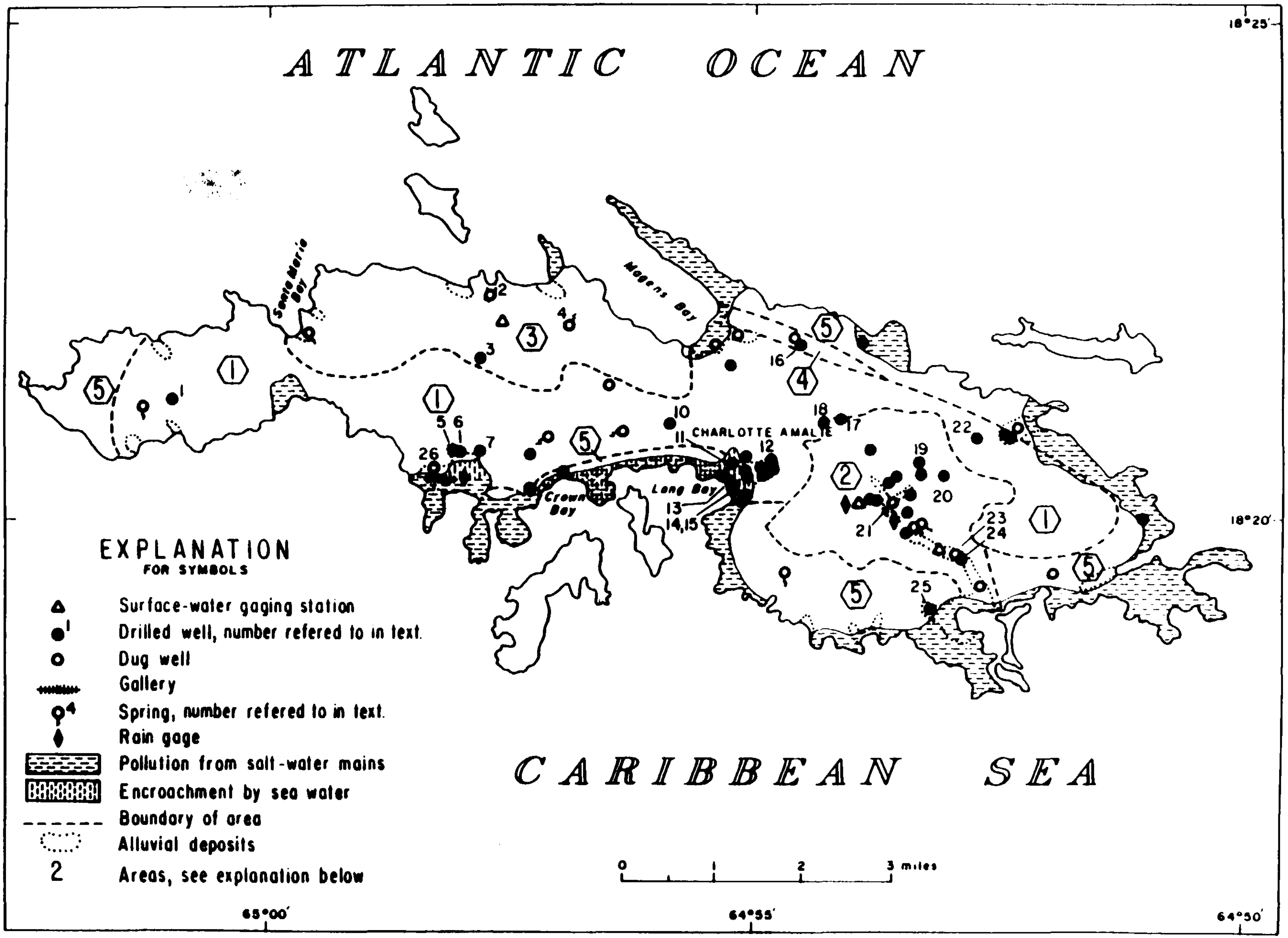
Ground-water area	Area, sq mi	Estimated yield		Annual recharge, inches
		gpd	mg/yr	
1	13.6	450,000	164	0.7
1 (Long Bay)	.3 1/	70,000 3/	25	4.9
1 (Lindberg Bay)	.2 1/	30,000 3/	11	4.3
2	3.4	350,000	128	2.2
2 Upper basin	2.3	300,000 4/	110	2.8
2 Lower basin	1.1	50,000 4/	18	1.1
3	4.6	250,000	91	1.2
4	.4 2/	100,000	36	5.3
5	10.0	100,000	36	.2
Total	32	1,250,000	455	

1/ Approximate area of alluvium only.
2/ Does not include drainage basins at Areas 1 and 5 which contribute recharge to Area 4 from surface-water runoff.
3/ Yield included in Area 1 total.
4/ Yield included in Area 2 total.

Ground-Water Areas

Area 1

Area 1 encompasses about half the land area. It is underlain principally by fractured volcanic tuff and breccia of the Louisenhoj Formation, on which 1 or 2 feet of soil have developed. On the south side of the island, from the vicinity of Charlotte Amalie westward to Brewers Bay, the volcanic rock has been extensively fractured. The fractures, however, have been filled with


ATLANTIC OCEAN
CARIBBEAN SEA
Santa Maria Bay
Magens Bay
CHARLOTTE AMALIE
Crown Bay
Long Bay
18°25'
18°20'
65°00'
64°55'
64°50'
0 1 2 3 miles
EXPLANATION FOR SYMBOLS
Surface-water gaging station
Drilled well, number refered to in text.
Dug well
Gallery
Spring, number refered to in text.
Rain gage
Pollution from salt-water mains
Encroachment by sea water
Boundary of area
Alluvial deposits
2 Areas, see explanation below

A[illegible] EXPLANATION

Area 1

Wells in rock 50 to 300 feet in depth will yield up to 1,000 gpd. In some larger basins and alluviated embayments yields up to 10,000 gpd may be possible. Water contains 1,000 to 1,500 mg/l chloride. Wells drilled near the sea and below sea level may yield brackish water when drilled or if pumped at excessive rates.

Area 2

Wells in rock 50 to 250 feet in depth will yield up to 30,000 gpd. Generally, deeper wells have a higher yield. Short-term yields of selected wells may be as great as 150,000 gpd. Wells tapping alluvium of lower Turpentine Run will yield up to 10,000 gpd. Water contains about 1,000 mg/l dissolved solids and about 200 mg/l chloride. Little danger of salt-water encroachment except in lower Turpentine Run.

Area 3

Wells in rock 50 to 200 feet in depth will yield up to 5,000 gpd. In some larger drainage basins, yields up to 10,000 gpd may be possible. Water contains about 1,000 mg/l dissolved solids and about 200 mg/l chloride. Wells drilled near the sea and below sea level may yield brackish water when drilled or if pumped at excessive rates.

Area 4

Wells in limestone 50 to 150 feet in depth will yield up to 50,000 gpd. Short-term yields of selected wells may be as great as 150,000 gpd. Water contains about 1,500 mg/l dissolved solids and 200 to 300 mg/l chloride. Wells drilled near the sea or below sea level may yield brackish water when drilled or if pumped at excessive rates.

Area 5

Wells in rock 50 to 300 feet in depth will yield up to 1,000 gpd. In general yields are small. Water contains 1,000 to 1,500 mg/l dissolved solids and 300 to 500 mg/l chloride. Wells drilled on peninsulas and in coastal areas generally will encounter brackish water. Ground water polluted by leaky salt-water mains in Charlotte Amalie area.

Figure 30.--Ground-water areas of St. Thomas showing location of wells, springs, stream gages, and rain gages.

secondary minerals.

Alluvium and beach deposits fill the coastal embayments and are especially prominent in the Charlotte Amalie area.

Ground-water levels range from a few feet below land surface in the embayments near the sea to as much as 120 feet below land surface on the central ridge. Depth to the water table is greatest beneath ridges and least in the valleys and lowlands.

Wells range in depth from 50 feet in the low coastal areas to 250 feet or more near the central ridge. In general, the higher the altitude of the well site the greater the depth of the well. There is really no particular depth at which an aquifer can be successfully tapped, as yield depends entirely on the depth and density of open water-bearing fractures. A well in the Long Bay area (well 12) at an altitude of 40 feet was drilled to a depth of 120 feet before water-bearing fractures were penetrated. Well 10, on the other hand, at an altitude of 320 feet on the slope of the central ridge, penetrated water-bearing fractures at 60 feet. These, of course, are extremes. Long-term yields of wells generally range from 250 to 1,000 gpd, although initial or short-term yields may be 10 times greater.

Two valley areas, Long Bay and Lindberg Bay on the east and west edge of Charlotte Amalie, respectively, have greater ground-water potential than the remainder of Area 1.

<u>Long Bay</u>.--The Long Bay area lies in a basin about 1 square mile in extent, of which about 0.3 square mile is alluviated coastal embayment, and the remainder is steep-sloped volcanic ridges with little soil cover. Alluvium as thick as 60 feet overlies the bedrock. Near the coast the alluvium underlies and interfingers with a thin beach-sand deposit. A relatively impervious clay overlies the bedrock from a line about 1,500 feet inland seaward to the shoreline at Long Bay, and probably extends out under Long Bay. Water is present in the alluvial deposits, but the main aquifer is the underlying volcanic rock. In general, the bedrock underlying the alluvium yields more water than that underlying the ridges. The zone of greatest yield to wells is bound by the two faults passing through the area.

A factor contributing to the productivity of the bedrock is the overlying alluvium that acts as a storage reservoir. The alluvium contains large quantities of water. Because of its low permeability it generally yields little water to wells, but it yields water slowly to the underlying bedrock aquifer. The principal area of recharge to the bedrock aquifer from the alluvium is at the foot of the volcanic ridges inland of the edge of the impervious clay wedge capping the bedrock and mostly upgradient from the area of leaky salt-water mains.

The long-term yield of the alluvium-bedrock aquifer is estimated to be from 60,000 to 80,000 gpd. The yield of wells ranges from about 500 to 70,000 gpd. The high yield of some of the wells, however, has little to do with the long-term yield of the aquifer. Sustained pumpage in excess of the long-term yield of the aquifer will deplete the fresh ground water in storage and probably result in salt-water encroachment.

Salt water has encroached in a narrow strip of the alluvial aquifer bordering Long Bay because of pumping dug wells 13, 14, and 15, which supply Pearson Gardens public housing. Nearly half the alluvial aquifer, however, is contaminated to some degree by leaky salt-water mains. The approximate limits of salt-water contamination are shown in figure 30. The bedrock aquifer underlying most of the contaminated alluvium contains fresh water because the principal recharge area is upgradient of the relatively impermeable clay cap overlying the bedrock throughout most of the contaminated areas.

Salt water has entered the bedrock in at least one place. Well 11 became salty after being pumped heavily for about 3 months. Salt water from the alluvium has apparently entered the bedrock aquifer through several improperly constructed wells. In each the annular space between the wall of the well and the casing was left open, and salt water moved down the annular space, contaminating the bedrock aquifer in the vicinity of the well.

[illegible] --The alluvial [illegible] is very similar to that of [illegible] except that there [illegible] no impervious [illegible] the [illegible] the [illegible]. Total basin area [illegible] 1.[illegible] square [illegible] which is [illegible] volcanic [illegible]s. [illegible] as thick [illegible] extends from [illegible]ge and [illegible] where it [illegible] been [illegible] alluvium cover- [illegible] extensive as [illegible] airport is [illegible] tests [illegible] wells in the [illegible] that it has [illegible] low permeability. [illegible] the [illegible] of the alluvium is probably [illegible] percent.

The underlying bedrock is volcanic breccia and tuff, much of it altered by heat from intrusions. [illegible] fracturing is extensive [illegible] many of the fractures are filled with secondary minerals.

Three wells, [illegible], [illegible], and [illegible] have been drilled in the bedrock along the upper edge of the alluvial deposits. Well [illegible] is dry, although it was drilled to a depth of 200 feet. Wells [illegible] and 6 have [illegible] long-term yield, estimated to be [illegible] gpd. Bedrock wells probably will yield 10,000 gpd in the central part of the embayment north of the airport. The alluvium is relatively thick there and, thus, it should contribute considerable quantities of water to the underlying bedrock aquifer.

[illegible] potential yield of the bedrock aquifer is estimated to be 30,000 gpd, assuming data obtained from the Long Bay area can be applied.

Salt-water mains in the Bourne Field housing area are known to leak, and it must be assumed that the alluvium in that vicinity is contaminated. The same care to prevent salt-water contamination by improper well construction must be taken here as in the Long Bay area.

At one time a gallery paralleling the runway at the airport was used for water supply. This gallery, which collected runoff from the runway and stored water in the alluvium and landfill for future use, had a yield estimated to be 13,000 gpd. Unfortunately, the gallery was overpumped and salt-water encroachment followed. Salt water is still present in the alluvium near the well and is in a position to intrude the bedrock aquifer.

Water from the gallery occasionally is used for [illegible]table purposes. The use of water from runway drainage for drinking purposes, of course, is dangerous because of the presence of toxic compounds such as hydrocarbons and tetraethyl lead from spilled aircraft fuels.

Area 2

Area 2 is the drainage basin of Turpentine Run. For convenience it is separated into an upper and lower basin: the upper basin above the stream-gaging station near Mt. Zion, and the lower basin below it. The principal rocks are volcanic flows, tuff, and breccia. Alluvium as thick as 40 feet lies in the main stream channel of the lower basin. A northwest-oriented fractured and jointed zone of hydrothermally altered rock bisects the upper basin.

Drilled wells range from 40 to 250 feet in depth. The shallower wells tap the alluvium and weathered bedrock of lower Turpentine Run. The depth of the rock wells is not necessarily a criterion of greater yield, but is usually an indication of where a zone of water-bearing fractures was penetrated. Short-term yields from individual rock wells in the upper basin are as great as 150,000 gpd. Sustained yields, however, range from about 3,000 to 30,000 gpd. Individual wells in lower Turpentine Run yield as much as 30,000 gpd, but sustained ground-water withdrawals of more than 10,000 gpd will probably result in sea-water encroachment.

Ground-water levels.--Contours of the ground-water surface during August 1965 and January 1966, are shown in figures 31 and 32. The arrows on these maps indicate the general direction of ground-water movement. In the upper basin, when water levels are high, ground-water flow is split--part moving along the course of Turpentine Run and part moving through the fractured and altered zone at Mt. Zion and emerging as a series of springs discharging to Turpentine Run in the lower basin. When ground-water levels are low in the upper basin, nearly all ground water is probably discharged through the fractured zone at Mt. Zion, and a temporary ground-water divide is established at the position shown in figure 31.

Ground-water levels in the basin fluctuate in relation to discharge from and recharge to the aquifers. Figures 29 and 27 are the hydrographs of wells 19 and 24 drilled in bedrock in the upper basin and in the alluvium and weathered rock of

REFERENCE NO. 17

No data base is available for a detailed assessment of population within a particular radius of the site. The best available information follows this note, and consists of a 1980 census by water district.

Populations were estimated by adding together the populations of each district within the radius of interest. In cases where only a portion of a district is within the radius, population was prorated by area.

Kris Buros

FINAL REPORT-FINAL

WATER MANAGEMENT PLAN FOR THE PUBLIC WATER SYSTEM

Prepared for
THE DEPARTMENT OF
CONSERVATION AND CULTURAL AFFAIRS

GOVERNMENT OF THE VIRGIN ISLANDS

CH2M HILL

Prepared by
CH2M HILL SOUTHEAST, INC.

Project No. GN14325.AO
July, 1983

TUT 002 0205

Table 3-3
DEMOGRAPHIC DATA FOR THE U.S. VIRGIN ISLANDS

Island District	Category	1980 Data: Population (persons) RES	1980 Data: Work Force (persons) WKF	1980 Data: Schools (pupils) SCH	1980 Data: Hotels (rooms) TUR	1980 Data: Restaurant (tables) TUR	1990 Projected Data: Population (persons) RES	1990 Projected Data: Work Force (persons) WKF	1990 Projected Data: Schools (pupils) SCH	1990 Projected Data: Hotels (rooms) TUR	1990 Projected Data: Restaurant (tables) TUR	2000 Projected Data: Population (persons) RES	2000 Projected Data: Work Force (persons) WKF	2000 Projected Data: Schools (pupils) SCH	2000 Projected Data: Hotels (rooms) TUR	2000 Projected Data: Restaurant (tables) TUR
St. John	1	1,033	470	429	41	60	1,245	510	429	84	100	1,454	554	429	96	120
	2	897	7	--	30	--	1,072	50	100	10	--	1,220	60	138	10	--
	3	351	436	[illegible]	300	25	382	450	--	358	25	398	450	--	358	25
	4	164	11	[illegible]	--	--	226	11	83	--	--	257	30	83	60	--
	5	35	--	[illegible]	--	--	40	--	--	--	--	46	--	--	--	--
STJ TOTALS		2,4[illegible]	924	[illegible]	[illegible]	85	2,965	1,021	612	457	125	3,375	1,094	658	574	145
St. Thomas	1	135	--	--	--	--	142	--	--	--	--	148	--	--	--	--
	2	376	11	48	--	--	395	11	48	--	--	410	12	48	--	--
	3	555	8	--	--	--	635	8	--	--	--	715	9	--	50	25
	4	1,523	45	260	--	40	1,742	50	260	70	50	1,961	53	260	70	70
	5	2,456	30	--	82	30	2,810	33	--	82	30	3,164	35	--	82	65
	6	4,599	6,619	3,061	433	90	4,820	7,120	3,237	433	115	5,010	7,547	3,514	433	115
	7	1,340	11	334	160	25	1,807	15	334	310	45	2,358	16	334	337	65
	8	1,622	58	--	--	--	2,757	600	794	--	--	3,926	636	1,294	--	10
	9	8,705	440	2,600	--	25	9,035	453	2,600	--	25	9,292	480	2,608	--	25
	10	740	130	150	321	100	1,274	519	858	647	125	1,825	550	858	671	125
	11	564	2	--	--	--	656	2	--	--	--	962	3	--	--	--
	12	2,133	114	996	234	70	2,906	117	996	234	70	3,732	124	1,699	344	70
	13	3,753	250	1,067	661	110	4,293	266	1,067	661	110	4,834	350	1,067	785	160
	14	697	22	364	--	--	797	23	364	--	--	897	24	364	--	--
	15	3,158	400	32	267	--	3,316	422	32	267	20	3,449	469	32	267	20
	16	6,926	6,605	4,235	194	110	7,923	7,105	4,235	194	135	8,921	7,531	4,235	234	160
	17	4,649	6,077	3,565	213	155	4,881	6,259	3,575	254	190	5,076	6,735	3,575	294	215
	18	11	--	--	--	--	13	--	--	--	--	15	46	--	100	25
	19	140	75	--	117	--	160	77	--	117	--	180	120	--	117	25
STT TOTALS		44,178	20,905	16,738	2,692	755	50,520	23,100	18,408	3,277	915	56,875	24,740	19,888	3,790	1,175
St. Croix	1	375	121	23	60	30	473	390	23	160	55	565	443	723	160	55
	2	3,887	831	2,095	65	55	4,562	914	2,095	65	55	5,198	1,040	2,095	115	65
	3	11,170	739	2,812	110	10	14,425	199	2,812	110	10	17,491	957	2,812	110	10
	4	637	175	--	--	10	700	199	--	--	10	836	226	--	--	10
	5	573	25	--	--	--	630	20	--	--	--	753	32	--	--	--
	6	404	70	9	91	25	509	89	9	91	25	608	101	9	154	50
	7	4,964	1,091	1,939	--	--	6,674	1,262	2,739	--	--	7,975	1,413	3,450	--	--
	8	2,260	1,479	2,200	25	20	4,270	1,603	3,149	56	20	5,112	1,915	3,317	56	20
	9	8,012	4,013	3,369	--	10	8,940	4,003	3,369	--	10	10,663	4,658	3,369	--	10
	10	2,005	306	440	82	25	2,629	348	440	82	25	3,142	396	440	82	25
	11	2,497	596	65	100	25	3,148	607	65	200	45	3,762	691	65	200	50
	12	3,520	8,196	1,369	303	190	3,080	9,106	1,369	303	190	4,637	10,364	1,369	303	190
	13	2,551	473	--	--	--	3,430	530	800	100	--	4,099	612	800	100	--
	14	504	--	--	--	--	555	10	--	--	--	663	11	--	--	--
	15	418	252	799	162	75	527	287	799	162	75	630	327	799	162	75
	16	546	110	40	100	25	600	125	40	100	25	822	142	40	282	25
	17	303	200	--	154	85	407	374	--	154	85	486	426	--	154	85
	18	40	30	--	--	--	53	11	--	--	--	63	13	--	--	--
	19	377	--	--	--	--	415	10	--	--	--	495	11	--	--	--
	20	4,141	1,741	3,168	180	10	5,222	1,775	3,168	180	10	6,240	2,020	3,168	180	10
IX TOTALS		9,200	20,516	18,320	1,312	595	62,145	22,670	20,077	1,843	640	74,240	25,798	22,456	2,138	680
TALS		,930	42,345	35,570	4,575	1,435	115,630	46,791	39,097	5,577	1,680	134,490	51,622	42,944	6,452	2,000

TUT 002 0206

ote: RES = r...); WKF = work force; SCH = school; TUR = tourist oriented.

[illegible]

OUTPUT DATA FOR YEAR 1980

	INTERNAL DEMAND			INTERNAL WATER SUPPLY: POTABLE WATER			INTERNAL WATER SUPPLY: NON-POTABLE WATER			EXTERNAL DEMAND		
	POTABLE KGAL/D	NON-POT KGAL/D	TOTAL KGAL/D	CISTERN KGAL/D	OTHER KGAL/D	TOTAL KGAL/D	SALT KGAL/D	OTHER KGAL/D	TOTAL KGAL/D	POTABLE KGAL/D	NON-POT KGAL/D	TOTAL KGAL/D
DISTRICT # 01	47.9	0.0	47.9	7.4	0.0	7.4	0.0	0.0	0.0	40.5	0.0	40.5
DISTRICT # 02	271.7	36.2	307.7	45.7	0.0	45.7	0.0	0.0	0.0	226.0	36.2	262.2
DISTRICT # 03	670.8	0.0	670.8	110.8	5.0	115.8	0.0	0.0	0.0	555.0	0.0	555.0
DISTRICT # 04	135.5	0.0	135.5	9.4	100.0	109.4	0.0	0.0	0.0	26.1	0.0	26.1
DISTRICT # 05	29.1	0.0	29.1	6.9	0.0	6.9	0.0	0.0	0.0	22.2	0.0	22.2
DISTRICT # 06	37.7	0.0	37.7	6.3	0.0	6.3	0.0	0.0	0.0	31.4	0.0	31.4
DISTRICT # 07	293.8	0.0	293.8	64.2	0.0	64.2	0.0	0.0	0.0	229.6	0.0	229.6
DISTRICT # 08	286.2	0.0	286.2	39.8	51.0	90.8	0.0	0.0	0.0	236.5	0.0	236.5
DISTRICT # 09	2486.0	19000.0	21486.0	110.9	4123.5	4234.4	21000.0	0.0	21000.0	415.3	0.0	415.3
DISTRICT # 10	131.1	0.0	131.1	29.1	0.0	29.1	0.0	0.0	0.0	102.0	0.0	102.0
DISTRICT # 11	233.0	0.0	233.0	37.9	0.0	37.9	0.0	0.0	0.0	195.1	0.0	195.1
DISTRICT # 12	607.1	27.6	634.5	56.2	0.0	56.2	0.0	0.0	0.0	550.9	27.6	578.5
DISTRICT # 13	134.7	0.0	134.7	31.5	0.0	31.5	0.0	0.0	0.0	103.2	0.0	103.2
DISTRICT # 14	25.2	0.0	25.2	6.0	0.0	6.0	0.0	0.0	0.0	19.2	0.0	19.2
DISTRICT # 15	118.5	50.0	168.5	9.9	50.0	59.9	0.0	50.0	50.0	58.6	0.0	58.6
DISTRICT # 16	96.7	0.0	96.7	6.1	5.0	11.1	0.0	50.0	50.0	90.5	0.0	90.5
DISTRICT # 17	43.3	7.7	51.0	5.4	110.0	115.4	0.0	10.0	10.0	24.2	0.0	24.2
DISTRICT # 18	2.6	0.0	2.6	0.4	0.0	0.4	0.0	0.0	0.0	2.2	0.0	2.2
DISTRICT # 19	18.9	0.0	18.9	3.4	0.0	3.4	0.0	0.0	0.0	15.5	0.0	15.5
DISTRICT # 20	318.5	37.2	355.6	50.8	0.0	50.8	0.0	0.0	0.0	267.7	37.2	304.9
TOTAL ISLAND	5988.3	19158.7	25146.5	638.1	4444.5	5082.6	21000.0	110.0	21110.0	3211.7	101.0	3312.7

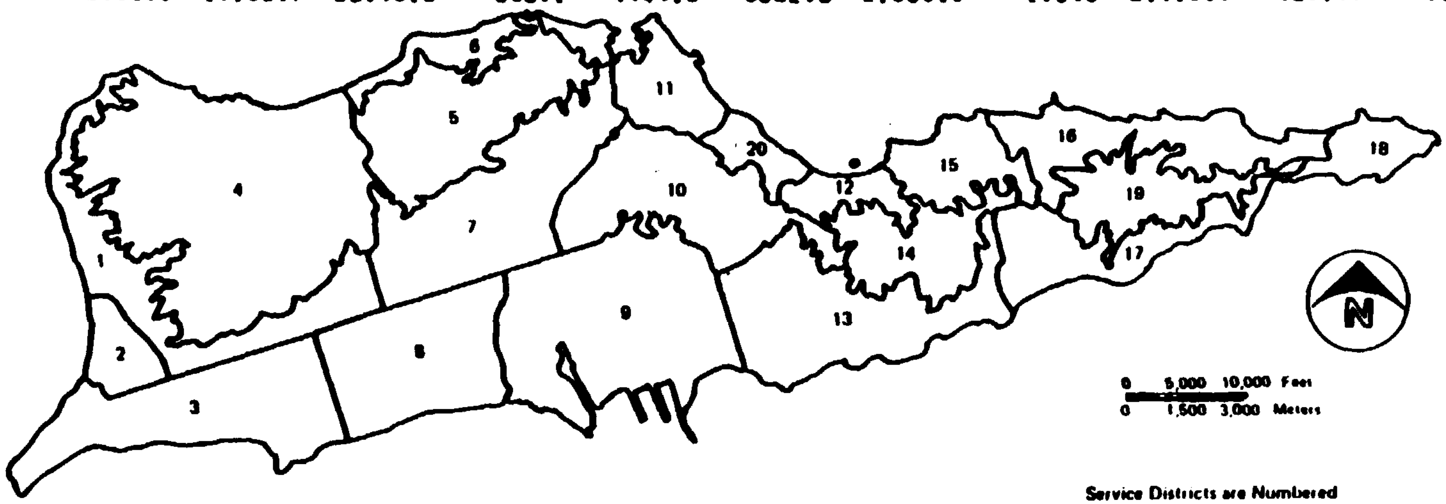


FIGURE 3-4. Projected demand of the service districts on St. Croix for the year 1980.

CH2M HILL

ISLAND OF S[illegible] THOMAS
OUTPUT DA[illegible] [illegible]R YEAR 1980

	INTERNAL DEMAND			INTERNAL WATER SUPPLY: POTABLE WATER			INTERNAL WATER SUPPLY: NON-POTABLE WATER			EXTERNAL DEMAND		
	POTABLE KGAL/D	NON-POT KGAL/D	TOTAL KGAL/D	CISTERN KGAL/D	OTHER KGAL/D	TOTAL KGAL/D	SALT KGAL/D	OTHER KGAL/D	TOTAL KGAL/D	POTABLE KGAL/D	NON-POT KGAL/D	TOTAL KGAL/D
DISTRICT # 01	6.8	0.0	6.8	1.4	0.0	1.4	0.0	0.0	0.0	5.4	0.0	5.4
DISTRICT # 02	19.7	0.0	19.7	4.1	0.0	4.1	0.0	0.0	0.0	15.6	0.0	15.6
DISTRICT # 03	27.9	0.0	27.9	5.0	0.0	5.0	0.0	0.0	0.0	22.9	0.0	22.9
DISTRICT # 04	85.8	0.0	85.8	22.1	0.0	22.1	0.0	0.0	0.0	63.7	0.0	63.7
DISTRICT # 05	137.0	1.9	138.9	34.7	0.0	34.7	0.0	4.0	4.0	102.3	0.0	102.3
DISTRICT # 06	584.7	[illegible]	616.5	83.8	30.0	113.8	0.0	0.0	0.0	475.7	31.8	507.5
DISTRICT # 07	104.1	[illegible]	210.1	20.3	65.0	85.3	0.0	56.0	56.0	73.4	50.0	123.4
DISTRICT # 08	82.5	0.0	82.5	11.2	8.0	19.2	0.0	0.0	0.0	63.3	0.0	63.3
DISTRICT # 09	540.8	0.0	540.8	102.8	16.0	118.8	0.0	0.0	0.0	422.2	0.0	422.2
DISTRICT # 10	97.0	11.1	108.1	13.1	0.0	13.1	0.0	15.0	15.0	83.9	0.0	83.9
DISTRICT # 11	50.3	0.0	50.3	3.4	0.0	3.4	0.0	0.0	0.0	46.9	0.0	46.9
DISTRICT # 12	174.9	10.5	185.4	28.6	10.0	38.6	0.0	15.0	15.0	139.7	0.0	139.7
DISTRICT # 13	281.7	[illegible]	342.8	40.0	170.0	210.0	0.0	62.0	62.0	195.8	4.2	200.0
DISTRICT # 14	40.7	0.0	40.7	9.7	0.0	9.7	0.0	0.0	0.0	31.0	0.0	31.0
DISTRICT # 15	215.4	26.3	[illegible]	33.8	0.0	33.8	0.0	0.0	0.0	181.6	26.3	207.9
DISTRICT # 16	712.0	57.6	769.6	112.7	8.0	120.7	0.0	0.0	0.0	591.3	57.6	648.9
DISTRICT # 17	567.2	20.7	587.9	93.5	25.0	118.5	0.0	0.0	0.0	448.7	20.7	469.4
DISTRICT # 18	0.6	0.0	0.6	0.1	0.0	0.1	0.0	0.0	0.0	0.5	0.0	0.5
DISTRICT # 19	25.7	0.0	25.7	3.6	0.0	3.6	0.0	0.0	[illegible]	22.1	0.0	22.1
TOTAL ISLAND	3754.8	327.0	4081.8	623.9	332.0	955.9	0.0	152.0	152.0	2986.0	190.6	3176.6

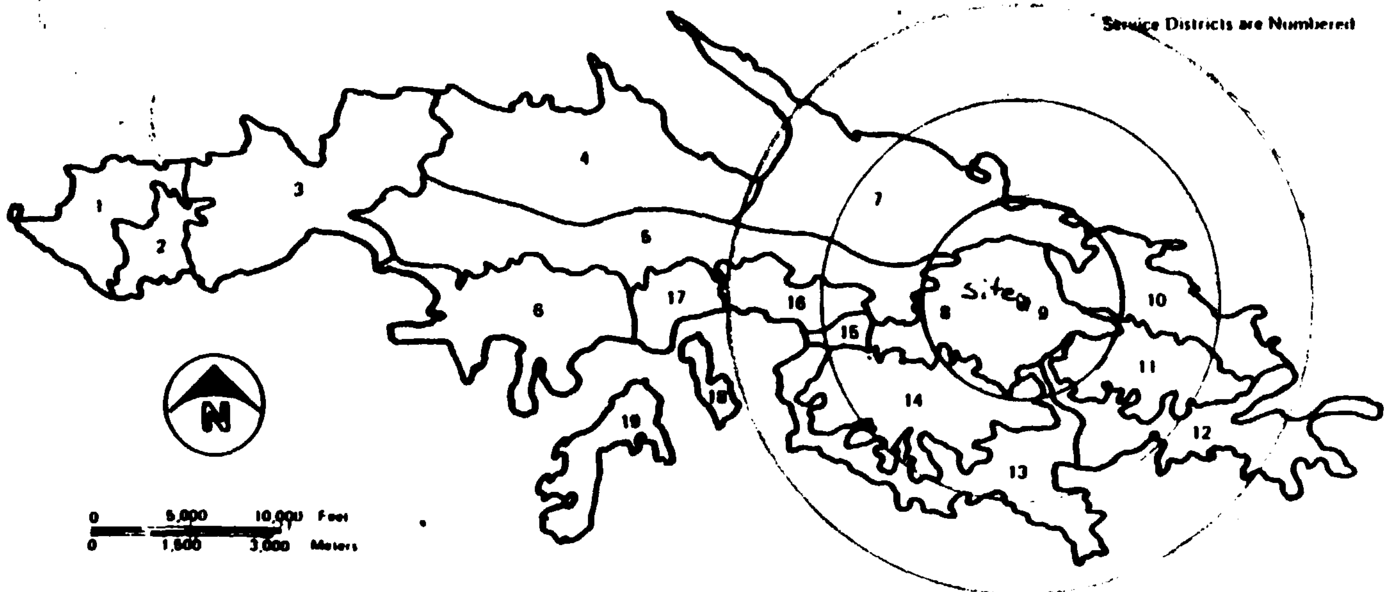


FIGURE 3-6. Projected demand of the service districts on St. Thomas for the year 1980.

CH2M HILL

REFERENCE NO. 18

NUS CORPORATION — **TELECON NOTE**

CONTROL NO: UR-8901-29	DATE: 3/10/89	TIME: ~~1025~~ 1045 AM

DISTRIBUTION:

BETWEEN: Fernando Gomez	OF: USGS, Puerto Rico	PHONE: (809) 749-4346

AND: Rich Feinberg (NUS)

DISCUSSION:

Asked Mr. Gomez if he knows whether the geologic x-sections and maps which were in Dorothy Commonatu's file were valid for use in a report. I explain that these maps which were depicting the area around the College of VI had a stamp on them "For Administrative Use Only". I asked if these x-sections are valid? Since I have sites close by I would like to use this reference. He said that the report "Optimization of Aquifer Yields From Coastal Embayments at the College of the Virgin Islands, St Thomas U.S.VI." October 1982, F. Gomez. He has the x-sections and geologic maps that I am referring to. He said that I can use these maps for stratigraphy in my report. When asked if he knew the hydraulic conductivity of layers in area of College of VI. He said That the semi-permeable clay/weathered rock was 150 ft²/Day and the transmissivity of the alluvium is at least 1000 ft/day.

ACTION ITEMS:

He said That the production of water from the consolidated aquifer is 10K/gpd. When I ask F. Gomez if he knew where groundwater was used for a drinking source on the island. He said he didn't believe that groundwater was used at all for a drinking source. The best groundwater has been found 1000's feet below the surface. The TDS is too high in aquifer above 1000 feet for a drinking water source. Groundwater is used for toilet flushing and clothes washing.

NUS 087 REVISED 0881

REFERENCE NO. 19

NUS CORPORATION TELECON NOTE

CONTROL NO:	DATE: 3/14/89	TIME: 1430

DISTRIBUTION:

~~02~~

BETWEEN: Don Goetz - well driller	OF: Polycaribe	PHONE: (809) 775-4660

AND: D Trube (NUS)

DISCUSSION:

Mr Goetz estimates 500-600 private wells on St Thomas
30 private wells on St. John

Private wells are used primarily for non-drinking, domestic use (washing, flushing, etc.). Local laws require a cistern at each house - needed for building permits.

Permit + well information are not generally documented, and there is unlicensed illegal drilling on the island. Some records are kept at Public Works (Ms. Laurel Grigg) or at DPNR. Well locations may be at DPW

Mr Goetz thinks VIHA wells are probably mixed with rain water.

There are several wells used for irrigation, including
- VI gov't wells at Estate Dorothea Agric. Station,
- Hydroponics at the eastern end of St. Thomas.
- Caret Bay - St Thomas Vegetable Products

ACTION ITEMS:

about 20 acres are irrigated on St Thomas

There are areas within 1/4 mile of shore they have fresh water wells.

There are many locally confining clay layers which haven't been mapped. Wells several hundred feet apart have unconnected ground water, determined by differences in conductivity. This also occurs in Turpentine Run Basin

NUS 087 REVISED 0581

TUT 002 0212

NUS CORPORATION TELECON NOTE

CONTROL NO:	DATE: 3/3/89	TIME: 440

DISTRIBUTION:

02-8901-29

BETWEEN: Leonard Reed	OF: DPNR (VI)	PHONE: (809) 7743320

AND: Diane Trube (NUS)

DISCUSSION:

Reed spoke w/ Amy Brochu today. She asked him to call me about the info we need from DPNR.

I requested (again!) this info.

1. Rainfall/evap data
2. site ownership
3. Permit (Reed said none of the sites have any environmental permits, except he thinks Yacht Haven Marina may have a water discharge permit - he will check)
4. Well locations, well logs, depth to groundwater, people served by wells
5. Locations of desal. plant intake + Sunny Mt. well.
6. Irrigation info (Reed says no groundwater is used for irrigation on St. Thomas or St. John - treated sewerage is used instead).

ACTION ITEMS:

TUT 002 0213

NUS 087 REVISED 0581

REFERENCE NO. 20