Hydrogeology in the Vicinity of Test Holes and Wells on St. Croix, St. Thomas, and St. John, U.S. Virgin Islands

By Robert P. Graves

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4004

Prepared in cooperation with the

U.S. OFFICE OF MANAGEMENT AND BUDGET

San Juan, Puerto Rico
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
GSA Center, Suite 400-15
651 Federal Drive
San Juan, Puerto Rico 00965

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

Abstract 1

Introduction 1

Test-hole drilling and well completion 3

Description of study areas 3

Geology 23

- St. Croix 23
- St. Thomas and St. John 27

Ground-water hydrology 27

- Ground-water occurrence and movement 27
- Hydraulic characteristics of the aquifers 34

Water quality 35

Summary 46

References 47

ILLUSTRATIONS

1 - 10. Maps showing:

1. Location of the U.S. Virgin Islands 2
2. Location of wells 1 through 5 and well 27, St. Croix, U.S. Virgin Islands 13
3. Location of wells 6 through 20, wells 24 through 26, and wells 28 through 36, St. Croix, U.S. Virgin Islands 14
4. Location of wells 21 through 23, St. Croix, U.S. Virgin Islands 16
5. Location of wells 37 through 58, St. Thomas, U.S. Virgin Islands 17
6. Location of wells 59 through 66, St. John, U.S. Virgin Islands 18
7. Location of wells 67 through 77, St. John, U.S. Virgin Islands 19
8. General drainage features of St. Croix, U.S. Virgin Islands 22
9. General drainage features of St. Thomas, U.S. Virgin Islands 24
10. General drainage features of St. John, U.S. Virgin Islands 25

11. Bar graphs showing mean monthly rainfall for St. Croix, St. Thomas, and St. John, U.S. Virgin Islands, 1982-92 26

12 - 17. Graphs showing:

12. Daily mean ground-water levels in wells VIWAPA 02, VIWAPA 03, and VIWAPA 17, Adventure well field, and monthly rainfall, St. Croix, U.S. Virgin Islands, May 1990 through September 1992 28

13. Daily mean ground-water levels in wells VIWAPA 06/DPW 06, Golden Grove, VIWAPA 02, Fairplains, and VIWAPA 23A, Barren Spot, and monthly rainfall, St. Croix, U.S. Virgin Islands, May 1990 through September 1992 29

14. Daily mean ground-water levels in wells STT-VIEO-06, STT-VIEO-11, and Grade School 03, St. Thomas, and monthly rainfall, St. Thomas, U.S. Virgin Islands, May 1990 through September 1992 30

15. Daily mean ground-water levels in wells STT-VIEO-01, STT-VIEO-10, and STT-VIEO-09, St. Thomas, and monthly rainfall, St. Thomas, U.S. Virgin Islands, May 1991 through September 1992 31

16. Daily mean ground-water levels in Guinea Gut well, DPW-06 Sussanaberg, and NPS-06 Cinnamon Bay, St. John, and monthly rainfall, St. John, U.S. Virgin Islands, May 1990 through September of 1992 32

17. Daily mean ground-water levels in STJ-VIEO- 02, 04, and 03, St. John, and monthly rainfall, St. John, U.S. Virgin Islands, May 1991 through September 1992 33

18 - 20. Diagrams showing:

18. Major constituents in ground water in wells on St. Croix, U.S. Virgin Islands 45

19. Major constituents in ground water in wells on St. Thomas, U.S. Virgin Islands 45

20. Major constituents in ground water in wells on St. John, U.S. Virgin Islands 46

TABLES

1. Description of test holes drilled on St. Croix, U.S. Virgin Islands 4
2. Description of test holes drilled on St. Thomas, U.S. Virgin Islands 8
3. Description of test holes drilled on St. John, U.S. Virgin Islands 11
4. Well name and site identification number of wells drilled on St. Croix, St. Thomas, and St. John, U.S. Virgin Islands 20
5. Transmissivity estimated from specific capacity at selected wells on St. Thomas and St. John, U.S. Virgin Islands 34
6. Chemical analyses of ground water on St. Croix, U.S. Virgin Islands 36
7. Chemical analyses of ground water on St. Thomas, U.S. Virgin Islands 39
8. Chemical analyses of ground water on St. John, U.S. Virgin Islands 40

CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
square mile	250.0	hectare
cubic foot per second	0.02832	cubic meter per second
gallon per minute	0.06308	liter per second
gallon per minute per foot	0.2070	liter per second per meter
foot per day[1]	0.3048	meter per day
square foot per day	0.09290	square meter per day

[1] The standard unit for transmissivity is cubic foot per day per square foot times foot of an aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C= 5/9 (°F - 32)

Abbreviated water-quality units used in report:

microgram per liter (µg/L)

milligram per liter (mg/L)

microsiemens per centimeter at 25 °C (µS/cm)

Acronyms used in report:

National Oceanic and Atmospheric Administration (NOAA)

U.S. Geological Survey (USGS)

U.S. Virgin Islands (USVI)

U.S. Virgin Islands Energy Office (VIEO)

U.S. Virgin Islands Water and Power Authority (VIWAPA)

Hydrogeology in the Vicinity of Test Holes and Wells on St. Croix, St. Thomas, and St. John, U.S. Virgin Islands

By **Robert P. Graves**

ABSTRACT

The islands of St. Croix, St. Thomas, and St. John, U.S. Virgin Islands, were devastated by Hurricane Hugo on September 17 and 18, 1989. Damage to the islands water-supply infrastructure prevented rapid restoration of this basic service. In St. Croix, several well fields, which had limited use in recent years, were used to provide emergency water supplies to the island. Recognizing the need for a better understanding of the hydrogeology of the U.S. Virgin Islands, the U.S. Geological Survey conducted an investigation from May 1990 through September 1992, to determine the occurrence and quality of ground water so emergency ground-water supplies could be developed to mitigate natural or man induced disasters.

The geology of the U.S. Virgin Islands is varied. The geology of St. Croix includes alluvial deposits and carbonate and volcanic rocks. The geology of St. Thomas and St. John is dominated by volcanic rocks with local alluvial deposits in small coastal embayments. Carbonate deposits are present on St. Thomas and St. John but only in minor isolated outcrops.

Ground water occurs under water-table conditions on St. Croix, St. Thomas, and St. John. On St. Croix, most ground-water development occurs in the carbonate rock and overlying alluvial deposits. On St. Thomas and St. John the principal source of ground water is from the fractured volcanic rock and overlying alluvial deposits. Ground water depth below land surface ranges from approximately 4 to 62 feet on St. Croix, 3 to 74 feet on St. Thomas, and 8 to 60 feet on St. John. Aquifer transmissivities range from about 200 to 4,000 feet squared per day on St. Croix and from 200 to 2,500 feet squared per day on St. Thomas and St. John. Well yields for emergency supply wells on St. Croix, St. Thomas, and St. John range from about 14 to 80 gallons per minute.

Ground water in the U.S. Virgin Islands is predominantly of the sodium chloride type. Ground-water samples collected from selected wells had chloride concentrations ranging from 116 to 3,870 milligrams per liter and dissolved solids concentrations ranging from 542 to 2,470 milligrams per liter. On St. Croix, depending on location, the sodium chloride is due to connate water or to seawater intrusion. Data were not available to determine the source of sodium chloride on St. Thomas or St. John.

INTRODUCTION

The islands of St. Croix, St. Thomas, and St. John, U.S. Virgin Islands (USVI) (fig. 1), were devastated by Hurricane Hugo on September 17 and 18, 1989. Rapid restoration of basic services such as drinking water was not possible because of damage to the infrastructure that provides water to these islands. For municipal water supplies, the USVI had been supplied primarily by desalinization plants and, only minimally, by isolated ground-water supplies.

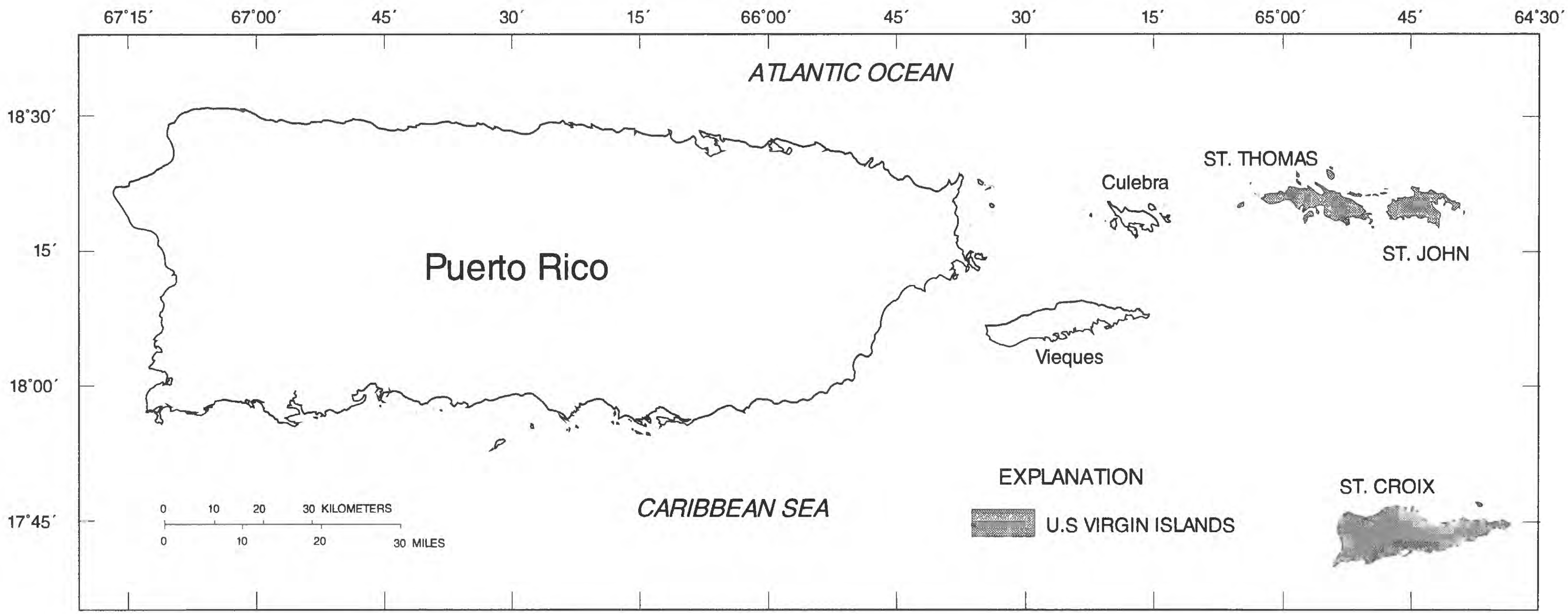


Figure 1. Location of the U.S. Virgin Islands.

Following Hurricane Hugo the desalination plant in St. Croix was so heavily damaged that full recovery of the plant was not possible for weeks following the storm. Fortunately, in St. Croix, several well fields, which had limited use in recent years, were connected to the water distribution system for emergency water supply. The availability of water from these well fields prevented a serious water crisis in St. Croix.

Recognizing the need for a better understanding of the hydrogeology of the USVI, the U.S. Geological Survey (USGS), in cooperation with the U.S. Office of Management and Budget, conducted an investigation from May 1990 through September 1992, to determine the occurrence and quality of ground water so emergency ground-water supplies could be developed to mitigate natural or man induced disasters. This report describes the hydrogeology of selected lands on the islands of St. Croix, St. Thomas, and St. John, USVI. Data used in this report are based largely on information obtained through test-hole drilling and well completion.

TEST-HOLE DRILLING AND WELL COMPLETION

During this investigation, 61 test holes were drilled (tables 1, 2, and 3). Of these test holes, 12 were completed as observation wells, 27 were completed as emergency water supply wells, and 22 were back-filled and abandoned. Of the 12 observation wells completed, 8 were instrumented by the USGS with continuous water-level recorders to monitor ground-water level fluctuations. Of the 27 emergency water supply wells completed, specific capacity tests to determine aquifer transmissivity were conducted on 12 wells and all of the wells were sampled for water-quality analysis. The test-hole drilling for this study was completed using the reverse-air circulation drilling method with an open-center reverse-air drill bit (Graves, 1992). Information used in this report not only includes data from the test holes drilled and wells completed, but also from 16 previously existing wells. Ten of the existing wells were instrumented with continuous water-level recorders. Water-quality samples were collected at six of the existing wells.

The locations of all wells used in this study are shown in figures 2 through 7. Well numbers, names, and site identification numbers for these wells are given in table 4. The well numbers in table 4 apply only to this report. However, the site-identification numbers conform with the established USGS Ground-Water Site Inventory numbering system (Mathey, 1990). The site-identification number does not change and can be used to reference a specific well in other USGS publications.

DESCRIPTION OF STUDY AREAS

St. Croix, St. Thomas, and St. John are the largest of more than 50 islands and cays that make up the USVI. The USVI are located from 50 to 100 miles east and southeast of Puerto Rico and form part of the Antilles island arch, which separates the Caribbean Sea from the Atlantic Ocean (fig.1) (Jordan and Cosner, 1973).

The island of St. Croix is approximately 22 miles long, ranges from 1 to 6 miles in width, and has an area of approximately 84 square miles. The island is characterized by a mountainous area in the north, west, and east, with the northern mountainous area flanked by a rolling plain to the south (fig. 8) (Rivera and others, 1970). The highest elevation on St. Croix is 1,165 feet above mean sea level. The northern and western mountains are marked by many narrow, steep-sided valleys through which deeply cut intermittent streams discharge. The stream valleys of the eastern mountainous area are also intermittent but are not as sharply incised as the northern and western areas. Drainage on St. Croix can occur in all directions; however, the principal direction of drainage is either south or southeast.

The island of St. Thomas is approximately 14 miles long, ranges from 2 to 3 miles in width, and has an approximate area of 32 square miles. The land surface of St. Thomas is almost entirely sloping and extends seaward from a central ridge, which attains an elevation of 800 to 1,200 feet above mean sea level and runs the length of the island (Jordan and Cosner, 1973). Coastal plains are almost completely absent and flat land is confined to only a few small embayments.

Table 1. Description of test holes drilled on St. Croix, U.S. Virgin Islands

[mm-dd-yy, month-day-year; ft-blsd, feet below land surface datum; gal/min, gallons per minute; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; STXT, St. Croix-test hole that was backfilled; STX, St. Croix; EGWS, emergency ground-water supply; --, data not available]

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
1 STXT-01	07-15-92	80	test hole back filled	--	440	2,230	Alluvial deposits Volcanic rock	0 - 46 46 - 80
2 STX-EGWS-01	07-15-92	70	6-inch casing 0 - 30 6-inch screen 30 - 70	45	210	1,470	Alluvial deposits Volcanic rock	0 - 70 70
3 STX-EGWS-02	07-17-92	69	6-inch casing 0 - 30 6-inch screen 30 - 69	30	225	1,400	Alluvial deposits Volcanic rock	0 - 60 60 - 69
4 STXT-02	07-20-92	60	test hole back filled	--	715	2,750	Topsoil Alluvial deposits	0 - 1 1 - 60
5 STX-EGWS-03	07-21-92	80	6-inch casing 0 - 40 6-inch screen 40 - 80	20	200	1,440	Alluvial deposits Volcanic rock	0 - 70 70 - 80
6 STXT-03	07-22-92	120	test hole back filled	--	1,400	5,650	Kinghill Limestone	0 - 120
7 STX-EGWS-04	07-23-92	160	6-inch casing 0 - 120 6-inch screen 120 - 160	15	465	2,680	Topsoil Kingshill Limestone	0 - 1 1 - 160
8 STXT-04	07-28-92	120	test hole back filled	--	--	--	Topsoil Alluvial deposits Kingshill Limestone	0 - 2 2 - 19 19 - 120

Table 1. Description of test holes drilled on St. Croix, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
9 STX-EGWS-05	07-28-92	130	6-inch casing 0 - 86 6-inch screen 86 - 126	35	340	2,290	Kingshill Limestone	0 - 130
10 STXT-05	07-29-92	110	test hole back filled	--	295	1,700	Alluvial deposits Kingshill Limestone Jealousy Formation	0 - 18 18 - 102 102 - 110
11 STXT-06	07-30-92	90	test hole back filled	--	310	1,900	Alluvial deposits Kingshill Limestone Jealousy Formation	0 - 13 13 - 88 88 - 90
12 STX-EGWS-06	07-30-92	96	6-inch casing 0 - 52 6-inch screen 52 - 92	25	290	1,990	Topsoil Kingshill Limestone Jealousy Formation	0 - 42 42 - 92 92 - 96
13 STX-EGWS-07	08-03-92	120	6-inch casing 0 - 60 6-inch screen 60 - 120	25	340	2,140	Alluvial deposits Kingshill Limestone	0 - 34 34 - 120
14 STX-EGWS-08	08-04-92	120	6-inch casing 0 - 70 6-inch screen 70 - 120	25	300	2,180	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 41 41 - 120
15 STXT-07	08-06-92	115	test hole back filled	--	275	--	Topsoil Alluvial deposits Kingshill Limestone Jealousy Formation	0 - 1 1 - ? ? - 112 112 - 115
16 STXT-08	08-06-92	120	test hole back filled	--	365	--	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 48 48 - 120

Table 1. Description of test holes drilled on St. Croix, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
17 STX-EGWS-09	08-07-92 - 08-10-92	120	6-inch casing 0 - 100 6-inch screen 100 - 120	80	720	3,670	Alluvial deposits Kingshill Limestone	0 - 64 64 - 120
18 STX-EGWS-10	08-11-92 - 08-12-92	120	6-inch casing 0 - 80 6-inch screen 80 - 120	35	740	3,640	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 60 60 - 120
19 STX-EGWS-11	08-13-92 - 08-14-92	190	6-inch casing 0 - 140 6-inch screen 140 - 190	35	290	2,520	Alluvial deposits Kingshill Limestone	0 - 8 8 - 190
20 STXT-09	08-18-92 - 08-19-92	140	test hole back filled	--	380	2,360	Alluvial deposits Kingshill Limestone	0 - 54 54 - 140
21 STX-EGWS-12	08-19-92 - 08-20-92	240	6-inch casing 0 - 150 6-inch screen 150 - 230	80	1,000	4,290	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 23 23 - 240
22 STXT-10	08-24-92	120	test hole back filled	--	705	4,270	Kingshill Limestone	0 - 120
23 STX-EGWS-13	08-25-92	130	6-inch casing 0 - 70 6-inch screen 70 - 130	14	375	2,210	Alluvial deposits Volcanic rock	0 - 60 60 - 130
24 STX-EGWS-14	08-31-92	120	6-inch casing 0 - 70 6-inch screen 70 - 120	35	285	1,980	Alluvial deposits Kinghill Limestone	0 - 70 70 - 120

Table 1. Description of test holes drilled on St. Croix, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
25 STXT-11	09-01-92 - 09-02-92	160	test hole back filled	--	340	2,200	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 77 77 - 160
26 STXT-12	09-02-92	70	test hole back filled	--	well dry	well dry	Alluvial deposits Volcanic rock	0 - 62 62 - 70
27 STXO-01	09-03-92	70	4-inch casing 0 - 30 4-inch screen 30 - 70	25	250	1,650	Alluvial deposits Volcanic rock	0 - 65 65 - 70
28 STXO-02	09-04-92	130	4-inch casing 0 - 90 4-inch screen 90 - 130	45	425	2,580	Topsoil Kingshill Limestone	0 - 2 2 - 130
29 STX-EGWS-15	09-10-92	130	6-inch casing 0 - 85 6-inch screen 85 - 125	20	350	2,270	Topsoil Alluvial deposits Kingshill Limestone Jealousy Formation	0 - 1 1 - 52 52 - 127 127 - 130
30 STXO-03	09-08-92	120	4-inch casing 0 - 80 4-inch screen 80 - 120	30	370	2,310	Topsoil Alluvial deposits Kingshill Limestone	0 - 1 1 - 40 40 - 120

[1] Well number refers to well location as shown on figures 2, 3, or 4.

Table 2. Description of test holes drilled on St. Thomas, U.S. Virgin Islands

[mm-dd-yy, month-day-year; ft-blsd, feet below land surface datum; gal/min, gallons per minute; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available; STT, St. Thomas; EGWS emergency ground-water supply; VIEO, Virgin Islands Energy Office]

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
37 STT-EGWS-01	11-19-90 - 12-04-90	160	6-inch casing 0 - 90 6-inch screen 90 - 160	17	400	2,150	Topsoil Alluvial deposits Volcanic rock	0 - 3 3 - 65 65 - 160
38 STT-EGWS-02	01-28-91 - 01-31-91	158	6-inch casing 0 - 100 6-inch screen 100 - 158	18	212	1,646	Alluvial deposits Volcanic rock	0 - 45 45 - 158
39 STT-EGWS-03	01-31-91 - 02-04-91	140	6-inch casing 0 - 100 6-inch screen 100 - 140	45	274	1,740	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 50 50 - 140
40 STT-VIEO-01 (observation well)	02-05-91	145	4-inch casing 0 - 100 4-inch screen 100 - 145	35	180	1,300	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 54 54 - 145
41 STT-EGWS-04	06-24-91 - 06-25-91	70	6-inch casing 0 - 50 6-inch screen 50 - 70	30	116	1,090	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 32 32 - 70
42 STT-EGWS-05	06-26-91 - 06-27-91	95	6-inch casing 0 - 62 6-inch screen 62 - 94	40	140	1,180	Alluvial deposits Volcanic rock	0 - 50 50 - 95
43 STT-VIEO-05	07-01-91	20	test hole back filled	--	--	--	Alluvial deposits Volcanic rock	0 - 12 12 - 20

Table 2. Description of test holes drilled on St. Thomas, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value μs/cm)	Subsurface material (ft-blsd)	
44 STT-VIEO-06 (observation well)	07-01-91	76	4-inch casing 0 - 56 4-inch screen 56 - 76	14	116	1,180	Topsoil Alluvial deposits Volcanic rock	0 - 2 2 - 35 35 - 76
45 STT-EGWS-06	07-02-91 - 07-05-91	120	6-inch casing 0 - 70 6-inch screen 70 - 120	50	224	1,680	Fill material Alluvial deposits Volcanic rock	0 - 12 12 - 63 63 - 120
46 STT-VIEO-07	07-08-91	40	test hole back filled	--	1,910	6,800	Alluvial deposits Volcanic rock	0 - 33 33 - 40
47 STT-VIEO-08 (observation well)	07-09-91	57	4-inch casing 0 - 37 4-inch screen 37 - 57	--	780	3,360	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 24 24 - 57
48 STT-VIEO-09 (observation well)	07-10-91	35	4-inch casing 0 - 6 4-inch screen 6 - 35	--	350	2,060	Alluvial deposits Volcanic rock	1 - 28 28 - 35
49 STT-EGWS-07	07-10-91 - 07-11-91	58	6-inch casing 0 - 38 6-inch screen 38 - 58	35	288	1,940	Alluvial deposits Volcanic rock	0 - 32 32 - 58
50 STT-VIEO-10 (observation well)	07-12-91 - 07-15-91	53	4-inch casing 0 - 27 4-inch screen 27 - 53	--	--	2,400	Limestone Volcanic rock	0 - 44 44 - 53
51 STT-EGWS-08	07-15-91 - 07-16-91	35	6-inch casing 0 - 13 6-inch screen 13 - 33	25	454	2,600	Alluvial deposits	0 - 35

Table 2. Description of test holes drilled on St. Thomas, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
52 STT-EGWS-09	07-17-91 - 07-18-91	140	6-inch casing 0 - 100 6-inch screen 100 - 140	40	222	1,290	Fill material Alluvial deposits Volcanic rock	0 - 2 2 - 38 38 - 140
53 STT-EGWS-10	07-19-91 - 07-22-91	120	6-inch casing 0 - 80 6-inch screen 80 - 120	40	182	1,475	Alluvial deposits Volcanic rock	0 - 100 100 - 120
54 STT-VIEO-11 (observation well)	07-23-91 - 07-24-91	110	6-inch casing 0 - 90 6-inch screen 90 - 110	14	426	2,200	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 87 87 - 110
55 STT-VIEO-12	07-24-91 - 07-25-91	115	test hole back filled	--	426	1,600	Alluvial deposits Volcanic rock	0 - 12 12 - 115
56 STT-EGWS-11	07-29-91 - 07-30-91	110	6-inch casing 0 - 70 6-inch screen 70 - 110	30	212	1,550	Alluvial deposits Volcanic rock	0 - 72 73 - 110
57 STT-VIEO-13	07-30-91 - 07-31-91	105	test hole back filled	--	676	3,475	Alluvial deposits Volcanic rock	0 - 12 12 - 105

[1] Well number refers to well location as shown in figure 5.

Table 3. Description of test holes drilled on St. John, U.S. Virgin Islands

[mm-dd-yy, month-day-year; ft-blsd, feet below land surface datum; gal/min, gallons per minute; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; STJ, St. John; SJWS, St. John water supply; VIEO, Virgin Islands Energy Office; --, data not available]

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
68 STJ-SJWS-01	02-14-91 - 02-15-91	100	test hole back filled	--	1,256	4,680	Alluvial deposits Volcanic rock	0 - 24 24 - 100
69 STJ-VIEO-02 (observation well)	02-15-91 - 02-19-91	70	4-inch casing 0 - 26 4-inch screen 26 - 66	7	1,048	4,180	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 32 32 - 70
70 STJ-SJWS-02	02-19-91 - 02-20-91	47	6-inch casing 0 - 26 6-inch screen 26 - 46	20	526	2,160	Topsoil Alluvial deposits Volcanic rock	0 - 1 1 - 20 20 - 47
71 STJ-SJWS-03	02-21-91	46	test hole back filled	--	3,870	11,870	Alluvial deposits Volcanic rock	0 - 30 30 - 46
72 STJ-SJWS-04	02-22-91	47	test hole back filled	--	550	3,100	Topsoil Alluvial deposits	0 - 1 1 - 47
73 STJ-VIEO-03 (observation well)	02-25-91 - 02-26-91	110	4-inch casing 0 - 50 4-inch screen 54 - 110	4	1,178	4,750	Alluvial deposits Volcanic rock	0 - 54 50 - 110
74 STJ-SJWS-05	02-26-91	50	test hole back filled	--	1,828	6,610	Alluvial deposits	0 - 50
75 STJ-VIEO-04 (observation well)	02-26-91 - 02-27-91	50	6-inch casing 0 - 20 6-inch screen 20 - 50	17	788	3,010	Topsoil Alluvial deposits	0 - 1 1 - 50

Table 3. Description of test holes drilled on St. John, U.S. Virgin Islands--Continued

Well number and name[1]	Date drilled (mm-dd-yy)	Depth of test hole (ft-blsd)	Well construction (ft-blsd)	Estimate sustained well yield (gal/min)	Chloride, dissolved (mg/L as Cl)	Specific conductance (lab value µs/cm)	Subsurface material (ft-blsd)	
76 STJ-SJWS-06	02-28-91	29	test hole back filled	--	894	2,600	Topsoil	0 - 1
							Alluvial deposits	1 - 21
							Volcanic rock	21 - 29
77 STJ-SJWS-07	02-28-91	10	test hole back filled	--	--	--	Alluvial deposits	0 - 6
							Volcanic rock	6 - 10

[1] Well number refers to well locations as shown on figures 6 or 7.

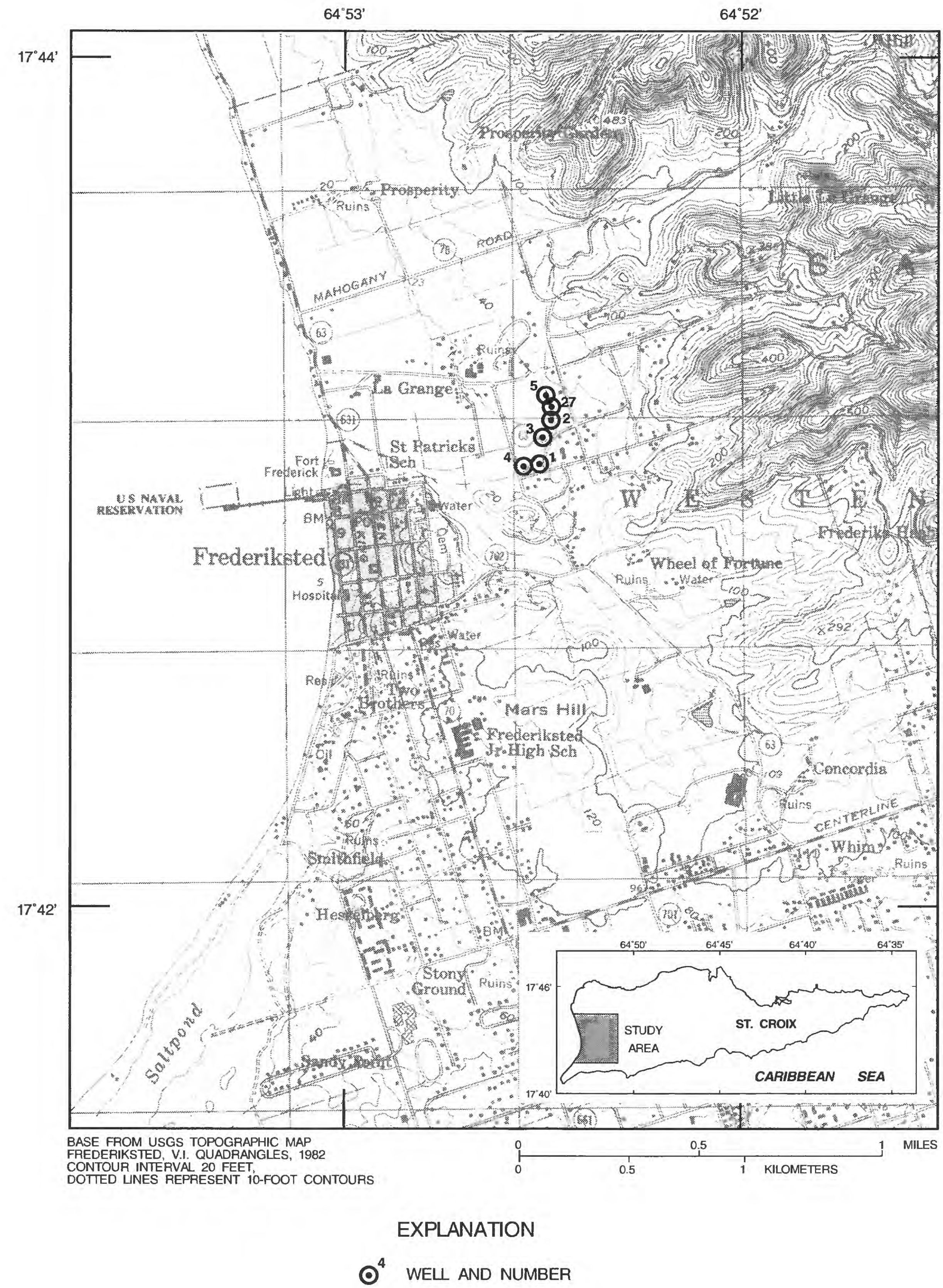
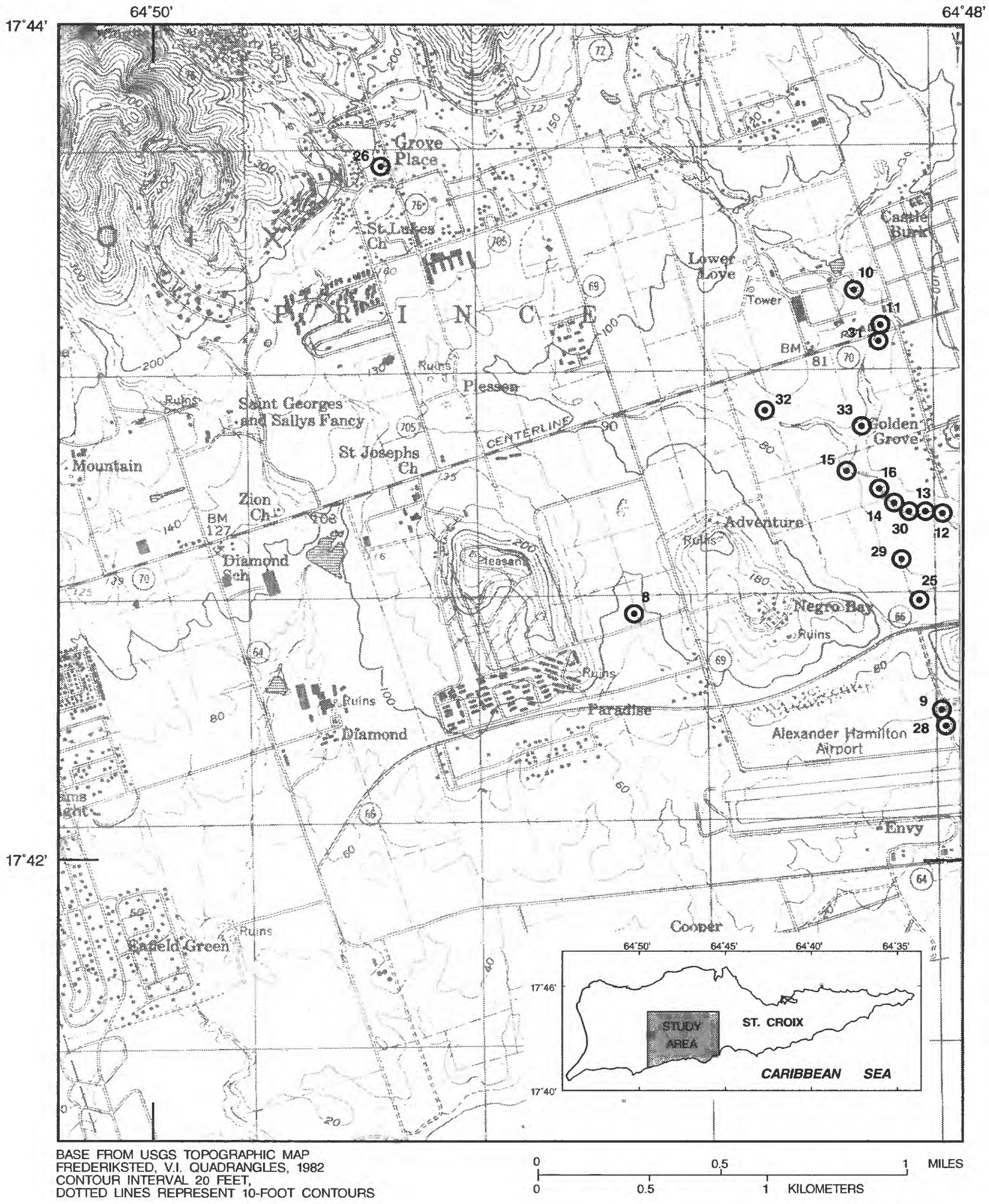


Figure 2. Location of wells 1 through 5 and well 27, St. Croix, U.S. Virgin Islands.



EXPLANATION

⊙ 8 WELL AND NUMBER

Figure 3. Location of wells 6 through 20, wells 24 through 26, and wells 28 through 36, St. Croix, U.S. Virgin Islands.

Figure 3. Location of wells 6 through 20, wells 24 through 26, and wells 28 through 36, St. Croix, U.S. Virgin Islands--Continued.

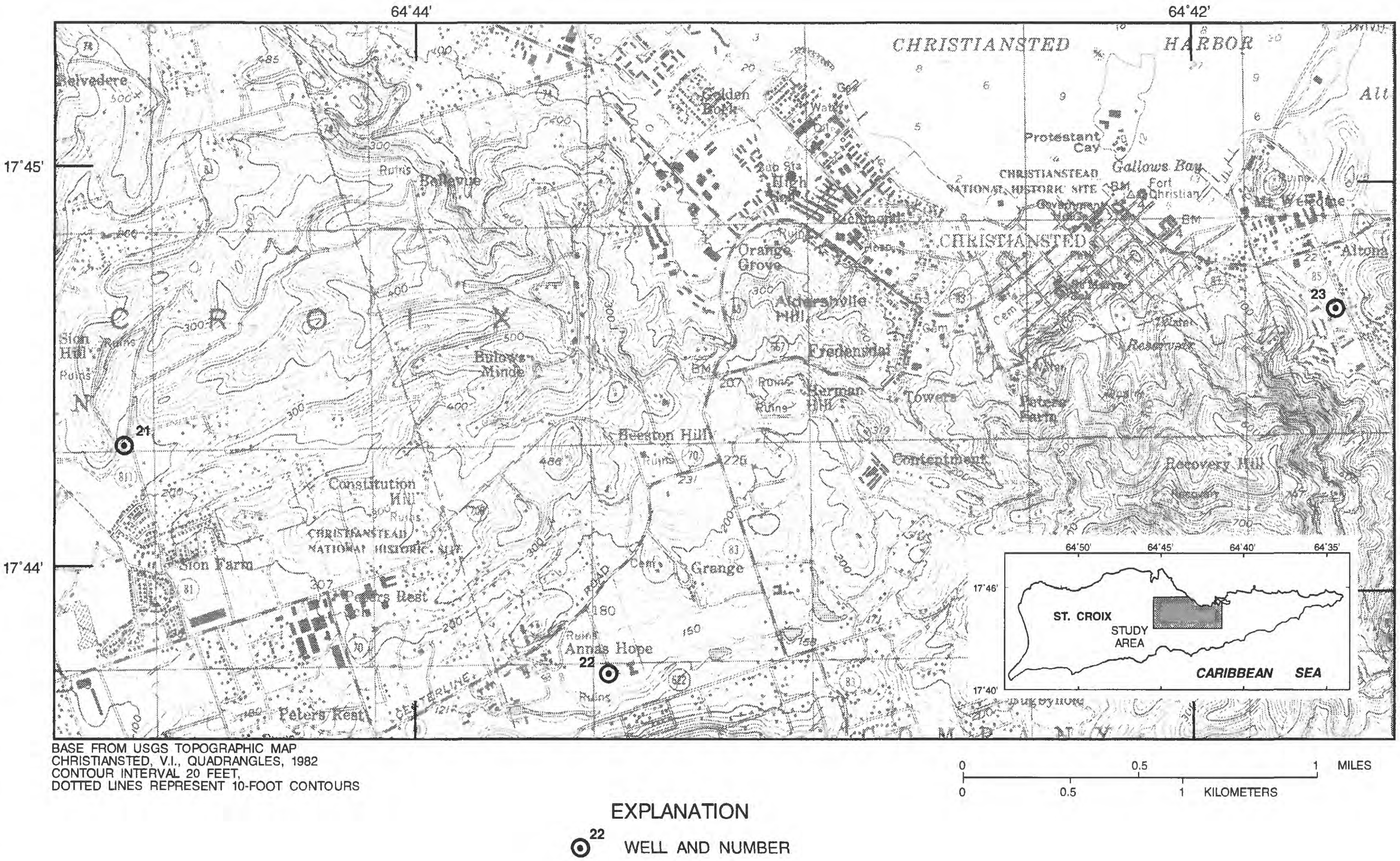


Figure 4. Location of wells 21 through 23, St. Croix, U.S. Virgin Islands.

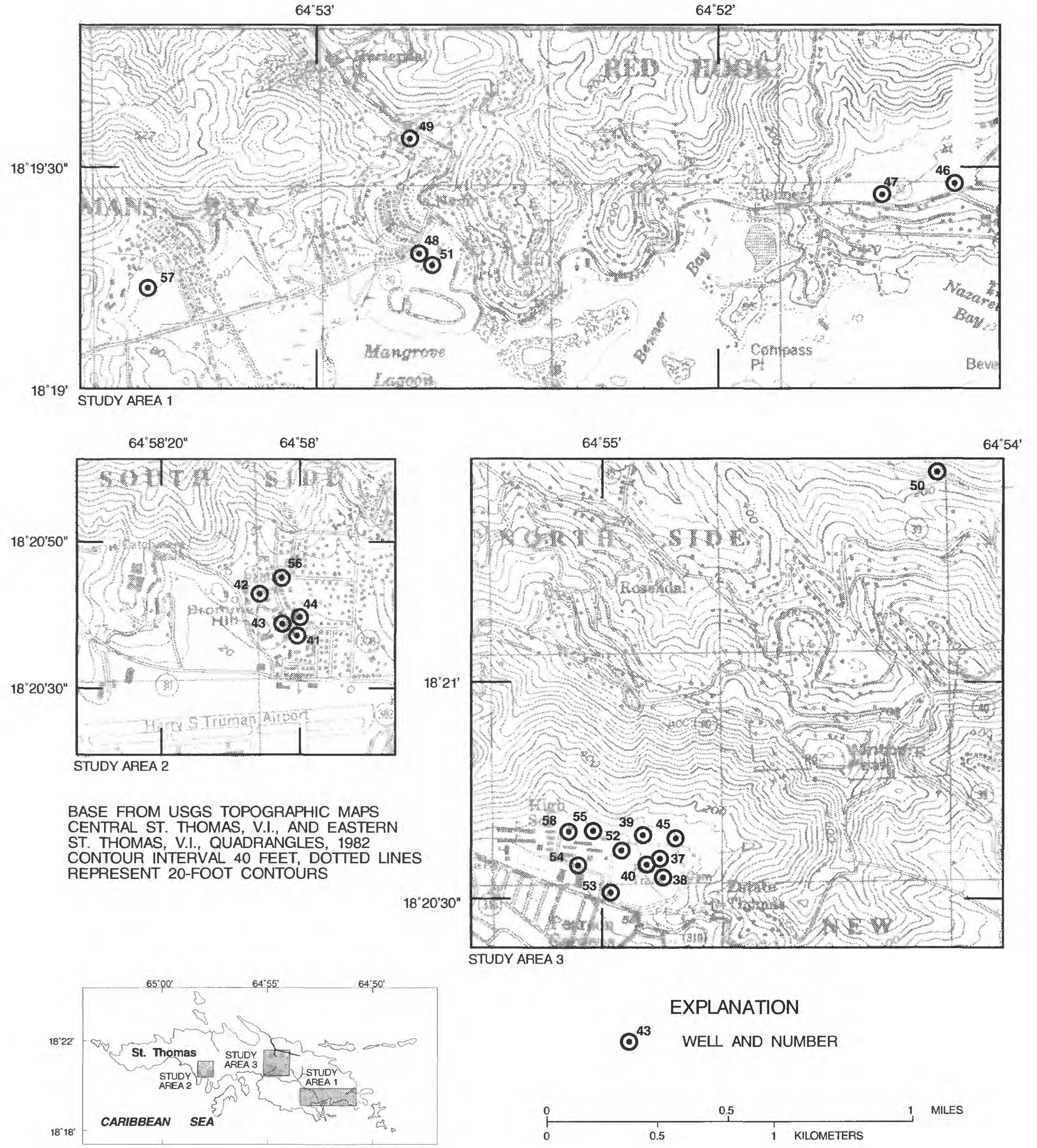


Figure 5. Location of wells 37 through 58, St. Thomas, U.S. Virgin Islands.

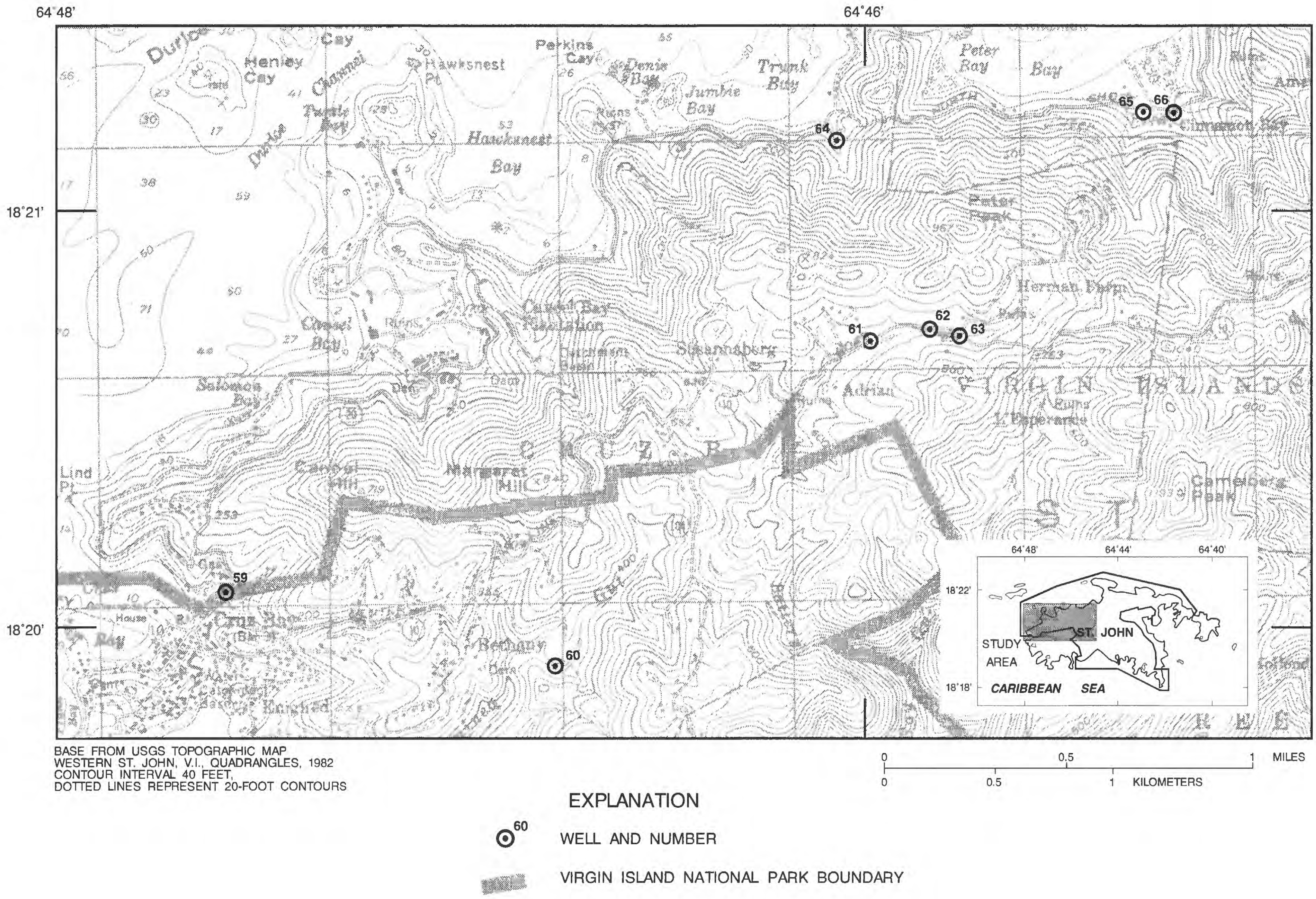


Figure 6. Location of wells 59 through 66, St. John, U.S. Virgin Islands.

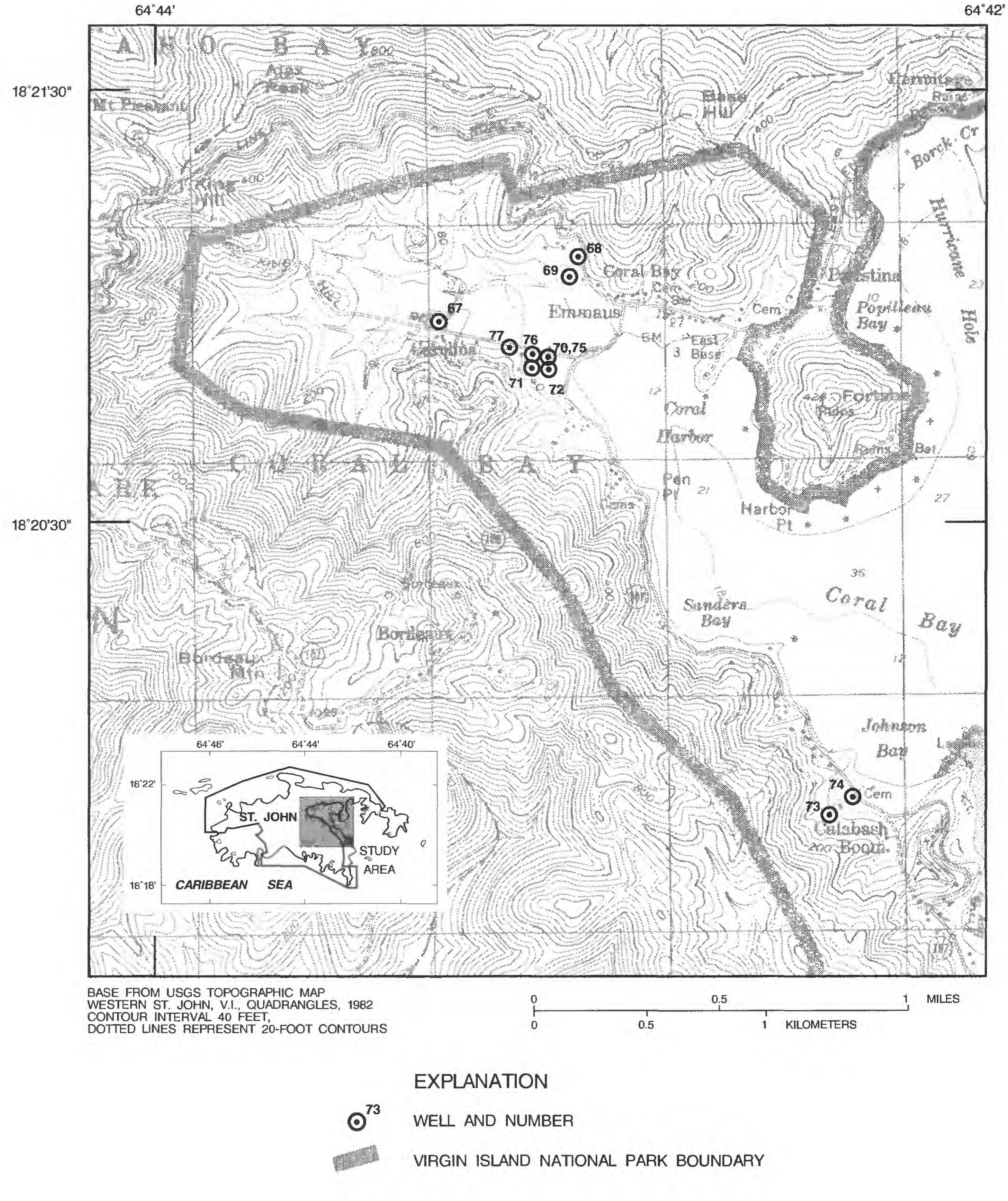


Figure 7. Location of wells 67 through 77, St. John, U.S. Virgin Islands.

Table 4. Well name and site identification number of wells drilled on St. Croix, St. Thomas, and St. John, U.S. Virgin Islands

[STXT, St. Croix-test hole that was backfilled; STX, St. Croix; EGWS, emergency ground-water supply; STXO, St. Croix, observation well; VIWAPA, Virgin Islands Water and Power Authority; Adv, Adventure; DPW; Department of Public Works; GG, Golden Grove; FP, Fairplains; BS, Barren Spot; STT, St. Thomas; VIEO Virgin Islands Energy Office; NPS, National Park Service; STJ, St. John; SJWS, St. John water supply; WAPA, Water and Power Authority]

Well number	Test hole name	USGS Site identification	Well number	Test hole name	USGS Site identification
1	STXT-01	174303064523200	26	STXT-12	174341064492600
2	STX-EGWS-01	174309064523000	27	STXO-01	174310064523000
3	STX-EGWS-02	174307064523000	28	STXO-02	174222064480200
4	STXT-02	174303064523300	29	STX-EGWS-15	174243064480800
5	STX-EGWS-03	174312064523000	30	STXO-03	174251064480600
6	STXT-03	174222064474800	31	VIWAPA 17, Adv	174316064480800
7	STX-EGWS-04	174222064475300	32	VIWAPA 03, Adv	174308064482800
8	STXT-04	174231064484900	33	VIWAPA 02, Adv	174303064481100
9	STX-EGWS-05	174223064480300	34	VIWAPA 06 / DPW 06, GG	174243064475100
10	STXT-05	174324064481600	35	VIWAPA 02, FP	174225064472000
11	STXT-06	174318064481300	36	VIWAPA 23A, BS	174319064454401
12	STX-EGWS-06	174251064480200	37	STT-EGWS-01	182037064545100
13	STX-EGWS-07	174251064480500	38	STT-EGWS-02	182033064545000
14	STX-EGWS-08	174252064480900	39	STT-EGWS-03	182038064545300
15	STXT-07	174257064481600	40	STT-VIEO-01	182036064545200
16	STXT-08	174253064481200	41	STT-EGWS-04	182037064580000
17	STX-EGWS-09	174237064471800	42	STT-EGWS-05	182042064580600
18	STX-EGWS-10	174247064471900	43	STT-VIEO-05	182037064580200
19	STX-EGWS-11	174309064464600	44	STT-VIEO-06	182038064580000
20	STXT-09	174240064473800	45	STT-EGWS-06	182039064544900
21	STX-EGWS-12	174419064444500	46	STT-VIEO-07	181928064512400
22	STXT-10	174344064433000	47	STT-VIEO-08	181927064513600
23	STX-EGWS-13	174438064413800	48	STT-VIEO-09	181917064524600
24	STX-EGWS-14	174240064474300	49	STT-EGWS-07	181936064524500
25	STXT-11	174238064480700	50	STT-VIEO-10	182131064541000

Table 4. Well name and site identification number of wells drilled on St. Croix, St. Thomas, and St. John, U.S. Virgin Islands--Continued

Well number	Test hole name	USGS Site identification
51	STT-EGWS-08	181917064524502
52	STT-EGWS-09	182037064545700
53	STT-EGWS-10	182031064545800
54	STT-VIEO-11	182035064550200
55	STT-VIEO-12	182039064550401
56	STT-EGWS-11	182043064580300
57	STT-VIEO-13	181914064532300
58	Grade School 03, St. Thomas	182038064550300
59	NPS-03, Cruz Bay	182008064473000
60	Guinea Gut Well, St. John	181956064464500
61	WAPA/ DPW-02, Susannaberg	182044064455000
62	WAPA/DPW-05, Susannaberg	182044064454600
63	DPW-06, Sussanaberg, St. John	182042064454500
64	NPS-05, Trunk Bay	182109064460300
65	Cinnamon Bay Campground	182113064451900
66	NPS-06, Cinnamon Bay, St. John	182116064451000
67	VI Government WAPA well (USGS 14A)	182058064432300
68	STJ-SJWS-01	182107064425900
69	STJ-VIEO-02	182110064430000
70	STJ-SJWS-02	182048064430500
71	STJ-SJWS-03	182052064430500
72	STJ-SJWS-04	182052064430400
73	STJ-VIEO-03	181950064422300
74	STJ-SJWS-05	181952064421700
75	STJ-VIEO-04	182048064430400
76	STJ-SJWS-06	182054064430600
77	STJ-SJWS-07	182054064430800

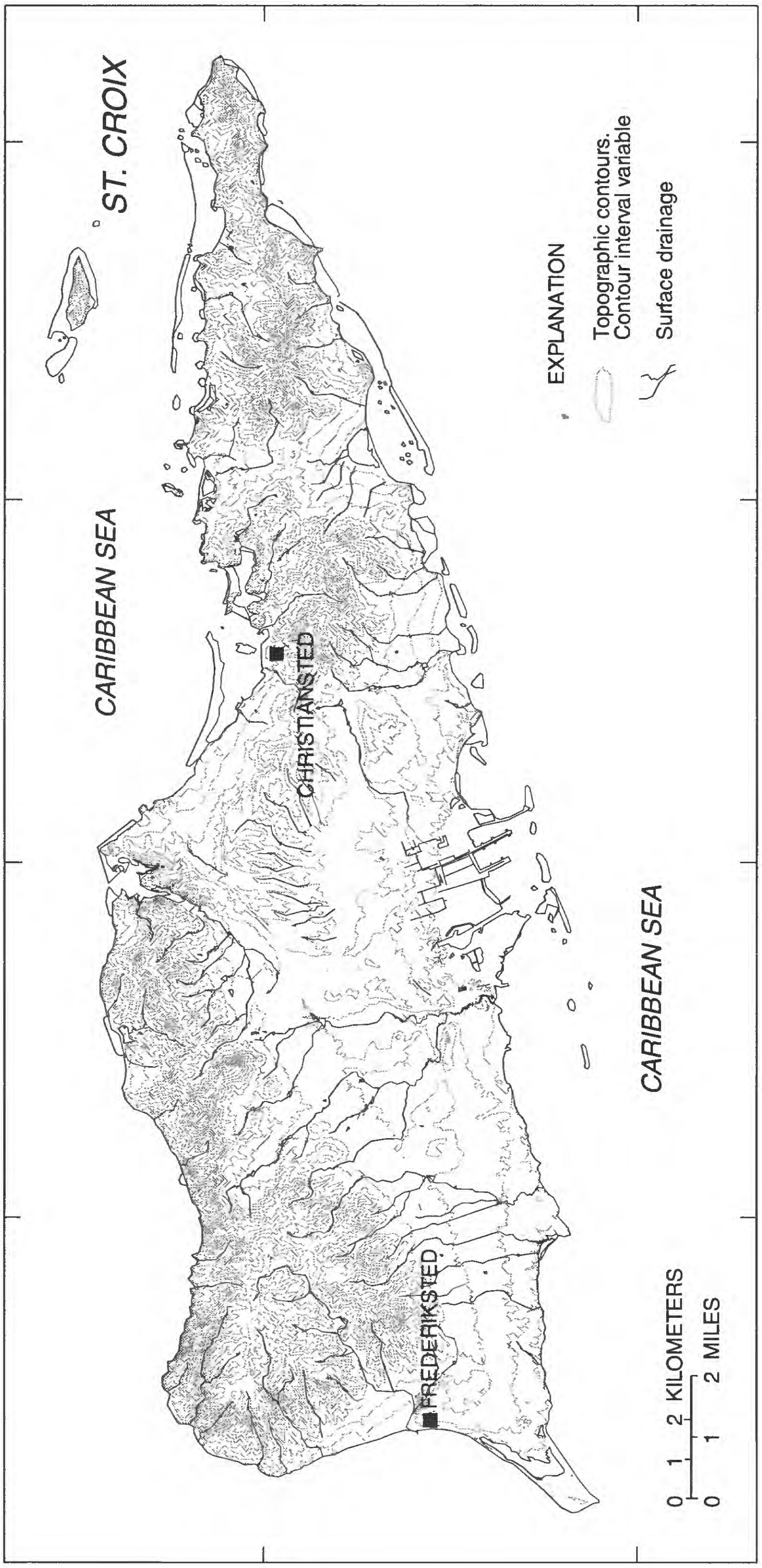


Figure 8. General drainage features of St. Croix, U.S. Virgin Islands.

The only variation in the generally rugged topography is in the upper valley of the Turpentine Run drainage basin (fig. 9) The valley has relatively gentle topography consisting of rolling hills in a basin surrounded by steep slopes and sharp ridges (Jordan and Cosner, 1973). Because of the central ridge running through St. Thomas, drainage can occur in all directions; however the principal direction of drainage is to the north and to the south.

The island of St. John is approximately 9 miles long, ranges 2 to 4 miles in width, and has an approximate area of 19 square miles. The island is composed of a main eastward trending ridge with steep slopes to the north descending to the sea. In contrast, the south side of the ridge has several prominent spur ridges that extend southward (fig. 10) (Cosner, 1972). The highest elevation on St. John is 1,277 feet above mean sea level. The prominent direction of surface drainage on St. John is to the north and to the south. As with St. Thomas, coastal plains are almost completely absent. Flat land is confined to only a few small embayments. About two-thirds of the island lies within the boundaries of the Virgin Islands National Park, which is administered by the U.S. National Park Service.

The mean annual air temperature recorded by the National Oceanic and Atmospheric Administration (NOAA) for St. Croix, St. Thomas, and St. John from 1982 to 1992 was 79.6, 80.5, and 78.4 degrees Fahrenheit respectively (U.S. Department of Commerce, 1982 to 1992). Mean annual rainfall recorded by NOAA from 1982 to 1992 for St. Croix, St. Thomas, and St. John was 40.26, 45.03, and 44.96 inches, respectively. Mean monthly rainfall for 1982 through 1992 ranged from 1.48 inches in February to 5.75 inches in November for St. Croix, ranged from 1.54 inches in March to 6.28 inches in November for St. Thomas, and ranged from 1.46 inches in March to 6.9 inches in November for St. John (fig. 11).

GEOLOGY

Much has been written about the geology of the U.S. Virgin Islands (Cederstrom, 1950; Donnelly 1959; Gerhard and others, 1978; Gill and Hubbard, 1986 and 1987; Hubbard, 1989; and Whetten 1966), as well as about the water resources of the islands (Cederstrom 1950; Cosner, 1972; Graves, 1995; Jordan, 1975; Jordan and Cosner, 1973; and Robison, 1972). Although the geology of the U.S. Virgin Islands is quite complex, in the literature of the water resources of the islands, the geology has been simplified and discussed in generalized terms of volcanic rock or rock of volcanic origin, localized igneous plutonic rock, and carbonate and alluvial deposits. For the purpose of this report, in terms of ground-water development, the geology of the U.S. Virgin Islands will be discussed only in terms of alluvial deposits and carbonate and volcanic rock. For a more detailed discussion of the geology of the U.S. Virgin Islands, the reader is referred to the sited references.

St. Croix

The geology of St. Croix includes alluvial deposits and carbonate and volcanic rocks. Volcanic rock underlies St. Croix and predominates in the mountainous areas around the island (Robison, 1972). The carbonate rock and alluvial deposits are principally in the southerly plains. The carbonate rock is comprised of the Jealousy Formation of Eocene to middle Miocene age, the Kingshill Limestone of Miocene to Pliocene age (Gerhard and others, 1978), and post-Kingshill Carbonates of Pliocene and younger age (Gill and Hubbard, 1986). The results of the test-hole drilling on St. Croix revealed the following lithologies (table 1).

ALLUVIAL DEPOSITS--gravel, sand, silt, and clay, with the dominating grain size varying over the study area. The alluvial deposits are localized and not laterally extensive. A thin 1- to 2-foot topsoil generally overlies the alluvial deposits. The alluvial deposits range in thickness from 8 to 76 feet.

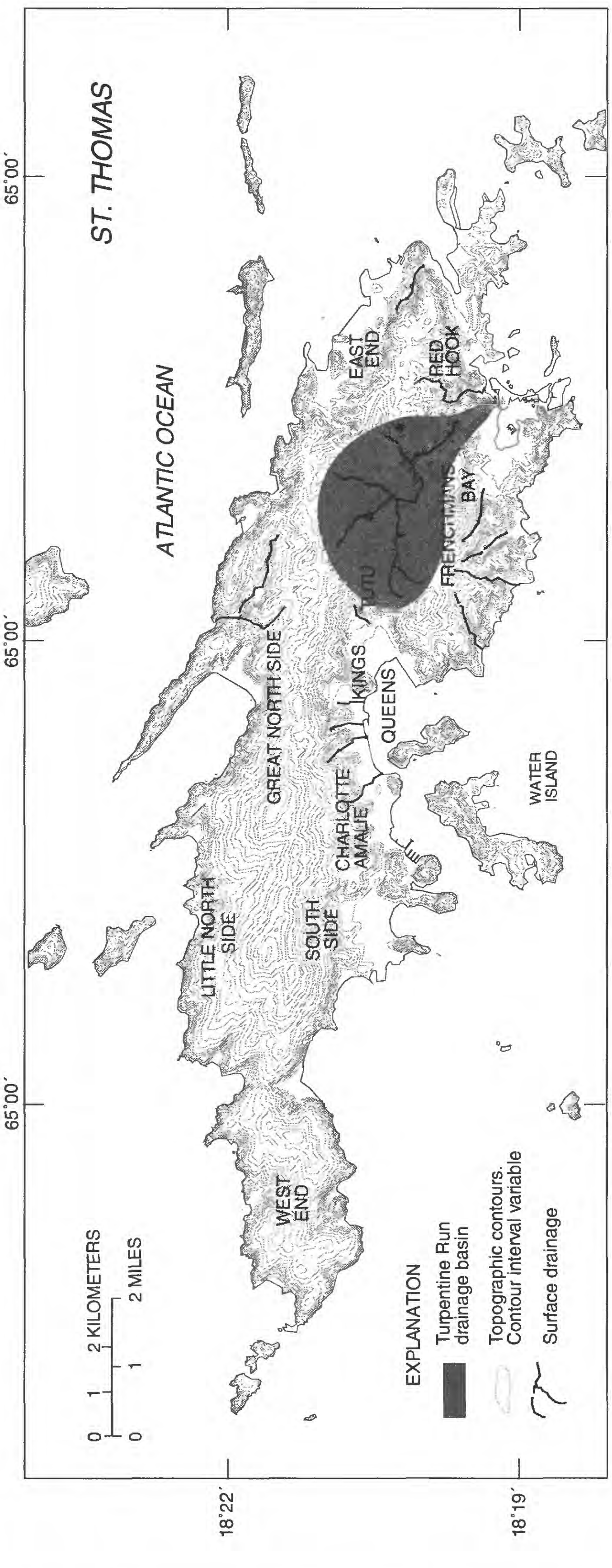


Figure 9. General drainage features of St. Thomas, U.S. Virgin Islands.

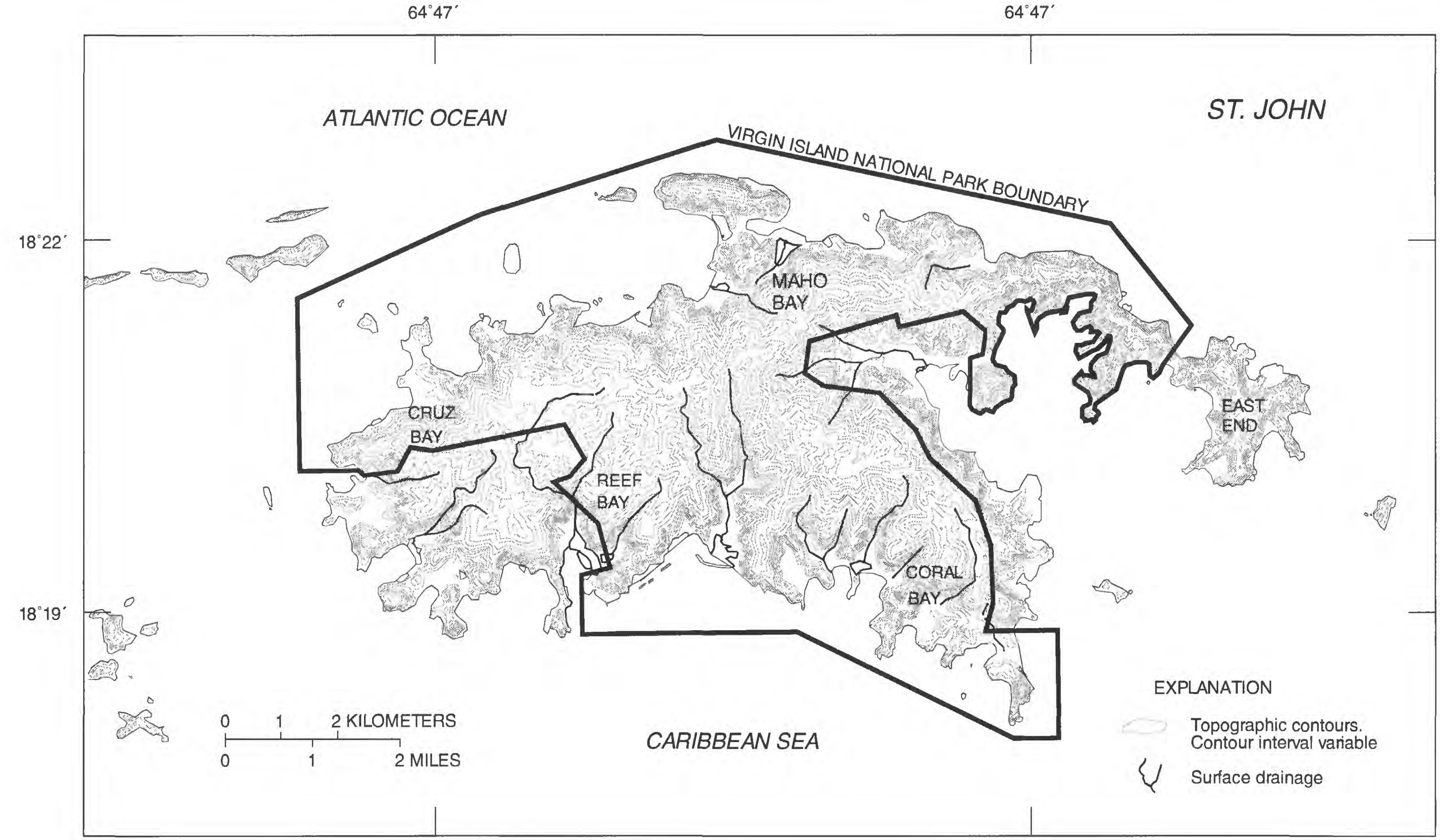


Figure 10. General drainage features of St. John, U.S. Virgin Islands.

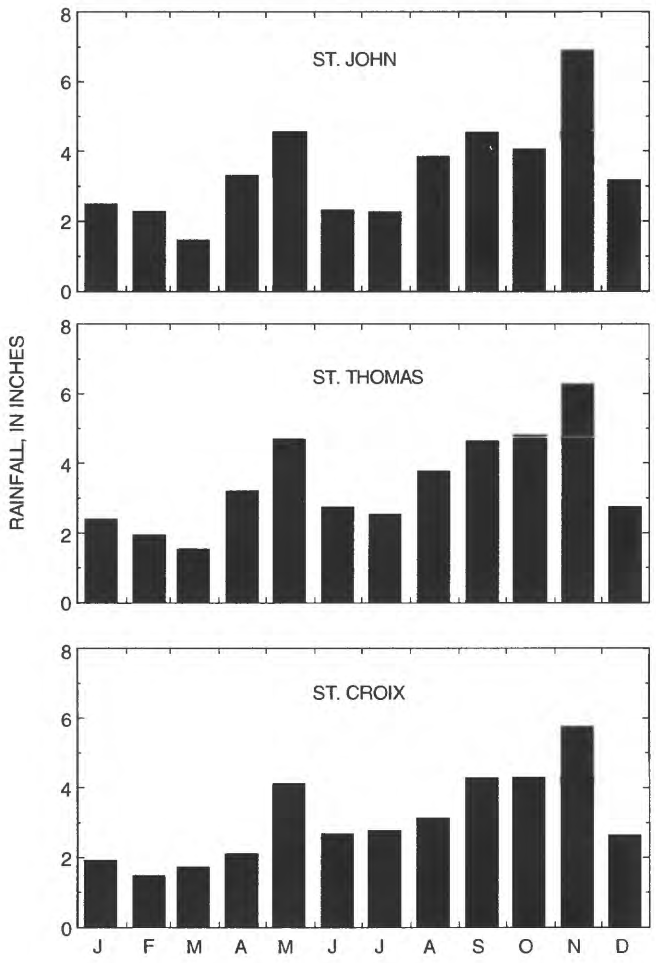


Figure 11. Mean monthly rainfall for St. Croix, St. Thomas, and St. John, U.S. Virgin Islands, 1982-92 (Data from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1982 and 1992).

KINGSHILL LIMESTONE--generally a white to buff marl which is locally fractured and commonly has iron and manganese oxide stains in the fracture zones. The top of the Kingshill Limestone is at land surface or underlies the thin topsoil or alluvial deposits. Where the bottom of the Kingshill Limestone was penetrated by test holes, the limestone had a thickness ranging from 50 to greater than 217 feet.

JEALOUSY FORMATION--Generally a bluish-gray marl. The Jealousy Formation underlies the Kingshill Limestone. The top of the Jealousy Formation, where penetrated by test holes, ranged from 88 to 127 feet below land surface. The thickness of the Jealousy Formation has been estimated to exceed 1,400 feet (Gill and Hubbard, 1986).

VOLCANIC ROCK--blue to olive gray in color, dense with minor fractures, locally contains zones of highly fractured or shattered rock. The drilling of most test holes on St. Croix was halted when the volcanic rock was encountered, so a thickness was not determined for this unit.

St. Thomas and St. John

The geology of St. Thomas is similar to that of St. John. The islands were formed primarily of volcanic rocks (Donnelly, 1959). The alluvial deposits on each island are present only in the small coastal embayments surrounding the islands and in the valley of Turpentine Run on St. Thomas (Cosner, 1972; Jordan and Cosner, 1973). Carbonate rock is found only rarely on St. Thomas and St. John and is comprised primarily of the Outer Brass Limestone (Donnelly, 1959). The results of the test-hole drilling on St. Thomas and St. John revealed the following lithologies (tables 2 and 3).

ALLUVIAL DEPOSITS--sand and gravel, with some cobbles and boulders, locally contains thin lenses of silt and clay. Locally a 1- to 2-foot top soil overlies the alluvial deposits. Also present locally overlying the alluvial deposits is fill material deposited for land surface build-up for local construction.

VOLCANIC ROCK--greenish to gray in color, dense, indurated, with horizontal and vertical fractures. Locally the volcanic rock is a highly weathered volcanic material (regolith) that occurs as saprolite. Localized zones of highly fractured to shattered volcanic rock are also present.

GROUND-WATER HYDROLOGY

Ground water on St. Croix, St. Thomas, and St. John occurs in the alluvial deposits and carbonate and volcanic rocks. On St. Croix, the principal sources of ground water are the carbonate rock and the overlying alluvial deposits; however, on St. Thomas and St. John, the principal sources of ground water are the volcanic rock and overlying alluvial deposits (Gómez-Gómez and others, 1985).

Ground-Water Occurrence and Movement

Ground-water occurs under water-table conditions on St. Croix and is present principally in the alluvial deposits and the Kingshill Limestone deposits in the southern plains of the island. Because the alluvial deposits are hydraulically connected to the Kingshill Limestone, the alluvial deposits and Kingshill Limestone are considered to be a single hydrologic unit in which the alluvial deposits are saturated. The bottom of this hydrologic unit is the top of the Jealousy Formation, which underlies all of south St. Croix. The Jealousy Formation has been described by Jordan (1975) as a unit of low permeability. Clay facies in the Jealousy Formation are believed to act as a boundary for the overlying Kingshill Limestone and alluvial deposits.

Only 7 of 30 wells were drilled into the volcanic rocks on St. Croix (table 1). Of these 7 wells, 2 were back filled and 1 was used as an observation well. Consequently, because of sparse data, a detailed discussion of the occurrence and movement of ground water in the volcanic rocks of St. Croix is not possible. However, when the results of the test-hole drilling into the volcanic rock of St. Thomas and St. John are discussed, it may be assumed that this information could be transferable to the island of St. Croix in terms of ground-water availability.

Ground-water occurs under water-table conditions on St. Thomas and St. John and is present primarily in the regolith and zones of highly fractured to shattered volcanic rock. As with the Kingshill Limestone on St. Croix, the alluvial deposits on St. Thomas and St. John are hydraulically connected to the underlying volcanic rock and, subsequently, a single hydrologic unit is assumed to exist in these two units where the alluvial deposits are saturated. The bottom of the water-table aquifer on St. Thomas and St. John is the dense indurated volcanic rock underlying the regolith and zones of highly fractured rock. The low permeability of this indurated rock limits vertical ground-water movement and subsequently acts as the boundary of the overlying rock and alluvial deposits.

Water-table fluctuation occurs seasonally in response to rainfall variation and can fluctuate daily in wells located near pumping wells. Depth below land surface to the water table can range from approximately 4 to 62 feet on St. Croix (figs. 12 and 13), 3 to 74 feet on St. Thomas (figs. 14 and 15), and 8 to 60 feet on St. John (figs. 16 and 17).

Because of the complexity of the aquifers on St. Croix, St. Thomas, and St. John it is impossible to complete an islandwide potentiometric map of any of the islands. Isolated potentiometric maps have been completed by Jordan and Cosner, (1973), Graves and González, (1988), and Torres-González and Rodríquez del Río, (1990). In general the water-table surface on St. Croix, St. Thomas, and St. John parallels the topography and ground-water movement is down gradient, perpendicular to the topographic contour lines, towards the sea.

The quantity of water recharging the Kingshill Limestone aquifer on St. Croix has been estimated to be 3 percent of annual rainfall (Robison, 1972). On St. Thomas, aquifer recharge is infrequent and probably occurs only after periods of heavy rainfall or a series of lesser rains (Jordan and Cosner, 1973). Jordan and Cosner postulated that because of relatively low annual rainfall and high average annual temperatures, most recharge occurred after major storms, which produced more than 2 inches of rainfall. On St. John, Cosner (1972), indicated that because of similarities between the soils of St. John and St. Thomas, recharge on St. John would be similar to that which occurs on St. Thomas. Large water-table rises corresponding with large amounts of rainfall (figs. 12 - 17) are strong evidence of the occurrence of aquifer recharge following a major rainstorm.

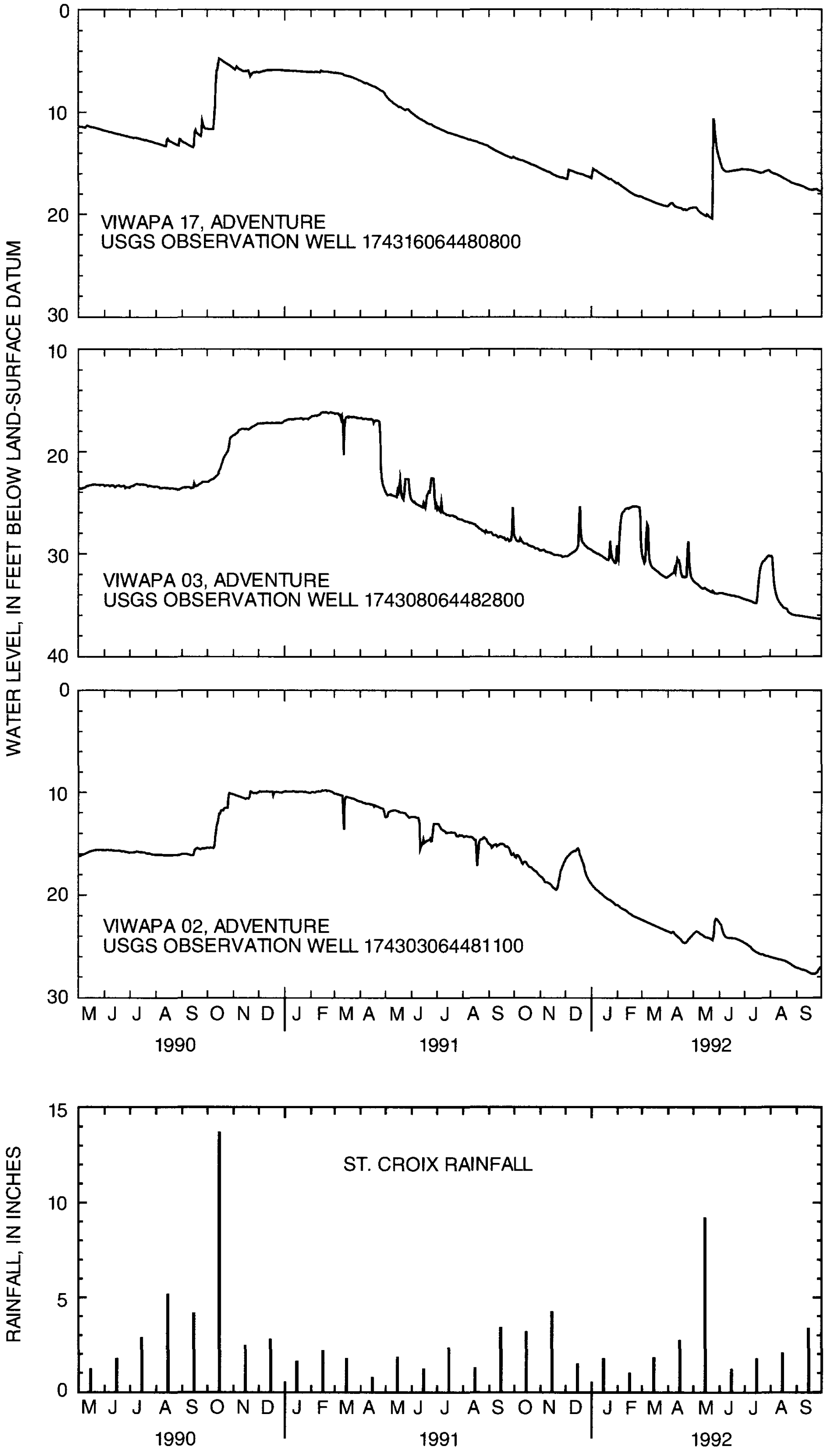


Figure 12. Daily mean ground-water levels in wells VIWAPA 02, VIWAPA 03, and VIWAPA 17, Adventure well field, and monthly rainfall, St. Croix, U.S. Virgin Islands, May 1990 through September 1992.

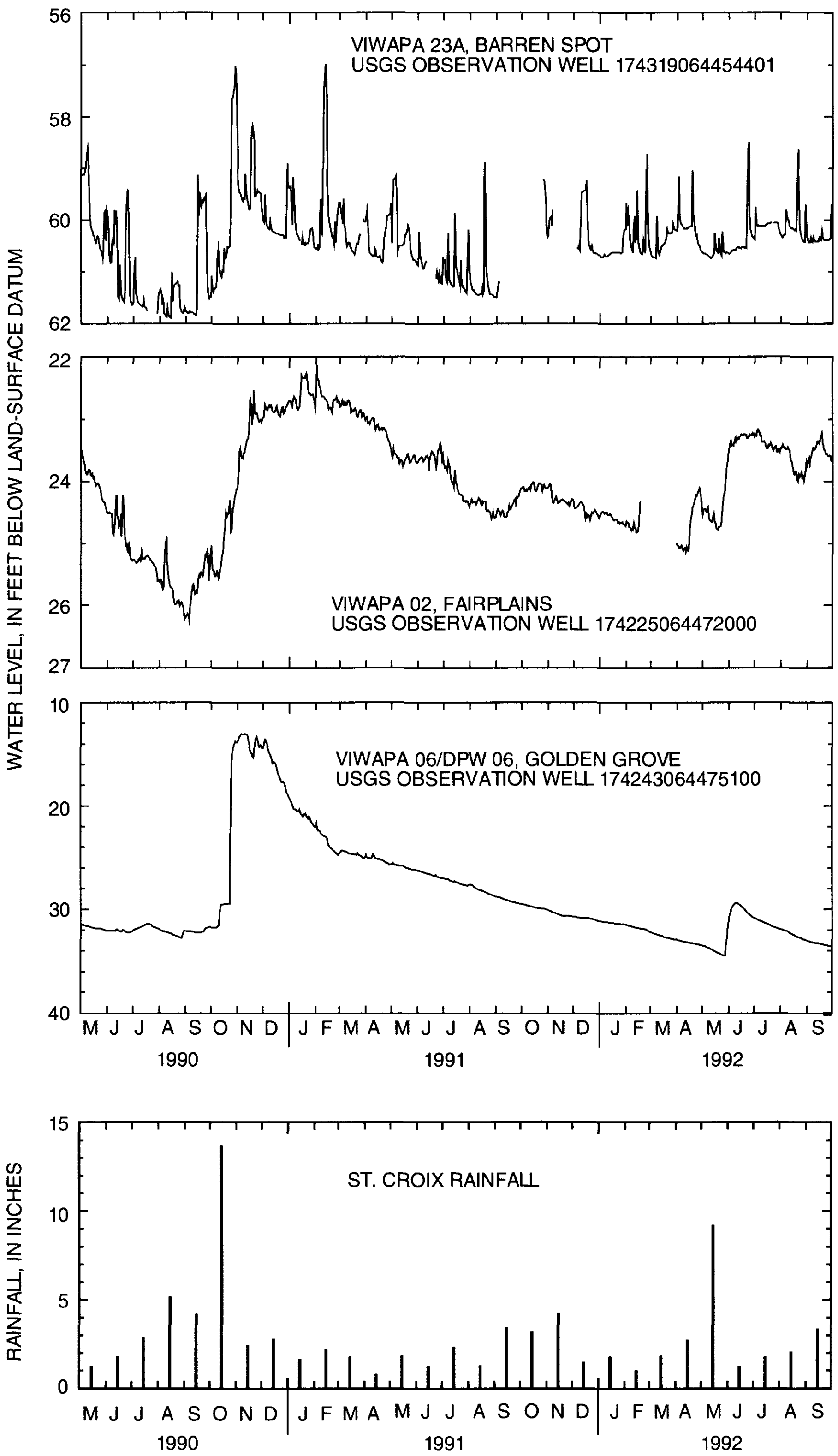


Figure 13. Daily mean ground-water levels in wells VIWAPA 06/DPW 06, Golden Grove, VIWAPA 02, Fairplains, and VIWAPA 23A, Barren Spot, and monthly rainfall, St. Croix, U.S. Virgin Islands, May 1990 through September 1992.

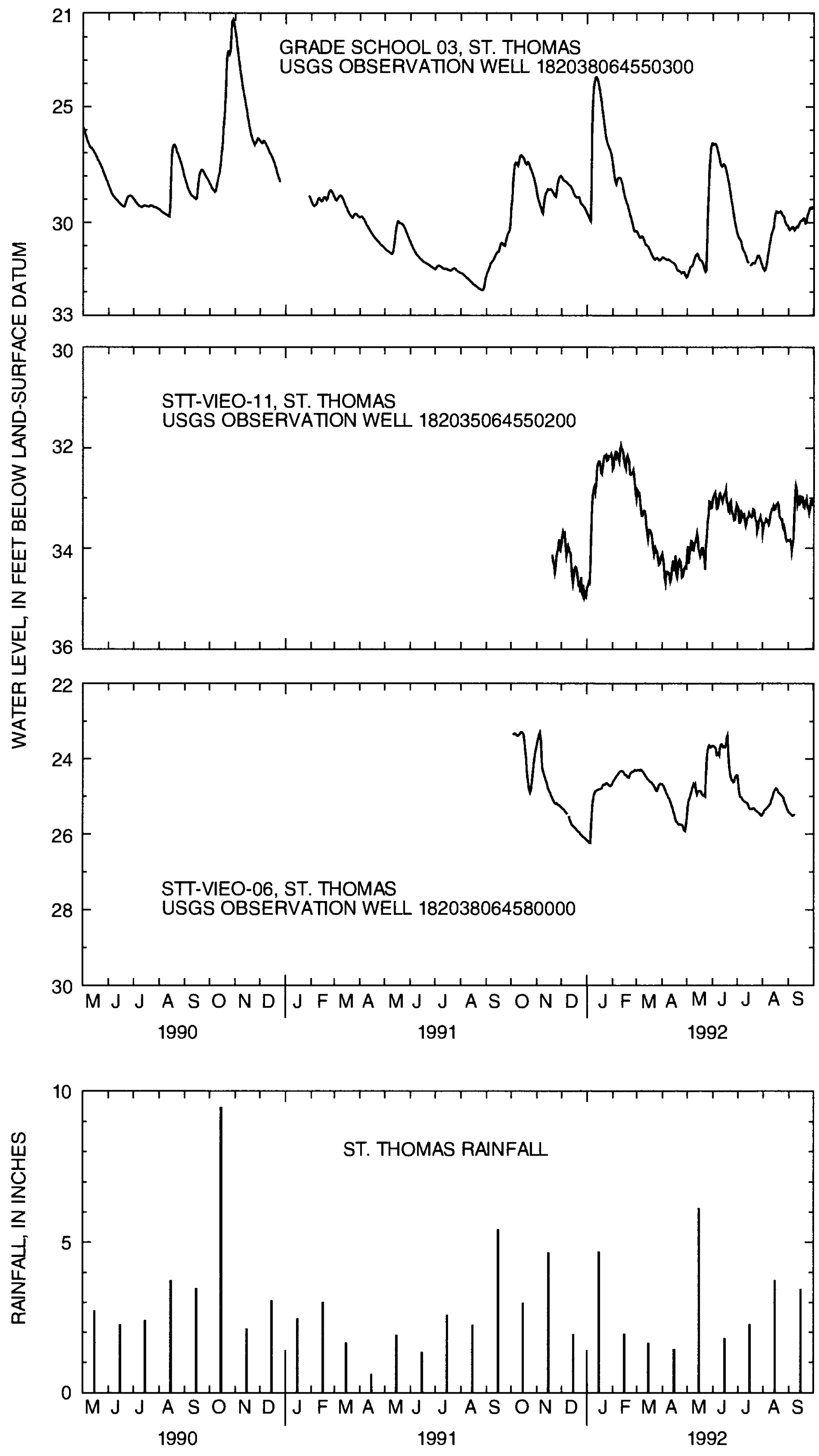


Figure 14. Daily mean ground-water levels in wells STT-VIEO-06, STT-VIEO-11, and Grade School 03, St. Thomas, and monthly rainfall, St. Thomas, U.S. Virgin Islands, May 1990 through September 1992.

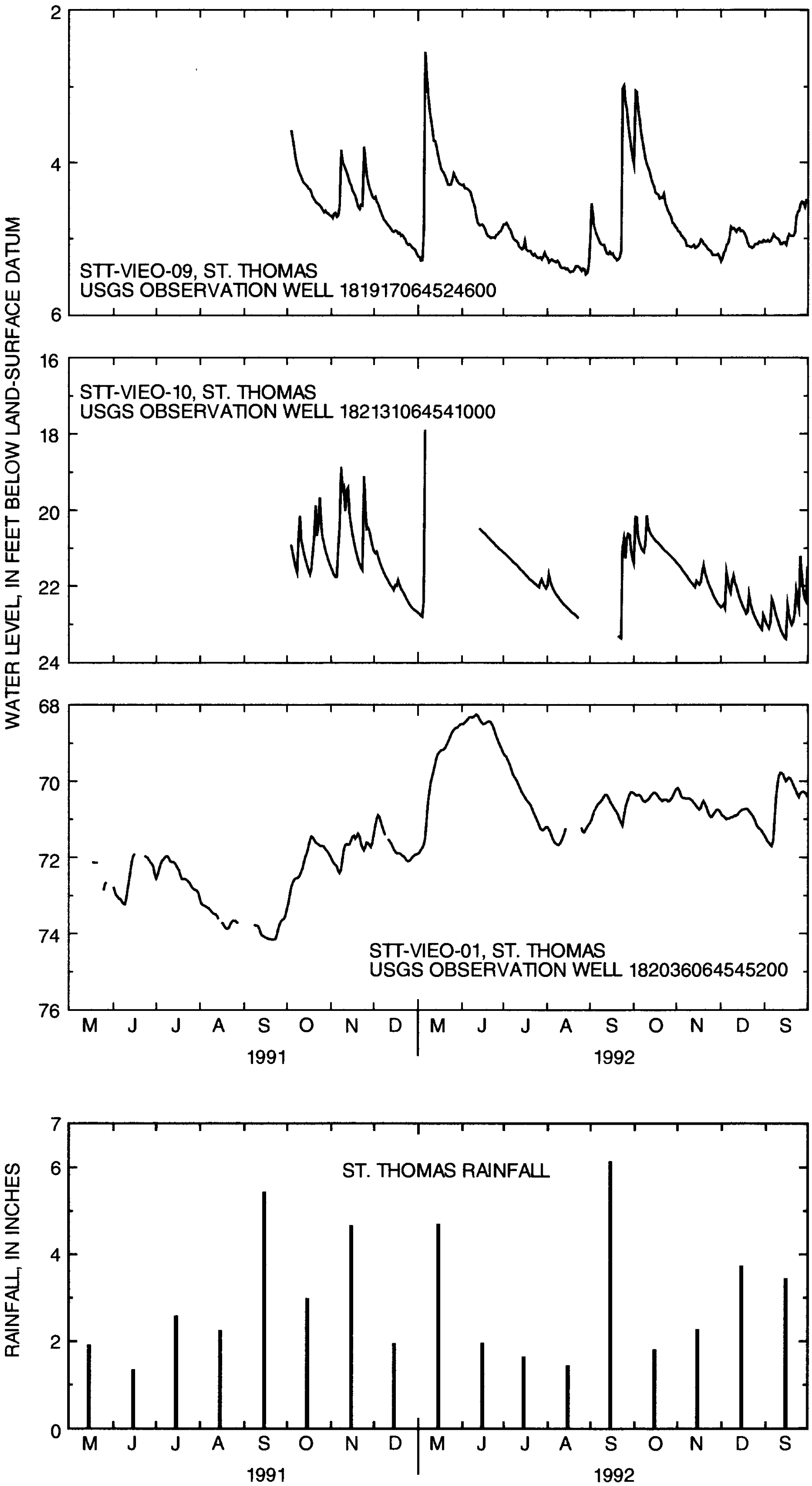


Figure 15. Daily mean ground-water levels in wells STT-VIEO-01, STT-VIEO-10, and STT-VIEO-09, St. Thomas, and monthly rainfall, St. Thomas, U.S. Virgin Islands, May 1991 through September 1992.

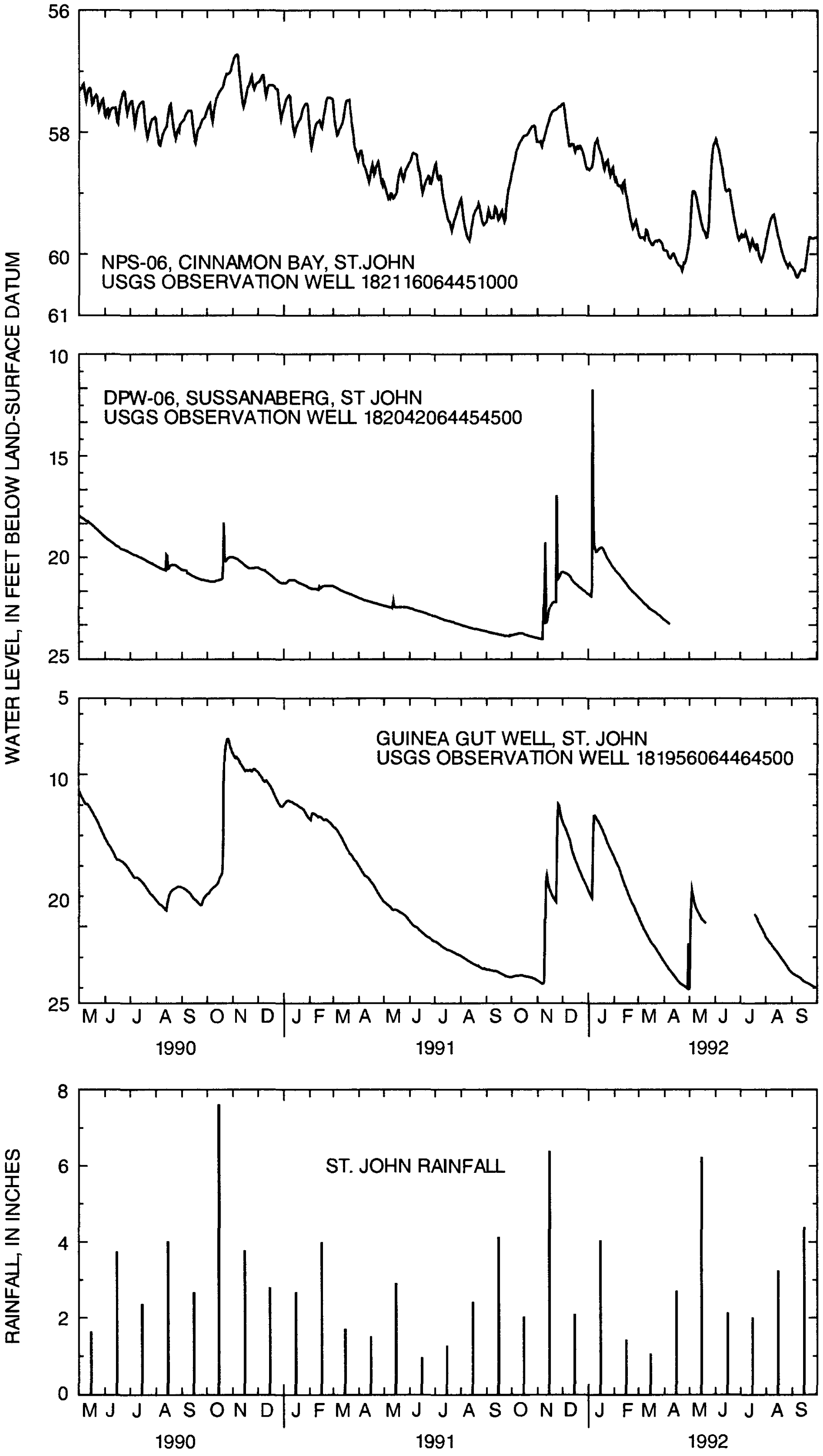


Figure 16. Daily mean ground-water levels in Guinea Gut well, DPW-06/Sussanaberg, and NPS-06/ Cinnamon Bay and monthly rainfall, St. John, U.S. Virgin Islands, May 1990 through September 1992.

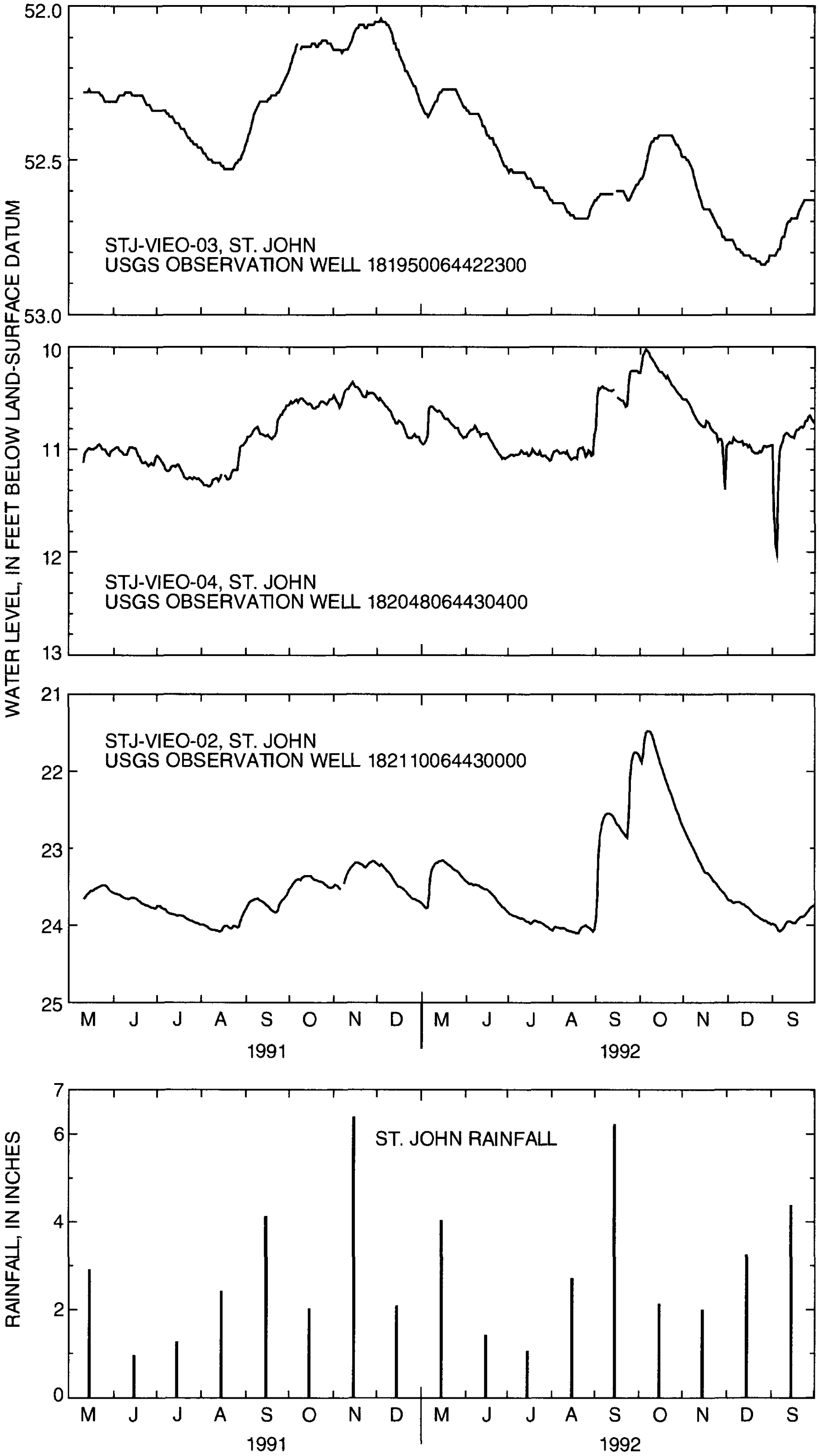


Figure 17. Daily mean ground-water levels in wells STJ-VIEO-02, 04, and 03, St. John, and monthly rainfall, St. John, U.S. Virgin Islands, May 1991 through September 1992.

Hydraulic Characteristics of the Aquifers

The ground-water development potential of any aquifer is dependent upon hydraulic characteristics of transmissivity and storage coefficient. Transmissivity is a measure of the ability of the aquifer to transmit water and is defined as the product of the hydraulic conductivity and the aquifer thickness. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

During this study, estimated aquifer transmissivities ranged from 200 to 2,500 feet squared per day in the fractured volcanic rock aquifers of St. Thomas and St. John (table 5). Transmissivity values based on data for selected wells were determined from specific capacity tests. The specific capacity tests were conducted for a period of 8 hours and values determined from these tests ranged from 1 to 11 gallons per minute per foot of drawdown. The specific capacity values were converted to transmissivity using a method described by Meyer (1963), that relates well diameter, specific capacity, and the aquifer storage coefficient to aquifer transmissivity. Aquifer storage coefficients were not determined from field tests for this report, but rather are assumed to be typical water-table storage coefficients, which range from 0.1 to 0.3 (Lohman, 1979). The specific capacity/aquifer transmissivity relation developed by Meyer (1963) assumes a water-table storage coefficient of 0.1.

Field tests to determine specific capacity and subsequently aquifer transmissivity were conducted only on St. Thomas and St. John. However, Graves (1995) and Torres-Gonzalez (1991) reported transmissivity values in the Kingshill Limestone ranging from 200 to 4,000 feet squared per day for St. Croix.

Table 5. Transmissivity estimated from specific capacity at selected wells on St. Thomas and St. John, U.S. Virgin Islands (Estimates based on method described by Meyer, 1963)

[(gal/min)/ft, gallons per minute per foot of drawdown; ft^2/d, feet squared per day; STT, St. Thomas; EGWS, emergency ground-water supply; STJ, St. John; SJWS, St. John water supply]

Well number and name[1]	Specific capacity [(gal/min)/ft]	Transmissivity (ft^2/d)	Length of test (hours)
37 STT-EGWS-01	1	200	8
38 STT-EGWS-02	1	200	8
39 STT-EGWS-03	3	600	8
41 STT-EGWS-04	2	400	8
42 STT-EGWS-05	3	600	8
45 STT-EGWS-06	4	800	8
49 STT-EGWS-07	2	400	8
51 STT-EGWS-08	11	2,500	8
52 STT-EGWS-09	2	400	8
53 STT-EGWS-10	2	400	8
56 STT-EGWS-11	2	400	8
70 STJ-SJWS-02	9	2,000	8

[1] Well number refers to well location as shown on figures 5, 6, or 7.

The relatively large range of transmissivity values is due to the heterogeneity of the aquifer material. On St. Croix the higher values of transmissivity in the Kingshill Limestone are common primarily in areas where there is a high density of intersecting fracture zones. On St. Thomas and St. John areas of high transmissivities will also coincide with areas of high fracture density within the volcanic rock aquifer. The large range of transmissivity values on St. Croix may be due to localized areas of dissolution along the fracture zones resulting in large openings and, subsequently, the high transmissivity values. These values of transmissivity may be larger than they would have been because of the presence of the overlying alluvial deposits where the deposits are sufficiently thick and saturated. In the alluvial deposits, where the percentage of sand or gravel is high the transmissivity will be high; conversely, where the percentage of silt or clay is high the transmissivity will be low.

The development of ground-water supplies from the aquifers of the USVI is complicated due to the nature of the aquifer materials (limestone, marl, and dense volcanic rock) and the localized extent of fracture zones within the aquifers. However, according to the literature, the chances of producing a well that might yield sufficient quantities of water for emergency use are greatly improved if the wells are drilled in the draws or valleys of principal drainage areas (Heath, 1980; Daniels and Sharpless, 1983; and Daniels, 1987). This concept was applied in choosing the location of most test holes drilled with reasonably acceptable results. If the number of test holes drilled for observation wells (12) and test holes back filled (22) are subtracted from the total test holes drilled (61), then by island, the percentage of emergency water-supply wells completed to test holes drilled was 50 percent for St. Croix (15 wells completed of 30 test holes drilled), 52 percent for St. Thomas (11 wells completed of 21 test holes drilled), and 10 percent for St. John (1 well completed of 8 test holes drilled) (tables 1, 2, and 3). Well yields for the 27 emergency supply wells ranged from about 14 to 80 gallons per minute (tables 1, 2, and 3).

WATER QUALITY

In order to determine the quality of ground water on St. Croix, St. Thomas, and St. John, 33 wells were sampled for common cations and anions and trace elements (tables 6, 7, and 8). Using the Piper diagram (Piper, 1953), results of these analyses indicate that ground water in the U.S. Virgin Islands is predominantly a sodium-chloride type water (figs. 18, 19, and 20). However, on St. Thomas, data for water samples from a majority of the wells sampled indicated that the ground water is a mixed type; no one cation or anion exceeded 50 percent of the total milliequivalents of cations or anions in water from 9 of 11 wells sampled.

In an island setting, ground water that is a sodium chloride type water commonly is considered to contain a mixture of freshwater and seawater (Gómez-Gómez, 1984). The source of the seawater could be lateral migration of seawater from the ocean through the aquifer, upconing of saline water as a result of excessive pumping, or connate seawater that has not been completely flushed out of the aquifer. To determine the source of the seawater, long-term water-quality data must be collected and seasonal changes in chloride concentrations compared. If the seasonal variations in the chloride concentrations are small, connate water is the most likely source of the sodium chloride, assuming that areal ground-water pumping is relatively constant. If the variations in chloride concentration are large, the source of the sodium chloride is most likely upconing or lateral migration (intrusion) of seawater that coincides with seasonal water-level fluctuations in the aquifer, and the related movement of the saltwater-freshwater interface. The limited timeframe of this study did not allow for long-term monitoring of seasonal water-quality changes. However, recent data available for the island of St. Croix (Graves, 1995) indicate that the source of the sodium chloride in wells STX-EGWS- 06, 07, 08, 14, and 15 could be connate water, and that the source in wells STX-EGWS- 09 and 10 is possibly seawater intrusion. To adequately discuss the source of seawater in the aquifers on St. Thomas and St. John, more information is needed.

Table 6. Chemical analyses of ground water on St. Croix, U.S. Virgin Islands

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; STX, St. Croix; EGWS, emergency ground-water supply; --, data not available; <, less than detection limit which is number following symbol]

Well number and name[1]	Date	Specific conductance (lab value, µS/cm)	pH (field value, standard units)	Hardness (mg/L as $CaCO_3$	Alkalinity, lab (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)
2 STX-EGWS-01	10-05-92	1,470	7.0	440	361	120	35	120	3.5	37
3 STX-EGWS-02	10-06-92	1,500	7.0	460	313	130	32	120	1.3	39
5 STX-EGWS-03	10-05-92	1,460	7.1	470	424	120	41	120	1.5	40
7 STX-EGWS-04	10-27-92	2,840	7.5	150	519	31	17	560	2.4	180
9 STX-EGWS-05	10-27-92	2,600	7.3	290	565	50	41	460	1.2	130
12 STX-EGWS-06	10-06-92	2,040	7.1	400	572	72	54	300	1.1	120
13 STX-EGWS-07	10-06-92	2,220	7.0	470	541	85	62	310	1.1	130
15 STX-EGWS-08	10-07-92	2,080	7.2	390	548	65	56	310	0.8	120
18 STX-EGWS-09	10-26-92	3,650	7.2	430	402	84	53	650	3.3	230
19 STX-EGWS-10	10-26-92	3,750	7.1	450	396	88	57	650	3.1	230
20 STX-EGWS-11	10-28-92	2,430	7.6	110	479	31	7	500	6.2	130
22 STX-EGWS-12	11-02-92	4,380	7.1	480	401	130	38	750	7.5	300
24 STX-EGWS-13	10-27-92	1,990	7.3	380	438	67	51	280	1.1	95
25 STX-EGWS-14	10-27-92	2,190	6.9	540	370	110	64	260	1.8	100
30 STX-EGWS-15	10-07-92	2,150	7.2	420	525	66	63	320	0.9	100

Table 6. Chemical analyses of ground water on St. Croix, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Chloride, dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids (mg/L)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium dissolved (µg/L as Ba)	Aluminum, dissolved (µg/L as Al)
2 STX-EGWS-01	10-05-92	220	0.5	35	787	--	3	2	7	20
3 STX-EGWS-02	10-06-92	260	0.5	37	808	--	7	1	8	20
5 STX-EGWS-03	10-05-92	200	0.5	34	811	--	4	6	10	10
7 STX-EGWS-04	10-27-92	480	0.8	30	1,610	5.2	20	<10	<100	10
9 STX-EGWS-05	10-27-92	410	0.9	42	1,470	3.3	<10	<10	<100	<10
12 STX-EGWS-06	10-06-92	230	0.4	51	1,170	--	10	10	<100	<10
13 STX-EGWS-07	10-06-92	360	0.4	45	1,320	--	<10	10	<100	<10
15 STX-EGWS-08	10-07-92	300	0.5	46	1,230	--	<10	<10	<100	10
18 STX-EGWS-09	10-26-92	750	0.8	39	2,050	3.8	<10	<10	<100	<10
19 STX-EGWS-10	10-26-92	770	0.7	41	2,080	3.5	<10	<10	<100	<10
20 STX-EGWS-11	10-28-92	360	0.6	16	1,340	10.0	<10	<10	<100	20
22 STX-EGWS-12	11-02-92	980	0.4	26	2,470	3.5	10	<10	<100	30
23 STX-EGWS-13	10-27-92	290	0.5	42	1,090	3.4	3	1	44	<10
25 STX-EGWS-14	10-27-92	350	0.5	31	1,140	3.2	<10	40	<100	<10
30 STX-EGWS-15	10-07-92	340	0.7	46	1,250	--	<10	<10	<100	<10

Table 6. Chemical analyses of ground water on St. Croix, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Arsenic, dissolved (µg/L as As)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Lead, dissolved (µg/L as Pb)
2 STX-EGWS-01	10-05-92	<1	<1	<1	<0.1	1	4	<1
3 STX-EGWS-02	10-06-92	<1	<1	<1	0.1	1	<1	<1
5 STX-EGWS-03	10-05-92	<1	<1	<1	0.2	1	<1	<1
7 STX-EGWS-04	10-27-92	<1	<1	<1	<0.1	4	<1	<1
9 STX-EGWS-05	10-27-92	2	<1	<1	0.2	4	<1	<1
12 STX-EGWS-06	10-06-92	2	<1	<1	0.1	4	<1	<1
13 STX-EGWS-07	10-06-92	2	<1	<1	<0.1	4	<1	<1
15 STX-EGWS-08	10-07-92	1	<1	<1	0.2	2	<1	<1
18 STX-EGWS-09	10-26-92	1	<1	<1	<0.1	4	<1	<1
19 STX-EGWS-10	10-26-92	1	<1	<1	<0.1	4	<1	<1
20 STX-EGWS-11	10-28-92	5	<1	<1	<0.1	3	<1	<1
22 STX-EGWS-12	11-02-92	<1	<1	11	<0.1	9	<1	<1
24 STX-EGWS-13	10-27-92	<1	<1	<1	<0.1	3	<1	<1
25 STX-EGWS-14	10-27-92	<1	<1	<1	<0.1	1	<1	<1
30 STX-EGWS-15	10-07-92	<1	<1	<1	<0.1	2	<1	<1

[1] Well number refers to well location as shown on figures 2, 3, or 4.

Table 7. Chemical analyses of ground water on St. Thomas, U.S. Virgin Islands

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; STT, St. Thomas; EGWS, emergency ground-water supply; --, Data not available; <, less than detection limit which is number following symbol; ug/L, micrograms per liter]

Well number and name[1]	Date	Specific conductance (lab value, µS/cm)	pH (field value, standard units)	Hardness (mg/L as $CaCO_3$	Alkalinity, lab (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)
37 STT-EGWS-1	04-23-91	2,240	7.5	290	486	48	42	390	0.6	44
38 STT-EGWS-2	04-24-91	1,680	7.4	250	538	45	34	260	0.7	35
39 STT-EGWS-3	05-08-91	1,740	7.5	250	488	41	35	290	0.4	35
41 STT-EGWS-4	08-12-91	1,180	7.4	160	401	31	20	220	0.7	29
42 STT-EGWS-5	08-13-91	1,290	7.3	190	392	42	20	210	1.9	34
45 STT-EGWS-6	08-26-91	1,810	7.2	250	582	45	33	300	0.7	42
49 STT-EGWS-7	08-14-91	2,100	7.4	220	616	30	35	400	2.0	49
51 STT-EGWS-8	08-14-91	1,950	7.4	320	619	48	48	310	4.4	56
52 STT-EGWS-9	08-26-91	1,450	7.3	210	411	35	30	240	0.4	24
53 STT-EGWS-10	08-19-91	1,540	7.3	230	489	37	33	270	0.4	33
56 STT-EGWS-11	08-13-91	1,630	7.4	140	544	28	16	320	1.1	39

Table 7. Chemical analyses of ground water on St. Thomas, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Chloride, dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids (mg/L)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium dissolved (µg/L as Ba)	Aluminum, dissolved (µg/L as Al)
37 STT-EGWS-1	04-23-91	390	0.9	27	1,230	0.05	10	760	100	--
38 STT-EGWS-2	04-24-91	200	0.7	32	930	5.10	5	<1	<2	--
39 STT-EGWS-3	05-08-91	270	1.1	31	996	<0.05	4	240	<2	--
41 STT-EGWS-4	08-12-91	130	0.8	37	709	5.40	8	13	3	<10
42 STT-EGWS-5	08-13-91	150	0.6	32	726	12.00	3	<1	5	<10
45 STT-EGWS-6	08-26-91	240	0.7	30	1,040	5.30	4	1	<2	<i0
49 STT-EGWS-7	08-14-91	260	0.8	27	1,170	2.10	10	310	<100	10
51 STT-EGWS-8	08-14-91	290	0.8	27	1,160	0.05	9	210	53	<10
52 STT-EGWS-9	08-26-91	220	1.1	32	829	0.28	5	5	<2	<10
53 STT-EGWS-10	08-19-91	170	0.8	33	870	4.00	6	47	3	<10
56 STT-EGWS-11	08-13-91	190	0.7	29	950	3.80	5	6	5	<10

Table 7. Chemical analyses of ground water on St. Thomas, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Arsenic, dissolved (µg/L as As)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Lead, dissolved (µg/L as Pb)
37 STT-EGWS-1	04-23-91	<1	<1	<1	<0.1	<1	<1	4
38 STT-EGWS-2	04-24-91	<1	<1	<1	<0.1	3	1	2
39 STT-EGWS-3	05-08-91	<1	<1	<1	<0.1	<1	<1	<1
41 STT-EGWS-4	08-12-91	<1	<1	2	0.3	2	<1	<1
42 STT-EGWS-5	08-13-91	<1	<1	1	<0.1	2	<1	<1
45 STT-EGWS-6	08-26-91	<1	<1	1	0.6	3	<1	<1
49 STT-EGWS-7	08-14-91	<1	<1	<1	<0.1	2	<1	<1
51 STT-EGWS-8	08-14-91	<1	<1	<1	<0.1	2	<1	<1
52 STT-EGWS-9	08-26-91	<1	<1	<1	0.6	<1	<1	<1
53 STT-EGWS-10	08-19-91	<1	<1	<1	<0.1	2	<1	<1
56 STT-EGWS-11	08-13-91	<1	<1	<1	0.3	2	<1	<1

[1] Well number refers to well location as shown on figure 5.

Table 8. Chemical analyses of ground-water on St. John, U.S. Virgin Islands

[µS/cm, microsiemens per centimeter at 25 degrees celsius; mg/L, milligrams per liter; NPS, National Park Service; VIWAPA, Virgin Islands Water and Power Authority; VI, Virgin Islands; USGS, U.S. Geological Survey; STJ, St. John; SJWS, St. John Water Supply; <, less than detection limit which is number following symbol; --, indicates data not available]

Well number and name[1]	Date	Specific conductance (lab value, µS/cm)	pH (field value, standard units)	Hardness (mg/L as $CaCO_3$	Alkalinity, lab (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)
59 NPS-03, Cruz Bay	05-20-91	2,280	7.1	490	462	86	68	330	2.2	54
61 VIWAPA DPW-02, Susannaberg	06-04-91	1,770	7.1	570	615	100	77	150	2.6	24
62 VIWAPA DPW-05, Susannaberg	06-04-91	1,520	7.1	390	563	69	53	180	3.4	24
64 NPS-05, Trunk Bay	05-20-91	1,720	7.2	470	463	100	54	180	3.1	52
65 Cinnamon Bay campground	05-21-91	2,020	7.2	510	519	86	72	250	2.8	24
67 VI Government/ VIWAPA well (USGS-14A)	03-09-90	825	7.1	150	113	24	21	120	4.8	21
70 STJ-SJWS-02	05-20-91	2,220	6.7	370	236	49	60	310	6.9	93

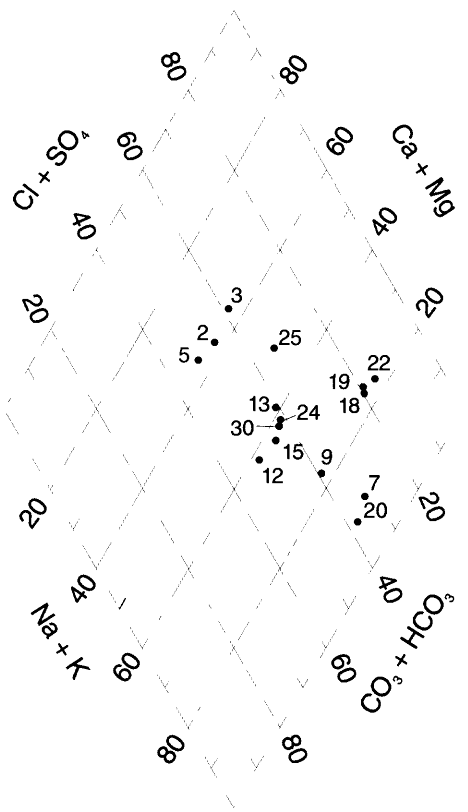
Table 8. Chemical analyses of ground-water on St. John, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Chloride, dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids (mg/L)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Barium dissolved (µg/L as Ba)	Aluminum, dissolved (µg/L as Al)
59 NPS-03 Cruz Bay	05-20-91	400	0.4	36	1,250	<0.05	10	<10	<100	--
61 VIWAPA DPW-02, Susannaberg	06-04-91	230	0.4	43	996	0.57	6	<1	19	--
62 VIWAPA DPW-05, Susannaberg	06-04-91	170	0.6	37	875	1.10	8	<1	5	--
64 NPS-05, Trunk Bay	05-20-91	270	0.5	38	975	<0.05	44	<1	66	--
65 Cinnamon Bay campground	05-21-91	360	0.9	40	1,150	<0.05	<10	<10	<100	--
67 VI Government/ VIWAPA well (USGS-14A)	03-09-90	250	0.2	27	542	0.10	5,600	310	49	<10
70 STJ-SJWS-02	05-20-91	540	0.2	34	1,230	1.40	270	70	<100	--

Table 8. Chemical analyses of ground-water on St. John, U.S. Virgin Islands--Continued

Well number and name[1]	Date	Arsenic, dissolved (µg/L as As)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Lead, dissolved (µg/L as Pb)
59 NPS-03, Cruz Bay	05-20-91	<1	<1	<1	<0.1	<1	<1	1
61 VIWAPA DPW-02, Susannaberg	06-04-91	1	<1	<1	<0.1	<1	<1	<1
62 VIWAPA DPW-05, Susannaberg	06-04-91	<1	<1	<1	<0.1	<1	<1	<1
64 NPS-05, Trunk Bay	05-20-91	<1	<1	<1	<0.1	<1	<1	1
65 Cinnamon Bay campground	05-21-91	<1	<1	<1	0.4	<1	<1	2
67 VI Government/ VIWAPA well (USGS-14A)	03-09-90	--	--	--	--	--	--	--
70 STJ-SJWS-02	05-20-91	<1	<1	6	<0.1	<1	<1	1

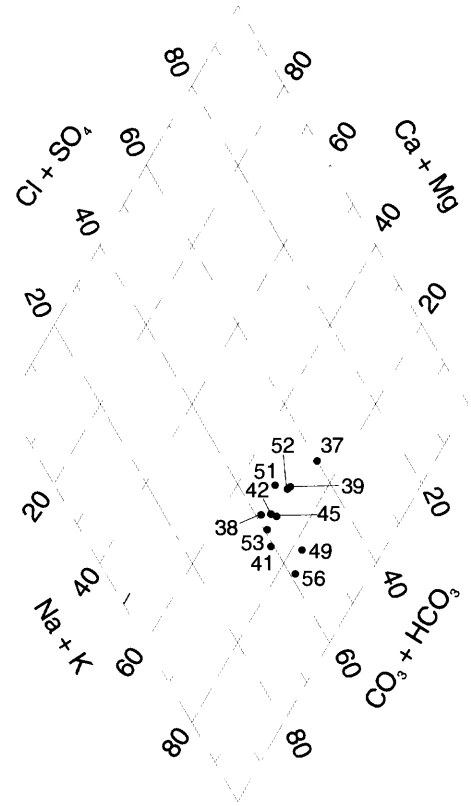
[1] Well number refers to well location as shown on figure 6 or 7.



EXPLANATION

Ca	Calsium
K	Potassium
Mg	Magnesium
Na	Sodium
Cl	Chloride
CO_3	Carbonate
HCO_3	Bicarbonate
SO_4	Sulfate

Figure 18. Diagram showing major constituents in ground water in wells on St. Croix, U.S. Virgin Islands. Values shown are percent of total milliequivalents per liter. Numbers refer to wells in table 6.



EXPLANATION

Ca	Calsium
K	Potassium
Mg	Magnesium
Na	Sodium
Cl	Chloride
CO_3	Carbonate
HCO_3	Bicarbonate
SO_4	Sulfate

Figure 19. Diagram showing major constituents in ground water in wells on St. Thomas, U.S. Virgin Islands. Values shown are percent of total milliequivalents per liter. Numbers refer to wells in table 7.

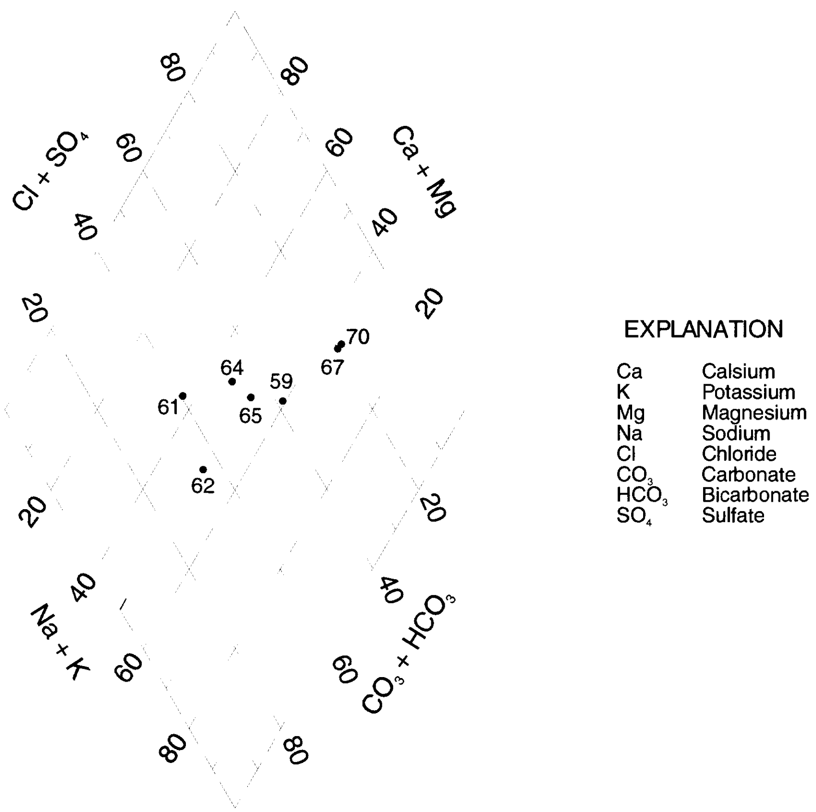


Figure 20. Diagram showing major constituents in ground water in wells on St. John, U.S. Virgin Islands. Values shown are percent of total milliequivalents per liter. Numbers refer to wells in table 8.

Chloride concentrations in ground-water samples collected from all wells drilled (tables 1, 2, and 3) and from wells sampled for analysis of common cations and anions (tables 6, 7, and 8) ranged from 116 to 3,870 milligrams per liter (mg/L). The dissolved solids concentrations in water sampled for analysis of common cations and anions (tables 6, 7, and 8) ranged from 542 to 2,470 mg/L. The U.S. Environmental Protection Agency's (EPA, 1992) Secondary Maximum Contaminant Level for chloride and dissolved solids concentrations is 250 and 500 mg/L, respectively. Of the water sampled for analysis of common cations and anions (tables 6, 7, and 8), these levels were exceeded in 61 percent of the wells for chloride concentrations and in 100 percent of the wells for dissolved solids concentrations. However, the recommended maximum level for chloride is based largely on taste; water having a chloride concentration as high as 500 mg/L can be potable. For dissolved solids the Secondary Maximum Contaminant Level is based on an increase in the mineral taste in the water and possible economic consequences due to deterioration of plumbing and pipes because of the high mineral content.

SUMMARY

Following the devastation by Hurricane Hugo on September 17 and 18, 1989, the islands of St. Croix, St. Thomas, and St. John, were without drinking water because of the damage to the infrastructure that provides water to the islands. However, on St. Croix, several well fields which had seen limited use in recent years were put on line and connected to the water distribution system. Recognizing the need for a better understanding of the hydrogeology of the USVI, the U.S. Geological Survey, in cooperation with the U.S. Office of Management and Budget, conducted an investigation from May 1990 through September 1992 to determine the occurrence and quality of ground water so emergency ground-water supplies could be developed to mitigate natural or man induced disasters.

The geology of the U.S. Virgin Islands is varied. The geology of St. Croix includes alluvial deposits and carbonate and volcanic rocks. The geology of St. Thomas and St. John is dominated by volcanic rock with local alluvial deposits in small coastal embayments. Carbonate deposits are present on St. Thomas and St. John but only in minor isolated outcrops.

Ground water occurs under water-table conditions on St. Croix, St. Thomas, and St. John. On St. Croix, the principal sources of ground water are the carbonate rock and overlying alluvial deposits. On St. Thomas and St. John the principal sources of ground water are the regolith and zones of highly fractured to shattered volcanic rock and overlying alluvial deposits. Depth below land surface to the water table ranges from 4 to 62 feet on St. Croix, 3 to 74 feet on St. Thomas, and 8 to 60 feet on St. John. Aquifer transmissivities range from 200 to 4,000 feet squared per day on St. Croix and from 200 to 2,500 feet squared per day on St. Thomas and St. John. Well yields for the emergency-supply wells on St. Croix, St. Thomas, and St. John range from 14 to 80 gallons per minute.

Ground water in the U.S. Virgin Islands is predominantly a sodium chloride type. Ground-water samples collected from selected wells had chloride concentrations ranging from 116 to 3,870 milligrams per liter and dissolved solids concentrations ranging from 542 to 2,470 milligrams per liter. On St. Croix, depending on location, the source of sodium chloride is connate water or seawater intrusion. Data were not available to determine the source of sodium chloride on St. Thomas or St. John.

REFERENCES

Cederstrom, D.J., 1950, Geology and ground-water resources of St. Croix, Virgin Islands: U.S. Geological Survey Water-Supply Paper 1067, 117 p., 6 pls.

Cosner, O.J., 1972, Water in St. John, U.S. Virgin Islands: U.S. Geological Survey Open-File Report 72-78, 46 p.

Daniels III, C.D., 1987, Statistical analysis relating well yield to construction practices and sitting of wells in the Piedmont and Blue Ridge provinces of North Carolina: U.S. Geological Survey Water-Resources Investigations Report 86-4132, 54 p.

Daniels III, C.D., and Sharpless, N.B., 1983, Ground-water supply potential and procedures for well-site selection in the upper Cape Fear river basin, North Carolina: Cape Fear Basin Study, North Carolina Department of Natural Resources and Community Development and U.S. Water Resources Council, 73 p.

Donnelly, T.W., 1959, Geology of St. Thomas and St. John, Virgin Islands: A dissertation presented to the faculty of Princeton University in candidacy for the degree of Doctor of Philosophy, accepted by the Department of Geology, May 2, 1959, 179 p.

Gerhard, L.C., Frost, S.H., and Curth, P.J., 1978, Stratigraphy and depositional setting, Kingshill Limestone, Miocene, St. Croix, U.S. Virgin Islands: Amer. Assoc. Petrol. Geol. Bull., v. 62, no. 3, p. 403-418.

Gill, I.P., and Hubbard, D.K., 1986, Subsurface geology of the St. Croix carbonate rock system: Water Resources Research Institute, College of the Virgin Islands, Technical Report No. 26, 71 p.

_____ 1987, Subsurface geology of the St. Croix carbonate rock system, phase II: Water Resources Research Institute, College of the Virgin Islands, Technical Report No. 28, 66 p.

Gómez-Gómez, Fernando, 1984, Water resources of the lower Río Grande de Manatí valley, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 83-4199, 42 p.

Gómez-Gómez, Fernando, Quiñones-Márquez, Ferdinand, and Zack, Allen, 1985, U.S. Virgin Islands, Ground-Water Resources: U.S. Geological Survey Water-Supply Paper 2275, p. 409-413.

Graves, R.P., 1992, Geohydrology of the Aguirre and Pozo Hondo areas, southern Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 91-4124, 43 p.

_____ 1995, Hydrogeology of south-central St. Croix, U.S. Virgin Islands: U.S. Geological Survey Water-Resources Investigations Report 93-4162, 33 p.

Graves, R.P., and González, Ralph, 1988, Potentiometric surface of the Turpentine Run basin aquifer in the Tutu area, eastern St. Thomas, September 11, 1987: U.S. Geological Survey Water-Resources Investigations Report 88-4131, 1 pl.

Heath, R.C., 1980, Basic elements of ground-water hydrology with reference to conditions in North Carolina: U.S. Geological Survey Open-File Report 80-44, 86 p.

Hubbard, D.K., editor, 1989, Terrestrial and marine geology of St. Croix, U.S. Virgin Islands; Special Publication Number 8, West Indies Laboratory, Teague Bay, St. Croix, ??p.

Jordan, D.G., 1975, A survey of the water resources of St. Croix, Virgin Islands: U.S. Geological Survey Open-File Report, 51 p.

Jordan, D.G., and Cosner, O.J., 1973, A survey of the water resources of St. Thomas, Virgin Islands: U.S. Geological Survey Open-File Report 72-201, 55 p.

Lohman, S.W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Mathey, S.B., 1990, National water information system user's manual, volume 2, chapter 4. Ground-Water Site Inventory System: U.S. Geological Survey Open-File Report, 89-587, 283 p.

Meyer, R.R., 1963, A chart relating well diameter, specific capacity, and the coefficient of transmissibility and storage, *in* Bentall, Ray, compiler, Methods of determining permeability, transmissivity, and drawdown: U.S. Geological Survey Water- Supply Paper 1536-I, p. 338-340.

Piper, A.M., 1953, A graphic procedure in the geochemical interpretation of water analyses: *in* U.S. Geological Survey Ground Water Notes, Geochemistry, no. 12, p. 1-14.

Rivera, L.H., Fredrick, W.D., Farris, Cornelius, Jensen, E.H., Davis, Lyle, Palmer, C.D., Jackson, L.F., and McKinzie, W.E., 1970, Soil survey of the Virgin Islands of the United States: United States Department of Agriculture Soil Conservation Service, 78 p.

Robison, T.M., 1972, Ground water in central St. Croix, U.S. Virgin Islands: U.S. Geological Survey Open-File Report, 18 p.

Torres-González, Sigfredo, and Rodríguez-del-Río, Félix, 1990, Potentiometric surface of the Kingshill aquifer and hydrologic conditions, St. Croix, U.S. Virgin Islands, July 1987: U.S. Geological Survey Water-Resources Investigations Report 89-4085, 1 pl.

Torres-González, Sigfredo, 1991, Steady-state simulation of ground-water flow conditions in the Kingshill aquifer, St. Croix, U.S. Virgin Islands, July 1987, *in* American Water Resources Association International Symposium on Tropical Hydrology, July 23 through 27, 1990, San Juan, Puerto Rico: AWRA Monograph Series No. 15, p. 93-108.

U.S. Department of Commerce, 1982 to 1992, Climatological data annual summary - Puerto Rico and the Virgin Islands: National Oceanic and Atmospheric Administration, v. 28-38.

U.S. Environmental Protection Agency, 1992, Secondary maximum contaminant levels (part 143, National primary drinking water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1992, p. 772-776.

Whetten, J.T., 1966, Geology of St. Croix, U.S. Virgin Islands: Geol. Soc. America Mem., 98, p. 177-239.