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

by

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CONTENTS

Page

ILLUSTRATIONS

Figure   Page

ILLUSTRATIONS

TABLES

ABSTRACT

St. Croix consists of two mountainous volcanic rock cores separated by a graben containing clays with minor limestone and conglomerate that is overlain by about 300 feet of marl and limestone. Predominantly fine-grained alluvium mantles much of the limestone and marl area and fills overdeepened south-trending valleys to depths of as much as 100 feet.

Rainfall follows an orographic pattern ranging from about 30 inches in eastern St. Croix to 55 inches in the northwestern mountains.

Four streams, all heading in the Northside Range, have intermittent reaches. All other streams in St. Croix are ephemeral, flowing only for a few hours or days following major rainstorms. Flow in the intermittent streams ranges from about 1 to 9 percent of the total rainfall and usually half or more of the flow is storm runoff resulting from two or three major storms. Storm runoff from individual storms seldom exceeds 5 percent of the rainfall. Only from 2 storms, one of 5 inches and the other of 7 inches in less than 48 hours, did runoff reach 20 percent, both times on River Gut at Golden Grove. The lack of storm runoff is attributed to the capability of the soil zone to accept large volumes of water and deficient soil moisture most of the year.

The dissolved-solids content of the water of St. Croix reflects the influence of the sea and land. Bulk precipitation is believed to be the source of the initial mineral content of the island water. Additional mineralization, particularly of ground water, results from the solution of soluble salts, mixing with residual sea water, and concentration by evapotranspiration. Water in the volcanic rocks is basically a calcium bicarbonate sodium chloride type with dissolved solids ranging from 500 to 1,000 mg/l (milligrams per liter), and chloride concentration of 100 to 300 mg/l. By contrast, water in the limestone is a sodium bicarbonate sodium chloride type with dissolved-solids content ranging from less than 1,000 to more than 20,000 mg/l and chloride concentration from less than 100 to more than 10,000 mg/l. The mineral content of water in the limestone invariably increases with depth. Water in the alluvial deposits and in the streams usually reflects the characteristics of water from the adjacent bedrock.

The retention of large volumes of rainfall in the soil zone from which it is evaporated and transpired by plants greatly reduces the water available for recharge to the aquifers of the island. Estimates of effective recharge to the aquifers range from less than 0.5 inch in some volcanic and marl rocks to 5

inches annually in more porous limestone and alluvium. Long-term yield from the aquifers is also affected by their storage capacity which may range from less than 1 percent in volcanic rocks and marl to 10 to 15 percent in limestone and alluvium.

The ground-water potential (equivalent to the quantity of recharge) of St. Croix is estimated at 3.9 mgd (million gallons per day)--0.9 mgd from the Northside Range (Area 1), 0.4 mgd from the East End Range (Area 2), and 2.6 mgd from the central lowlands (Area 3). Most areas where major ground-water supplies are available, principally in Central St. Croix, have already been developed. The Castle Coakley area, with a potential yield of 400,000 gpd, is the only major ground-water area still undeveloped.

The ground-water potential could be increased by reducing the brush and forest cover thus reducing water losses from transpiration; artificial recharge of alluvial aquifer by water spreading; utilizing streamflow (including storm runoff) or treated sewage effluent; or by lowering the ground-water level adjacent to streams to induce infiltration.

Advancements in desalination have made the brackish ground water in the Kingshill Marl (estimated at 35 billion recoverable gallons by Robison, 1972) a potential source of water. Recovery of this water would partly de-water the aquifer, which would cause water of better quality in the overlying rocks to move into the aquifer and also cause salt-water encroachment from the sea. It is conceivable that withdrawals could be balanced by artificial recharge using treated sewage effluent.

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

by Donald G. Jordan

INTRODUCTION

Water is not an abundant resource in St. Croix. Streamflow is meager and not reliable. Aquifers are small and yield mineralized water, often unfit for human consumption. There is need, however, to utilize all the available usable water to meet the rapidly increasing demand.

The data for this report were largely obtained between 1962 and 1967, during an investigation of the water resources of the U.S. Virgin Islands by the U.S. Geological Survey made in cooperation with the Government of the Virgin Islands and the U.S. National Park Service. The purpose of the study was to describe the potential for development of the water resources of St. Croix by investigating the extent and magnitude of streamflow and storm runoff, the location and yield of the water bearing rocks, and the chemical quality of surface and ground water.

Geography

The U.S. Virgin Islands consist of more than 40 islands and cays located about 1,400 miles southeast of New York, 1,100 miles east-southeast of Miami, Florida, and about 50 miles east of Puerto Rico. The islands form part of the Antilles Island Arc, which separates the Caribbean Sea from the Atlantic Ocean. The largest and most important islands are St. Croix, St. Thomas, and St. John, whose respective areas are approximately 84, 32, and 19 square miles (fig. 1). St. Croix lies about 40 miles south of St. Thomas and St. John. Buck Island, about a mile to the northeast, is St. Croix's only major satellite island.

At one time almost all of the land including the steep mountain slopes was under cultivation, primarily for sugarcane and cotton, or was grazed. In recent years, however, agriculture has declined almost to extinction. Some land is still used for pasture, but over the years the greater part of the island has been allowed to revert to brush and secondary forest.

After sugarcane farming ceased in 1966, only about 5,000 acres were under cultivation or in pasture. Another 2,000 acres were occupied by urban areas, rural communities, and other non-farm uses. The rest of the island, about 45,000 acres, was covered by small stands of second-growth forest, false tamarind and acacia bush, yielding to thorn and cactus on the semiarid eastern end. The expected increases in population and tourism will require more land for development, as will any substantial industrialization. Truck farming, now almost nonexistent, is expected to exceed 6,000 acres by 1980 (unpub. data, Virgin

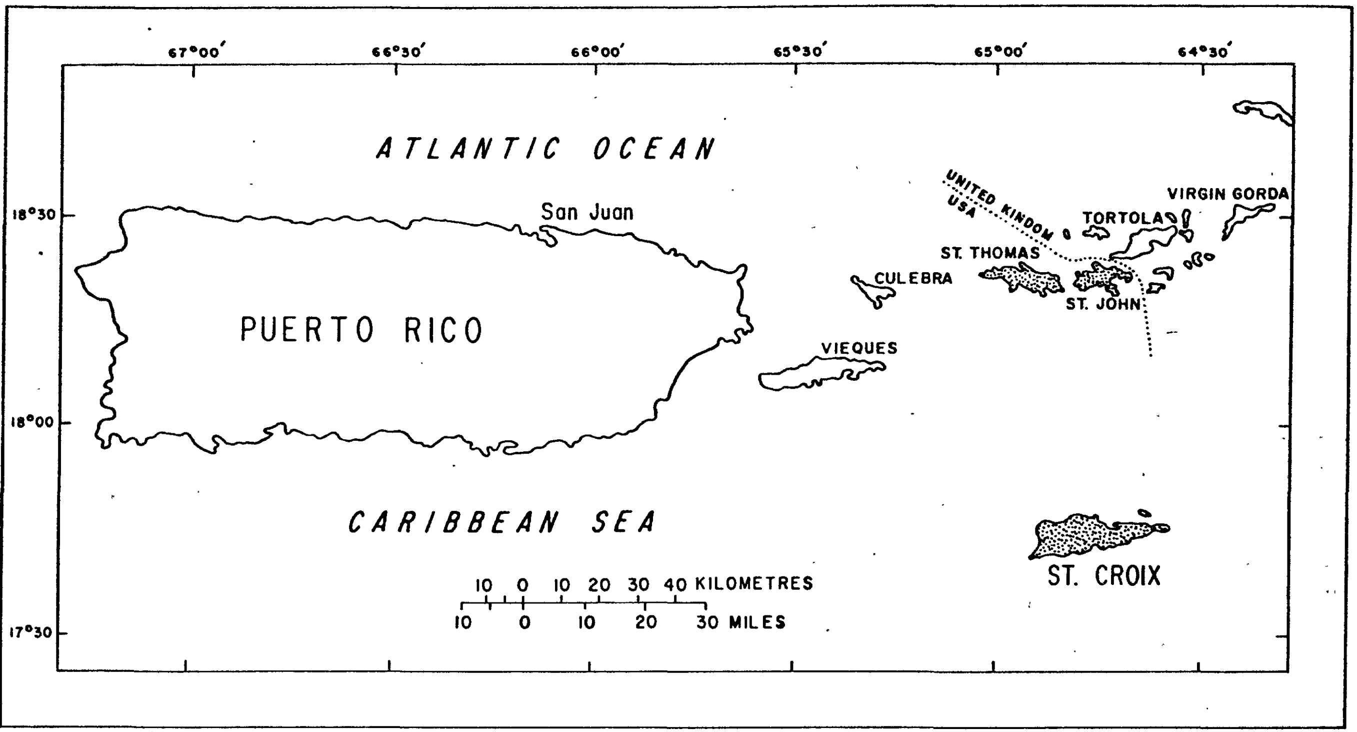


Figure 1.--Location of the U.S. Virgin Islands.

Island, Planning Board, 1965). Such changes will increase the demand for water and may exceed the available water supply.

The northwestern part of St. Croix is a rugged mountainous area underlain chiefly by volcanic rocks. A nearly continuous mountain ridge, running from the west end of the island to Salt River Bay, lies parallel to the north coast a half to 1 mile inland. The crest generally ranges from 600 to 800 feet above sea level, but two peaks are higher than 1,000 feet. The highest peak is Blue Mountain, 1,096 feet above sea level. Steep-sided, deeply entrenched valleys extend to the north, south, and west from the central ridge. To the north and northwest, the mountains plunge directly to the sea, the coastline broken only by small embayments marking the mouths of valleys.

To the south and southwest the mountainous area is bound by a gently rolling plain underlain by limestone and marl and mantled by alluvium. South of Frederiksted the lowland adjoins the sea. Eastward, in the central and southern part of the island, the lowland broadens and is marked by rounded limestone hills rising above broad valleys. West and southwest of Christiansted the lowland terminates against high limestone hills and elongated ridges cut by narrow valleys.

East of Christiansted the terrain is mountainous and underlain chiefly by volcanic rocks, but here the peaks are more rounded and the valleys are not as steep-sided or deeply incised as in the northwest. A central ridge extends from south of Christiansted to the east end of the island, with several peaks more than 800 feet above sea level. The ridge is broken by two broad lowlands underlain by diorite, one extending inland from Southgate Pond on the north and the other from Great Pond on the south.

St. Croix has four major streams that flow intermittently. All four rise in the mountains of the northwestern part of the island. River Gut, the largest, has a drainage area of about 11 square miles and flows to the south coast. The others, Caledonia Gut, Creque Gut, and Jolly Hill Gut discharge to the west coast and have drainage areas ranging from 1 to 4 square miles. The remainder of the island's water courses usually carry flow only after heavy rains.

Climate

The average annual rainfall on St. Croix is about 40 inches, ranging from about 30 inches in the east to more than 50 inches in the mountains of the northwest. Average annual temperature is a moderate 79°F, with an average low in winter of 76°F and an average high in summer of 84°F; temperatures are 2 to 3 degrees lower at altitudes of 800 to 1,000 feet. Occassionally maximum daily temperatures will exceed 90°F and minimum temperatures will be less than 70°F. Prevailing wind direction is from the east or northeast.

Rain generally occurs in brief, intense showers of less than a few tenths of an inch. Rains exceeding 1 inch in 48 hours occur about 7 or 8 times a year in the central part of the island; they are slightly more frequent in the mountains of the northwest and less frequent in the eastern part. February and March are the driest months and September is the wettest. Nearly half the average annual rain falls from August through November (fig. 2). Large storms can occur in any month although more likely during July to November, the hurricane season.

Rainfall records have been kept in St. Croix since 1852 but not continuously at any one station. A composite of the record at Christiansted, Frederiksted, and Kingshill from 1852 to 1935 (Johnson, 1937) and more recent data collected by the National Weather Service at Anna's Hope have been graphed in figure 3. Average yearly rainfall from 1852 to 1935 was 46.34 inches. At Anna's Hope where rainfall data have been obtained since 1920 the annual average is 42.45 inches. The difference in average rainfall between the two periods is probably because of the changes of station location.

In the past 100 years there have been two severe droughts interspersed with periods of above-average rainfall. A 10-year running average (fig. 3) shows a variation of as much as 10 inches between the average rainfall of the wet and dry periods. Both the accumulated departure from average and the running average indicate a declining trend of rainfall that started in the late 1930's. St. Croix again may be entering a lengthy drought.

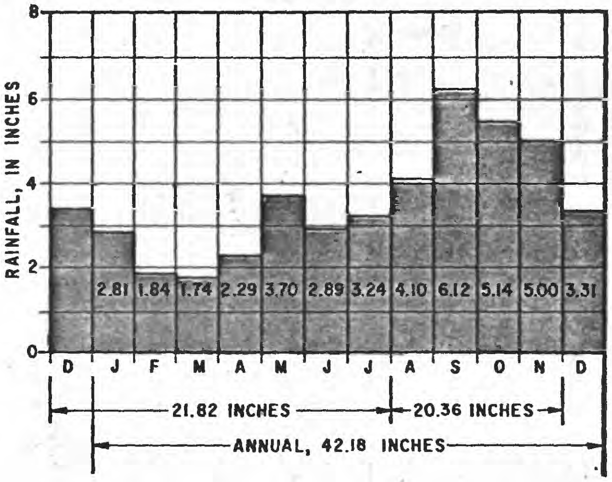


Figure 2.--Mean monthly rainfall at Anna's Hope, 1920-67.

[National Weather Service data.]

Annual rainfall distribution is controlled by the island's orographic features and the direction of the prevailing wind (fig. 4). The northwest mountain area receives the most rain. The southwestern part of the island, in the shadow of these mountains, and the narrow, relatively low eastern part receive the least. The distribution of rain from individual storms, however, varies widely in response to deviations of wind direction.

Geology

The mountainous areas at the east and west ends of St. Croix are composed largely of fractured and deformed epiclastic and pyroclastic rocks. A probable altered volcanic ash fills what may be a graben (Whetten, 1966) between these two masses and in turn is overlain by marl and limestone. Alluvium mantles the coastal lowlands and fills the lower reaches of deeply eroded bedrock valleys to depths of 100 feet or more. The major stratigraphic units, their distribution and

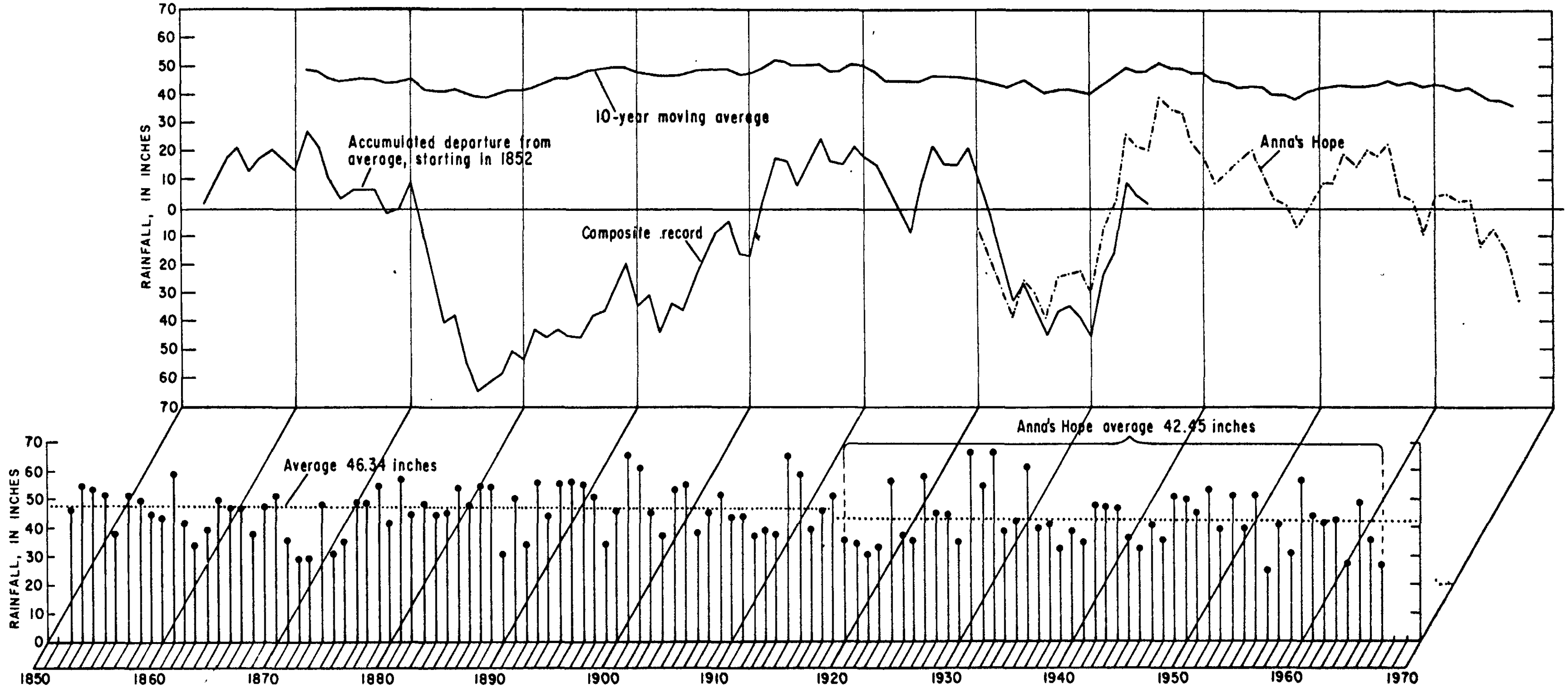
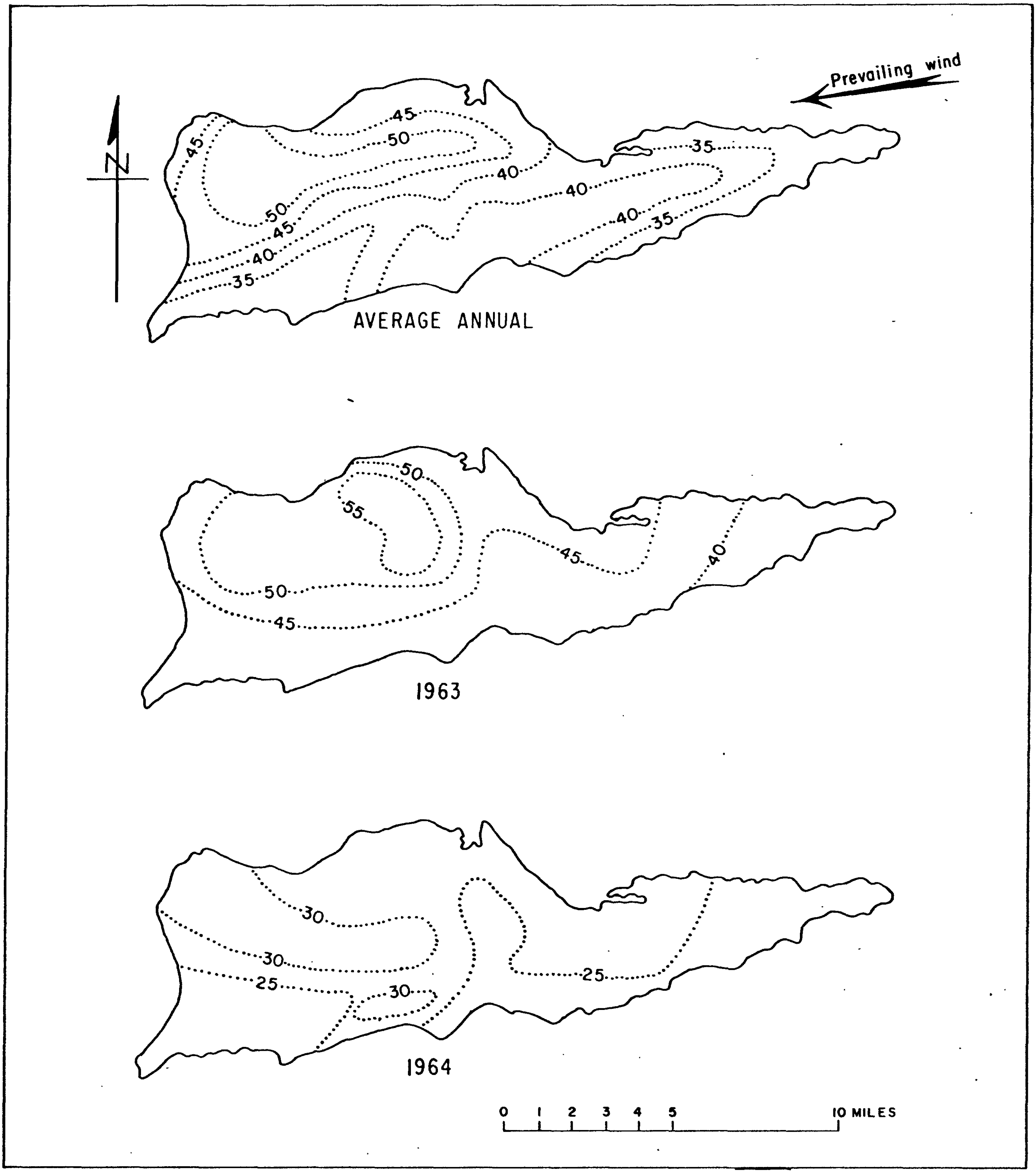


Figure 3.--Ten-year moving average, accumulative departure from average, and annual rainfall, St. Croix, 1852-1967. From composite record of Christiansted, Fredricksted, and Kingshill, 1852-1935 compiled by A. F. Johnson (1936a, b), U.S. Bureau of Reclamantion, and record for 1920-67. [National Weather Service gage at Anna's Hope, 1920-67.]



AVERAGE ANNUAL

1963

1964

Figure 4.--Rainfall distribution in inches on St. Croix for 1963, 1964, and average annual precipitation, 1918-67.

water-bearing properties are described briefly in table 1, and the general geology of the island is shown in figures 5a and 5b (in pocket).

The rocks forming the mountain areas are the Mount Eagle Group (Whetten, 1966) and consists of a wide variety of calcareous, siliceous and tuffaceous rocks primarily of volcanic origin. The area underwent a period of considerable structural movement marked by major faulting, the folding and tilting of the rocks, and the intrusion of two small stocks; gabbro in the Northside Range and diorite in the East End Range. Toward the end of this period, the landmass that would become St. Croix was uplifted above the sea as two islands separated by a trough several miles wide (see inset in fig. 5a).

In the shallow sea along the edges of the trough, coarse- and fine-grained alluvial material from the land mixed with calcareous mud and shallow reef deposits, and these materials are in turn interfingered with the volcanic ash that was deposited in the trough (Whetten, 1966). These sediments formed the Jealousy Formation, now represented at land surface by a calcareous conglomerate, which crops out along the southeastern foot of the Northside Range, and by a dark-gray to blue-green clay in the subsurface locally referred to as the "blue clay." The Jealousy Formation apparently underwent some mild deformation or erosion resulting in a topographic high in the northern part of the trough (fig. 6). The setting for the deposition of the Kingshill Marl, therefore, was a shallow trough between the two islands, partly blocked on the north by the topographic high.

The deposition of the Kingshill Marl probably started with coral debris eroded from a group of isolated reefs to the south of the St. Croix landmass. This debris was swept into the lagoon between the reefs and the two exposed parts of the island. At the same time material eroded from the volcanics of the western part of the island was deposited in the shallow water on the edge of the developing lagoon where it mixed with calcareous mud being formed in the calm water. Streams flowing from the west cut across the mud flats and sand and gravel were deposited in the channels, later to be buried by calcareous mud.

Material eroded from the eastern part of the island was subject to wave action and ocean currents, and much of the fine material was removed. The sand and gravel that remained was mixed with coral sand from the reefs and formed a predominantly calcareous sand blanket in a north-south channel along the eastern end of the lagoon. As the barrier reef to the south continued to grow eastward, this channel gradually closed, and less and less sand was carried into the trough. Because of this change to a fully-formed lagoonal environment, deposition of calcareous mud and limestone became prevalent. The calcareous mud was deposited principally along the southwestern edge of the trough and the limestone in the remainder. Small isolated reefs grew throughout the lagoon and were buried from time to time by mud and limestone. Material eroded from the volcanics continued to be deposited in the lagoon but was disseminated throughout the forming marls and limestones.

A period of mild deformation, uplift, and considerable erosion followed the deposition of the Kingshill Marl, forming the major present-day topographic features. Westward-flowing streams developed on the Kingshill Marl generally following the crests of folds in the rocks (Cederstrom, 1950). Southward-flowing streams also developed on the flanks of the folds. Eventually, headward erosion of the south-flowing streams captured the west-flowing streams with the possible exception of a stream paralleling the foot of the Northside Range.

History of Water Supply

For centuries the principal source of water for the population of St. Croix has been rooftop rain catchments with cisterns, supplemented by wells. Catchments have not always been satisfactory because of droughts and lack of adequate catchment area and cistern storage, and even in times of average rainfall the yield from rooftop catchments is small. Wells generally are reliable, though small, sources of water, but in some parts of the island, ground water is of such poor quality as to be unusable.

The first public water supplies of St. Croix consisted of dug wells, later replaced by drilled

Table 1.--Rocks of St. Croix and their water-bearing properties

Geologic Age	Formation	General Character and Distribution	Water-Bearing Properties
Pleistocene and Holocene	Beach deposits	Unconsolidated calcareous sand; consolidated beach rock in intertidal zones. Occurs irregularly along shore particularly in beaches in embayments.	Have moderate permeability, and are saturated below sea level mostly with brackish water.
Pleistocene and Holocene	Alluvium	Poorly sorted silt, clayey sand and some gravel. Thin beds of sand and gravel usually associated with over-deepened bedrock valleys principally on south coast. Alluvium covers limestone in central part of island. Maximum thickness in valleys over 80 feet; average 20 feet.	Low permeability in silt and clay deposits, but some sand and gravel beds have moderate permeability. Although often yields water slowly to wells, is often major source of water to underlying and adjacent rocks. Water is fresh becoming brackish near shore.
Early Miocene, Late Oligocene	Kingshill Marl	A complex of reef and lagoonal limestone underlies central part of island with reef complex on south coast with limestone and marl lagoonal deposits extending inland. Possible basal calcarenite underlies lagoonal deposits in southeastern part of outcrop area.	Permeability of reef and clastic facies generally moderate to high but irregular. Solution channels and fissures may promote sea-water intrusion along part of south coast. Commonly contains slightly brackish water more salty with depth. Permeability of lagoonal deposits generally low--water even inland usually brackish to saline.
Late Oligocene	Jealousy Formation	Calcareous basal conglomerate cropping out along southern flank of Northside Range and a dark-gray to blue-green clay in subsurface underlying the Kingshill Marl in the central part of the island.	Conglomerate has low permeability--generally contains brackish or saline water. Clay facies is not water bearing but is believed to exert considerable control on water-bearing capabilities and water quality of overlying Kingshill Marl.
Early Tertiary, Late Cretaceous	Fountain Gabbro [1] Southgate Diorite	Well fractured and weathered to depths of 50 feet. Fountain Gabbro in Northside Range; Southgate Diorite in East End Range.	Moderate to low permeability--weathered zones readily accept recharge. Water brackish in coastal parts of Southgate Diorite.
Late Cretaceous	Mount Eagle Group [1]	Tuffaceous sandstone, tuffaceous sandstone-mudstone, calcareous mudstone and siltstone.	Permeability generally low. Porosity of rocks due to open fractures and joints. Water of good quality in central mountains. Brackish in immediate coastal areas and easternmost end of island. Yields generally greatest where alluvial deposits overlie bedrock.

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[1] Geologic names by Whetten (1966) are not approved by the U.S. Geological Survey nomenclature.

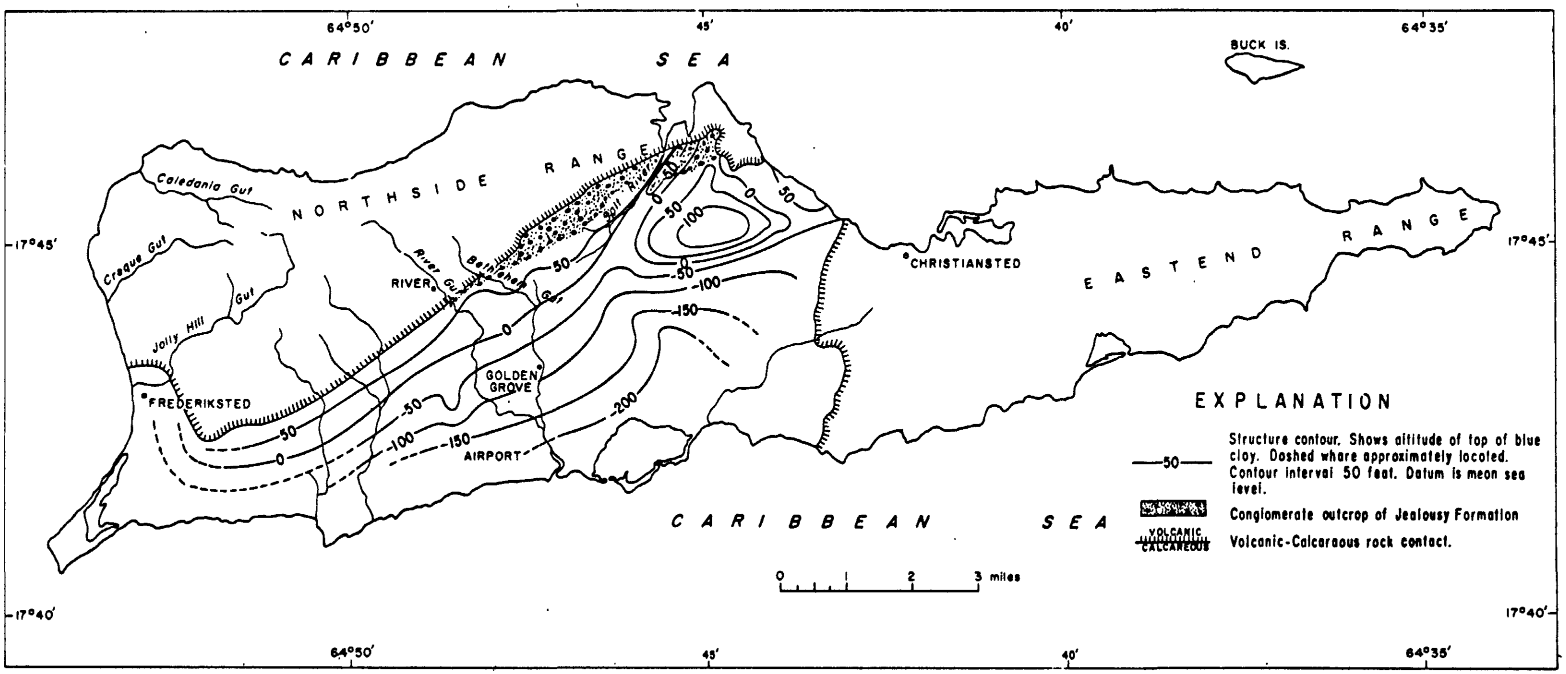


Figure 6.--Altitude of the top of the "blue clay" of the Jealousy Formation.

wells in the communities of the island. Water from wells supplying inland villages generally was and is of fair quality, but water from wells supplying the coastal towns of Frederiksted and Christiansted was brackish with few exceptions.

During the 1920's a small reservoir was constructed on Creque Gut north of Frederiksted to serve the town. The water was not treated and consequently was only used for sanitary purposes. It was not until the 1960's that a small well field developed on Mahogany Road provided the first safe, good quality, public water supply for Frederiksted. Unfortunately, during the 1964 drought, the well field was overpumped and salt-water encroachment occurred. A new well field at Estate Adventure was connected to the Frederiksted system in 1967 but yielded little water because the water table declined during the drought.

About the time the Frederiksted reservoir was being constructed, a rainfall catchment was built for Christiansted, and two other catchments were built in rural areas. In 1949 the Estate Concordia well field was developed to supply Christiansted, and although the water is of poor quality, the well field has provided a safe, dependable supply. During 1965 a well field at Estate Barren Spot was put into production to meet the increasing demands for water by Christiansted. The quality of the water from this well field is also poor.

A well field was developed in the 1940's at Manning to supply U.S. Army facilities at what is now Alexander Hamilton Airport. In the 1950's a well field was developed at Golden Grove to supply water to the sugar factory at Bethlehem. The sugar factory also made use of several of the wells at Manning after the Army facilities were abandoned. In late 1967 the first major privately-developed well field was put into operation south of the Barren Spot well field.

Christiansted and Frederiksted have systems to provide salt water for firefighting and sanitary purposes in order to conserve fresh water. However, only about one-third of the dwellings in Christiansted and none in Frederiksted make use of salt water for sanitary purposes (Public Works Department Survey, 1965).

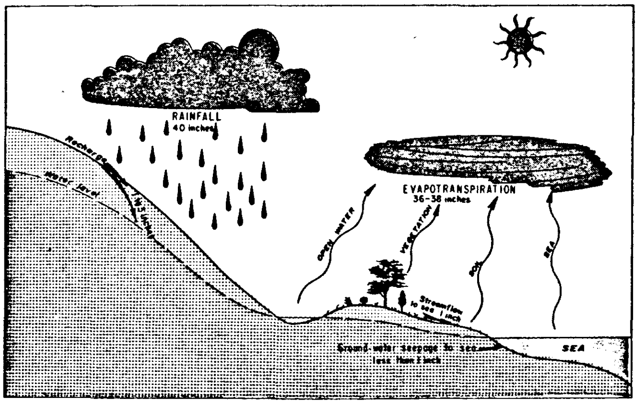
Historical information indicates that the flow in streams of the island have greatly diminished--particularly since the turn of the century. Early maps and histories refer to streams that no longer exist and there are records of streams being used for industrial and minor irrigation supplies. For example, Jolly Hill Gut once furnished water for the sugar factory and irrigation at La Grange, and as recently as the 1920's water from Salt River was pumped to a rum plant at Christiansted. In the 1930's water from River Gut was used to supply water for the sugar factory at Bethlehem. Presently, these streams are dry or at best have short, intermittent reaches with but a trickle of water.

HYDROLOGY

In an average year, about 40 inches of rain falls on St. Croix or about 150 million gallons of water per day. Most of this water returns to the atmosphere by evapotranspiration, part runs off overland and in streams, and part enters the ground-water system. The ground water eventually discharges to streams, directly to the sea, or is evapotranspired. Figure 7 shows this hydrologic cycle as estimated for an average climatological year in St. Croix.

Ground-water recharge in the volcanic terrane is slight, partly because of the low storage capacity of the aquifers. Indications are that most of the rainfall is required to satisfy soil-moisture demands, and so returns to the atmosphere by evapotranspiration. Throughout a large part of the limestone and alluvial terrane of Central St. Croix, water moves rapidly downward through the permeable rock and alluvium and then more slowly to points of discharge at the coast. Much of the water that infiltrates, however, is evaporated or transpired before reaching the sea.

During the waxing and waning of the Pleistocene continental glaciers, the ocean surface fluctuated as much as 120 feet above and 300 feet below present sea level. The south-flowing streams rapidly entrenched their valleys during the lower sea levels to more than 100 feet below present sea level. With rising sea levels the valleys were flooded and aggraded. South-flowing streams



igure 7.--Movement of water through the hydrologic cycle in an average year as estimated for St. Croix.

from the Northside Range carried sediment to the valley paralleling the mountains, building up fan deposits containing sand and gravel at their mouths and depositing finer-grain material in the main valley (fig. 5a). Aggradation of what is now the lower River Gut drainage probably was slight until the valley parallel to the foot of the mountains was filled with sediment. Once this valley was filled, the alluvium spread out from the foot of the mountains and the present-day drainage was established. It probably was not until this time that the overdeepened valleys of the River Gut drainage were filled with alluvium derived from the mountains and to some extent from the adjacent limestone hills.

The overdeepened south-flowing valleys through Barren Spot and Jerusalem were slowly filled with alluvium derived principally from the surrounding limestone hills. Beds of volcanic rock-derived sand and gravel found in the alluvium of the valleys are stream-channel deposits derived from the erosion of the volcanic rocks of the eastern hills and of the Kingshill Marl, which has sand and pebbles of volcanic rock disseminated through it.

Surface Water

The four most important streams on the island originate in the mountains of the Northside Range and flow intermittently. Other water courses carry storm runoff two or three times a year for a short time following heavy rainstorms. Streamflow seldom reaches the sea and even storm runoff usually infiltrates the alluvial-filled valleys in the lowlands.

In the mountains, streams follow steep, boulder-strewn channels through narrow valleys with sharply rising flanks. Near the sea the larger valleys broaden and gradients are gentler; the stream channels meander slightly and are incised a few feet into the alluvium.

In the central part of the island, upland valleys underlain by limestone and marl are "U-shaped" with moderate gradients and often are filled with a thin mantle of alluvim. In the lowland these valleys join and become broad, flat plains separated by limestone ridges. The streams in the uplands are incised from a few inches to a few feet in the bedrock or the alluvium. In the broad valleys of the lowland, the stream channels disappear. Only streams that originate in the volcanic mountains have natural channels that are discernable across the lowlands.

Investigations indicate that River Gut, Bethlehem Gut, Jolly Hill Gut, Creque Gut, Salt River and other streams flowed considerably more in the distant and recent past than at present. Only 40 or 50 years ago, they were perennial streams heading in the mountains and discharging to the sea.

The River Gut system, including Bethlehem Gut and Adventure Gut, comprises about 11 square miles. River Gut rises in the Northside Range where it has eroded a broad valley in the gabbro intrusion (fig. 5a). As the stream leaves the upper basin it crosses a sill of volcanic rocks and flows over alluvium overlying calcareous conglomerate and limestone or marl. About 2.5 miles about the mouth of the stream, the valley becomes sharply defined by limestone ridges and the valley flat narrows from nearly 0.6 mile to about 0.1 mile from sea. At this point the stream cuts through a limestone ridge and crosses a half-mile-wide alluviated coastal plain to sea. Four farm ponds with a total storage capacity of 48 million gallons are located on the stream. Water was diverted from the stream in the 1930's for use at the Bethlehem Sugar Factory.

Bethlehem Gut drains about 4 square miles and also heads in the gabbro intrusive. Like River Gut it flows across alluvium underlain by marl and limestone. About a mile above its junction with River Gut, Bethlehem Gut enters an alluviated valley, 0.2 mile wide, bound by limestone ridges. Bethlehem Gut flows intermittently for a few months of the year in the rainy season. Chimney Bush Reservoir, located on Bethlehem Gut, has a capacity of about 21 million gallons. Leakage from the reservoir contributes to the flow of the stream particularly when the water level is high. Water from the reservoir was once used at the sugar factory at Bethlehem and effluent from the factory was returned to Bethlehem Gut below the reservoir.

Adventure Gut, another tributary to River Gut, draining about 2 square miles, heads in the volcanic sandstone and tuff on the south slope of the Northside Range. Adventure Gut occasionally carries storm runoff. Three farm ponds with a total capacity of 3 million gallons are located on the alluvium. In 1962-63 water from the ponds was used to irrigate citrus seedlings.

Jolly Hill Gut drains about 4.5 square miles and reportedly was once a perennial stream, which flowed from its headwaters in the Northside Range to a fresh-water pond on the north edge of Frederiksted and then to sea. Flow was diverted for irrigation and the sugar factory at Estate La Grange as late as the 1920's. The present-day stream usually flows only in a short reach in the vicinity of Jolly Hill. It is estimated that a maximum of 15,000 gpd (gallons per day) is diverted from the stream for irrigation of truck crops when water is flowing. Estimates of total quantities of water diverted from Jolly Hill Gut for irrigation annually from 1963-67 are as follows:

Year	Diversion, in million gallons
1963	5.2
1964	1.2
1965	3.5
1966	2.2
1967	.1

The 1-square-mile Creque Gut basin is predominantly grass covered--about 80 percent of the basin is used for pasture. Mt. Washington Reservoir was built on Creque Gut in the late 1920's to supply water to Frederiksted. The reservoir is now used to supply water to cattle on a few estates between the reservoir and Frederiksted. Originally, the reservoir had an estimated capacity of about 10 million gallons but the capacity has been reduced by about one-third by the accumulation of sediment.

Caledonia Gut has a few pools that hold water throughout the year, and usually flows in short reaches in its upper basin. This gut has a drainage area of about 1 square mile, entirely in the mountains, which is marked by steep slopes covered by second-growth forest and brush.

Salt River, which drains a basin of about 4 square miles, once flowed perennially from headwaters to sea. Water was pumped from the stream to a rum distillery in Christiansted in the 1920's, but in the early 1930's, the perennial flow ceased. At present the upper reach of stream in the Northside Range occasionally carries storm runoff. Invariably, this flow either is retained by a small farm pond at the head of the alluvial valley or infiltrates the alluvium a short distance farther downstream.

A total of about 100 small ponds and reservoirs with a storage capacity of about 300 million gallons have been constructed on St. Croix, in addition to those described previously. Most of the ponds are used for watering stock. Three others help supply a rum distillery at Estate Diamond and two ponds at Estate Fountain are used for irrigation of a golf course.

Runoff Characteristics

Streamflow was recorded at four gaging stations and discharge was also measured periodically at other sites for purposes of the study. Data are shown in an open-file report (Robison, 1972). Figure 5a shows the location of all these sites and table 2 summarizes flow information at the gaging stations. Rainfall in 1962 and 1963 was close to average (figs. 3 and 4) and, therefore, streamflow probably reflected near-average conditions when records were collected in 1963.

Table 2.--Summary of streamflow at gaging stations, 1963-67

Station number	Gaging station	Year	Rainfall, in inches	Discharge								Maximum flow recorded			
				Total annual		Minimum daily		Average daily		Maximum daily		Date	Discharge		Gage height, in feet
				Millions of gallons	Inches of runoff	Millions of gallons	Cubic feet per second	Millions of gallons	Cubic feet per second	Millions of gallons	Cubic feet per second		Millions of gallons	Cubic feet per second	
3320	River Gut at River (Drainage area, 1.42 sq mi)	1963	52.1	[illegible]5.8	3.5	0.035	0.05	0.235	0.36	9.84	15.2	05/18	109	169	3.39
		64	27.2	15.6	.6	.004	.01	.043	.06	.16	.25	'09/22	1.36	2.1	1.53
		65	47.7	17.8	.7	.004	.01	.049	.08	2.63	4.07	05/24	7.61	11.8	1.94
		66	32.8	5.4	.2	0	0	.015	.02	.10	.15	10/14	4.11	6.4	1.77
		67	33.6	1.4	.06	0	0	.004	.01	.029	.04	06/20	8.57	13.3	1.98
3330	River Gut at Golden Grove (Drainage area, 5.16 sq mi)	1963	55.4	392	4.4	0.025	0.04	1.07	1.66	78.5	121	05/18	304	470	9.03
		64	34.8	5.9	.07	0	0	.016	.02	.13	.20	01/23	.19	.3	1.82
		65	49.3	14.2	.16	0	0	.039	.06	6.77	10.5	05/24	9.88	15.3	2.62
		66	27.5	0	0	0	0	0	0	0	0	--	0	0	0
		67	35.2	.9	.01	0	0	.002	.003	.91	1.41	10/31	11.1	17.2	2.67
3450	Jolly Hill Gut at Jolly Hill (Drainage area, 2.10 sq mi)	1963	47.1	22.5 1/	0.62 1/	0	0	0.062	0.10	5.64	8.73	01/04	128	198	3.04
		64	32.2	2.1 1/	.06 1/	0	0	.006	.01	.01	.02	01/20	.01	.02	.44
		65	51.3	8.1 1/	.22 1/	0	0	.022	.03	2.56	3.96	12/12	143	221	3.15
		66	40.6	9.0 1/	.25 1/	0	0	.025	.04	2.34	3.62	10/14	19.2	29.7	2.40
		67	35.1	.2 1/	0.01 1/	0	0	.001	.002	.05	.08	11/20	1.46	2.3	1.13
3470	Creque Gut above Mt. Washington Reservoir (Drainage area, 0.50 sq mi)	1963	54.3	43.3 2/	5.0 2/	--	--	.119	.18	--	--	--	--	--	--
		64	34.4	8.0 2/	.92 2/	--	--	.022	.03	--	--	--	--	--	--
		65	57.0	28.0	3.2	0	0	0.077	0.12	2.96	4.58	12/11	99.4	154	3.77
		66	43.3	16.0	1.8	.001	.002	.044	.07	1.03	1.59	10/14	59.1	91.4	3.30
		67	35.9	1.3	.15	0	0	.004	.01	.28	.43	10/10	16.5	25.5	2,59

1/ Adjusted for diversions.

2/ Estimated.

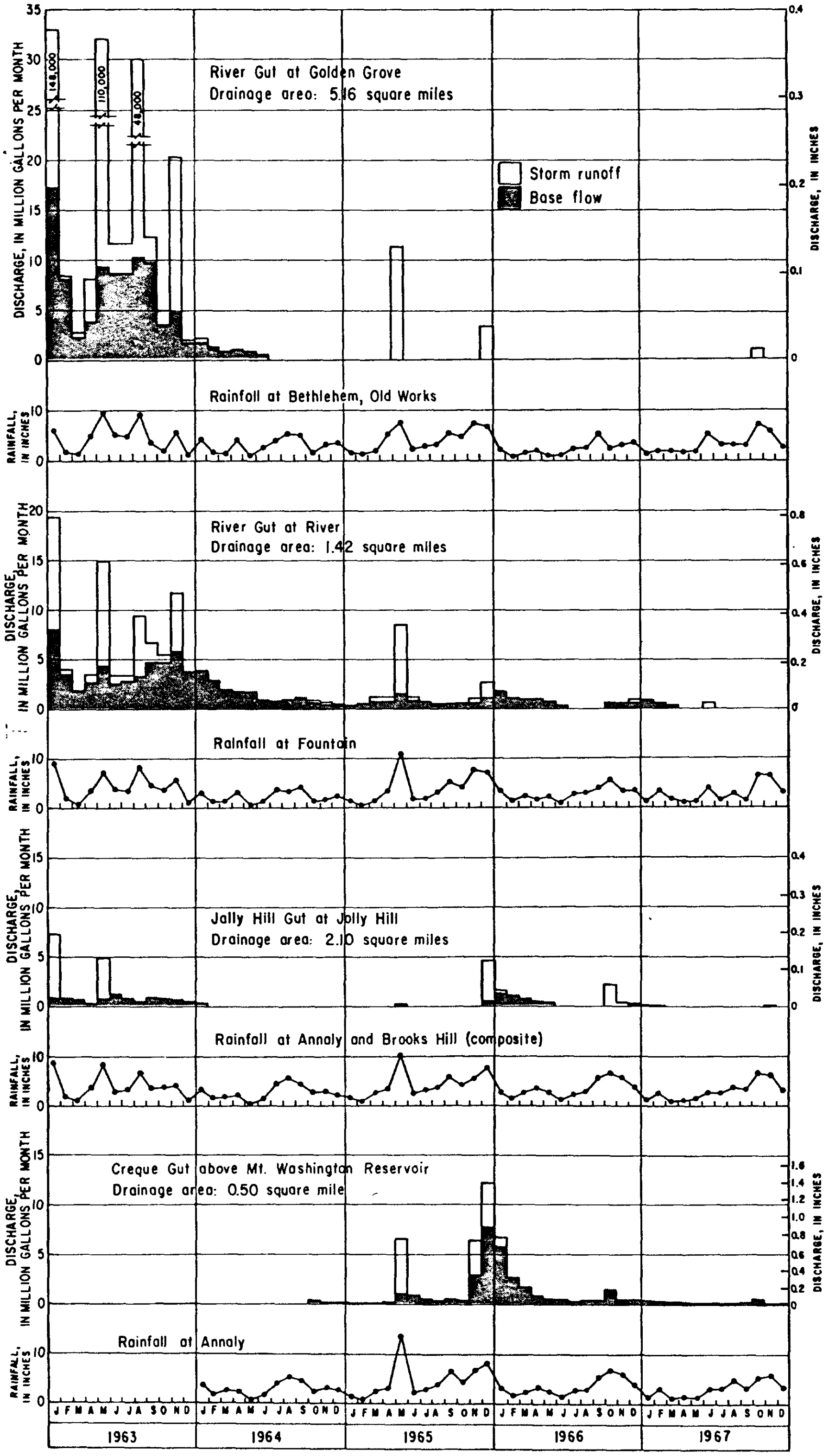


Figure 8.--Monthly streamflow at gaging stations and rainfall at U.S. National Weather Service gages. [See figure 5 (in pocket) for site locations.]

A drought began in 1964 and, although rainfall was above average in 1965, continued through 1967. In general, streamflow responded in a somewhat similar pattern; a sharp decrease in 1964, followed by a slight recovery in 1965 and then a marked decline to low flows that persisted throughout 1967.

The bar graphs in figure 8 show the monthly rainfall and runoff of the major streams heading in the Northside Range. Monthly runoff seldom exceeds 10 percent of rainfall except when there is a major storm or when there is carryover from the previous month. The bar graphs indicate that a monthly rainfall of 4 to 5 inches is necessary to prevent flow from declining significantly. If several months elapse with less rainfall, then several months with rainfall in excess of that amount are required for flow to recover. This can be noted in the latter part of 1965, as shown on the graphs.

In 1963, discharge at River Gut at River was about 7 percent of rainfall and at Jolly Hill Gut at Jolly Hill, about 1.3 percent. Estimated discharge at the Creque Gut gage in 1963 was about 9 percent. From 1964 to 1967, the ratio of discharge to rainfall of all streams was even less.

Storm runoff is usually a major part of streamflow. The rainstorms that produce runoff generally are short but of high intensity. Drainage basins are small and steep; runoff usually peaks within a few hours after the start of a storm, recedes rapidly, and seldom takes more than a day or two to return to previous low flow, as shown in the stage hydrograph in figure 9. For example, in 1963 seven days of storm runoff produced a total flow of 33 million gallons at River Gut at River and 250 million gallons at River Gut at Golden Grove, 39 and 64 percent respectively of the flow for the year. Four days of storm runoff in 1963 produced a total of 10 million gallons of flow at the Jolly Hill Gut gage, 44 percent of the year's flow.

Storm runoff seldom exceeds 5 percent of the rainfall on a basin during a storm. The two peaks on Jolly Hill Gut shown in figure 9 accounted for only 0.4 and 6 percent, respectively, of the rain from the storms. The maximum storm runoff from

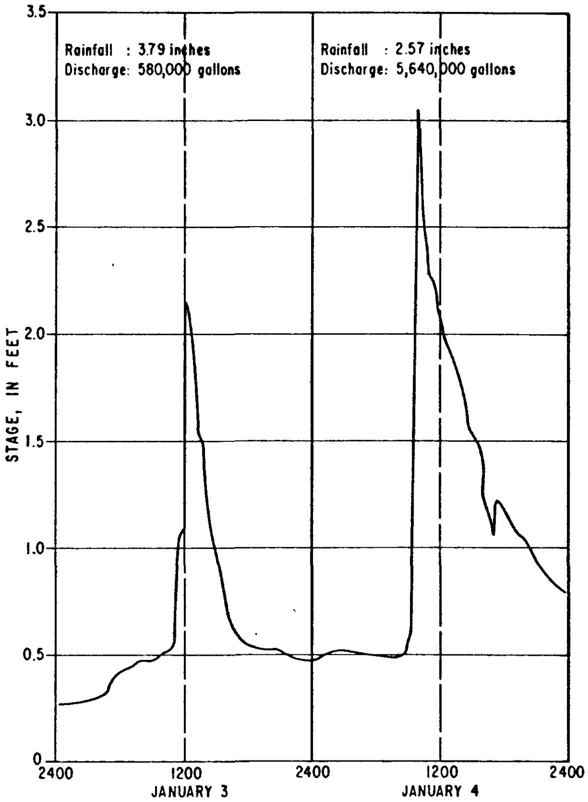


Figure 9.--Stage hydrograph of storm runoff, Jolly Hill Gut, January 3-4, 1963.

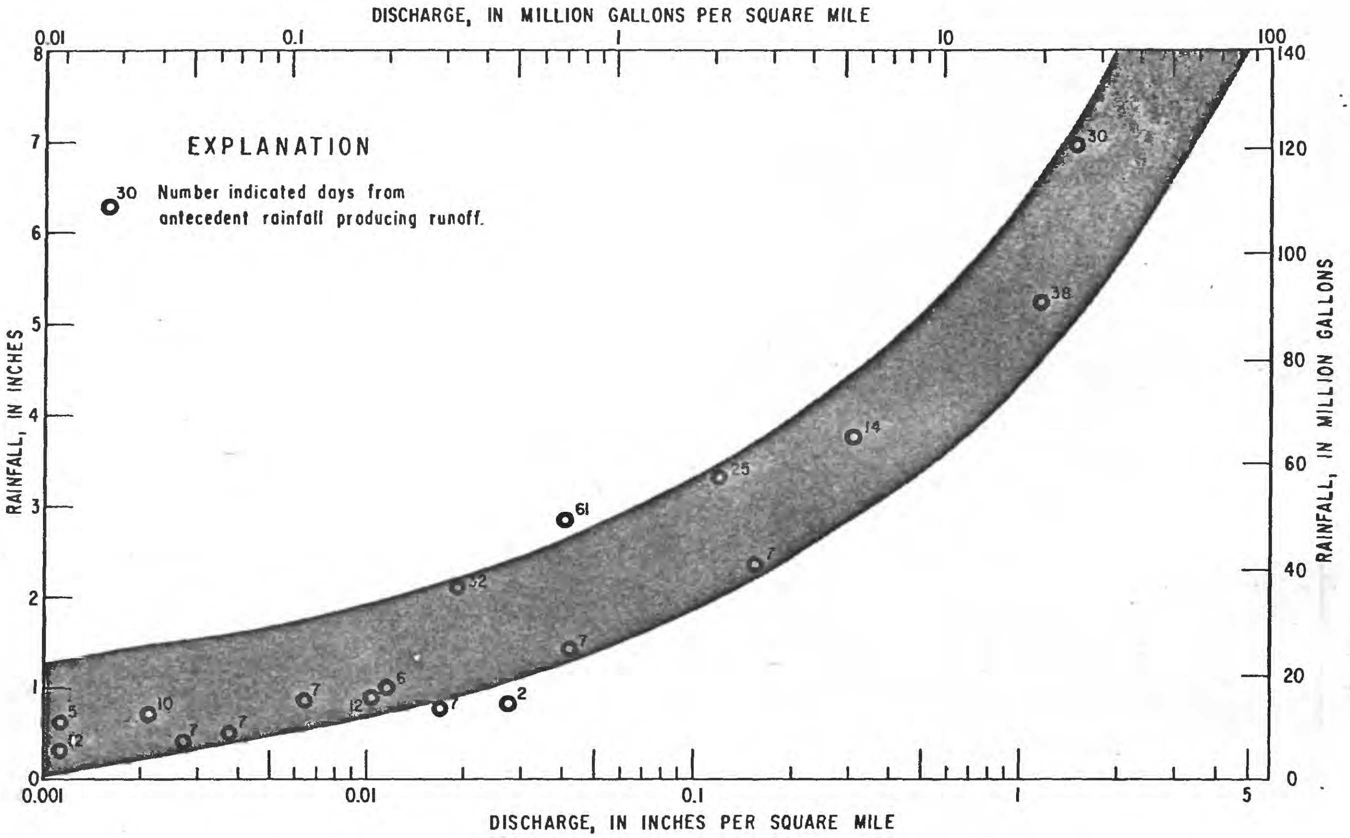


Figure 10.--Rainfall-storm runoff relationship of River Gut at Golden Grove.

1963 to 1967, 20 percent, was recorded twice at River Gut at Golden Grove, and resulted from one rain of 5 inches and another of 7 inches.

Characteristics of the soil and the type and density of vegetation are factors that affect runoff. The soil that mantles the island has a high moisture demand; when dry, it is jointed and granulated and, therefore, highly permeable. When saturated, the joints and openings squeeze tight and the soil becomes much less permeable, but it retains large quantities of water. The Soil Conservation Service (R. Scott, oral commun., 1964) estimates that in St. Croix water will infiltrate dry soil at a rate of 2 inches per hour and that the storage capacity is 3 inches of water per foot of thickness. These characteristics reduce runoff from rainfall and, although the aquifers are recharged somewhat, the greater part of the water held by the soil is returned to the atmosphere by evapotranspiration.

Rainfall is seldom sufficient to saturate the soil enough so that a large proportion of water runs off, and antecedent soil-moisture conditions cause the amount of runoff to vary considerably from storm to storm. For example, when the soil is wet, half an inch of rain can produce runoff. If no rain has fallen for 20 or 30 days, nearly 2 inches may be required before runoff will occur. The effect of antecedent moisture conditions on storm runoff at River Gut at Golden Grove is shown in figure 10. As much as 3 inches of rain has fallen during 24 hours without recharging the ground-water reservoir or producing significant runoff--the rain served little but to replenish soil moisture.

Vegetation can severely deplete water in the soil zone and water held by capillary action in underlying materials. The effective zone of influence of the roots of crops and grasses may be about 6 feet below land surface. Brush and trees, however, may have root zones extending 20 feet deep or more and may intercept water from greater depths because of capillary action. For example, in a pit dug at Cinnamon Bay, St. John, a thick mat of tree roots was observed at the top of the water table, 20 feet below ground. Vegetation probably intercepts a considerable part of the water that moves through the ground. Even shallow-rooted plants can tap ground water as it nears the surface, prior to discharging to seeps, streams, or sea.

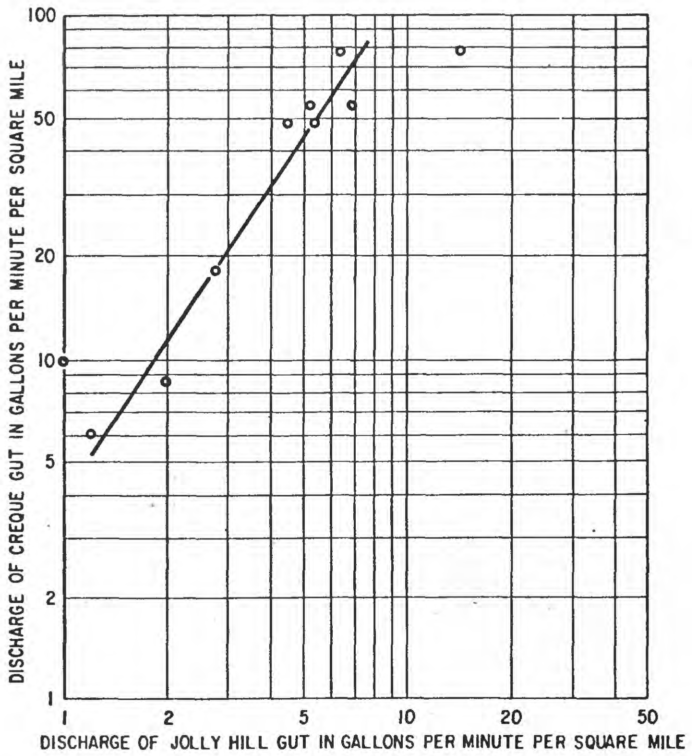


Figure 11.--Relation of base flow in Creque Gut to that in Jolly Hill Gut on selected days during 1963.

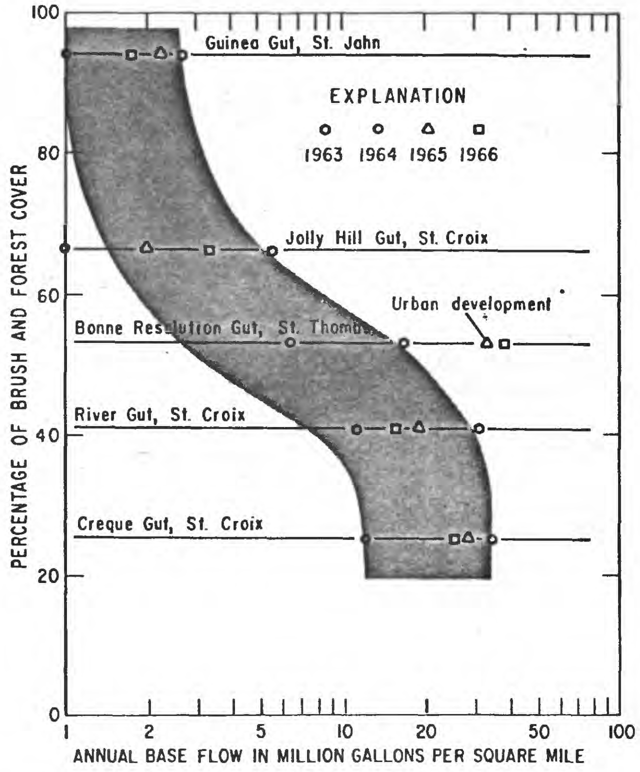


Figure 12.--Relation of annual base flow and percentage of brush and forest cover in major stream basins. [Base flow obtained from separation of discharge hydrograph.]

Not only does vegetation return water to the atmosphere by transpiration but the leafy canopy above ground intercepts considerable rain. In heavily forested mountain areas, vegetation appears to retain rain, as much as one-quarter of an inch on the foliage in a day's time.

Figure 11 compares base flow of Creque Gut and Jolly Hill Gut, where the former has about eight times the flow of the latter per unit area. The only major geohydrologic difference between the basins is the amount of forest and brush cover. Selective reduction of forest and brush in the Jolly Hill Gut basin from the present 65 percent to 40 percent, particularly along the stream channel, theoretically could increase annual base flow from about 16 to 130 million gallons. It is estimated that in part of Bonne Resolution Gut basin, St. Thomas, the quantity of water intercepted by trees and brush exceeds 1 million gallons per acre annually (Jordan, Cosner, 1973). The effect of brush and forest cover on the base flow of Virgin Island streams is shown in figure 12.

It seems from these sparse data that base flow declines most appreciably once brush and forest occupy from 40 to 60 percent of basin area. More comprehensive analysis including evaluation of the effects of basin altitude and orientation, geology, type of cover other than forest and brush, and rainfall distribution is beyond the scope of this study.

Duration of Streamflow

Duration curves of streamflow show the percentage of time within a given period for which any particular discharge was equaled or exceeded. The shape and slope of a duration curve indicate hydrologic conditions in the drainage basin. A steep slope indicates a stream mostly supplied by overland runoff, whereas a flat slope shows the effect of sustained releases from surface- or ground-water storage. A change in slope may be caused by drought, the draining of an aquifer, changes in land use or vegetation, or by variations in water use or management, among other factors.

In general, the duration curves for streams in northwestern St. Croix are characterized by steep slopes at high and medium flows. At low flows, the curves reveal variations in basin characteristics. Figure 13 shows duration curves for River Gut and Jolly Hill Gut in 1963. The curve for River Gut at River reflects sustained ground-water discharge from the sandy alluvium and weathered gabbro aquifer. River Gut at Golden Grove probably had a more rapid low-flow recession because some streamflow infiltrated the alluvium of the lower basin and because of increased transpiration by the dense vegetation bordering the stream channel. Jolly Hill Gut basin is underlain by fine-grained indurated volcanic rocks of low permeability and is extensively covered by dense vegetation. Ground-water storage is estimated to be less per unit area than in the nearby upper basin of River Gut, but total storage is probably similar. However, the lower storage per unit area in conjunction with a large evapotranspiration rate results in rapid recession of stream discharge. The flow may decline to, or near, zero even during short dry spells.

Figure 14 shows duration curves for River and Jolly Hill Guts from 1963-67 and for Creque Gut from 1965-67. The curves for River Gut and Jolly Hill Gut show that there was little or no flow much of the time, as the result of the drought that began in 1964. Starting in 1965, River Gut was also affected by the highly increased use of surface and ground water from the basin, principally for irrigation of a golf course; it is estimated by the author that average streamflow may have been reduced by as much as 120,000 gpd. The Creque Gut basin is underlain by rocks like those in the Jolly Hill Gut basin--low permeability with small capacity for storage of ground water. Creque Gut had a larger sustained low flow, probably because almost 80 percent of the basin is covered by grass and, therefore, transpiration was much less than in the Jolly Hill Gut basin.

Low flow can vary considerably from place to place along a stream. Many times flow in an upstream reach infiltrates the alluvium of the streambed or is returned to the atmosphere by evapotranspiration so that discharge declines to zero. Flow in River Gut, for example, varies in response to antecedent rainfall conditions, altitude of the water table with respect to the stream channel, geology, evapotranspiration, and water use. Figure 15 shows that base-flow regimen

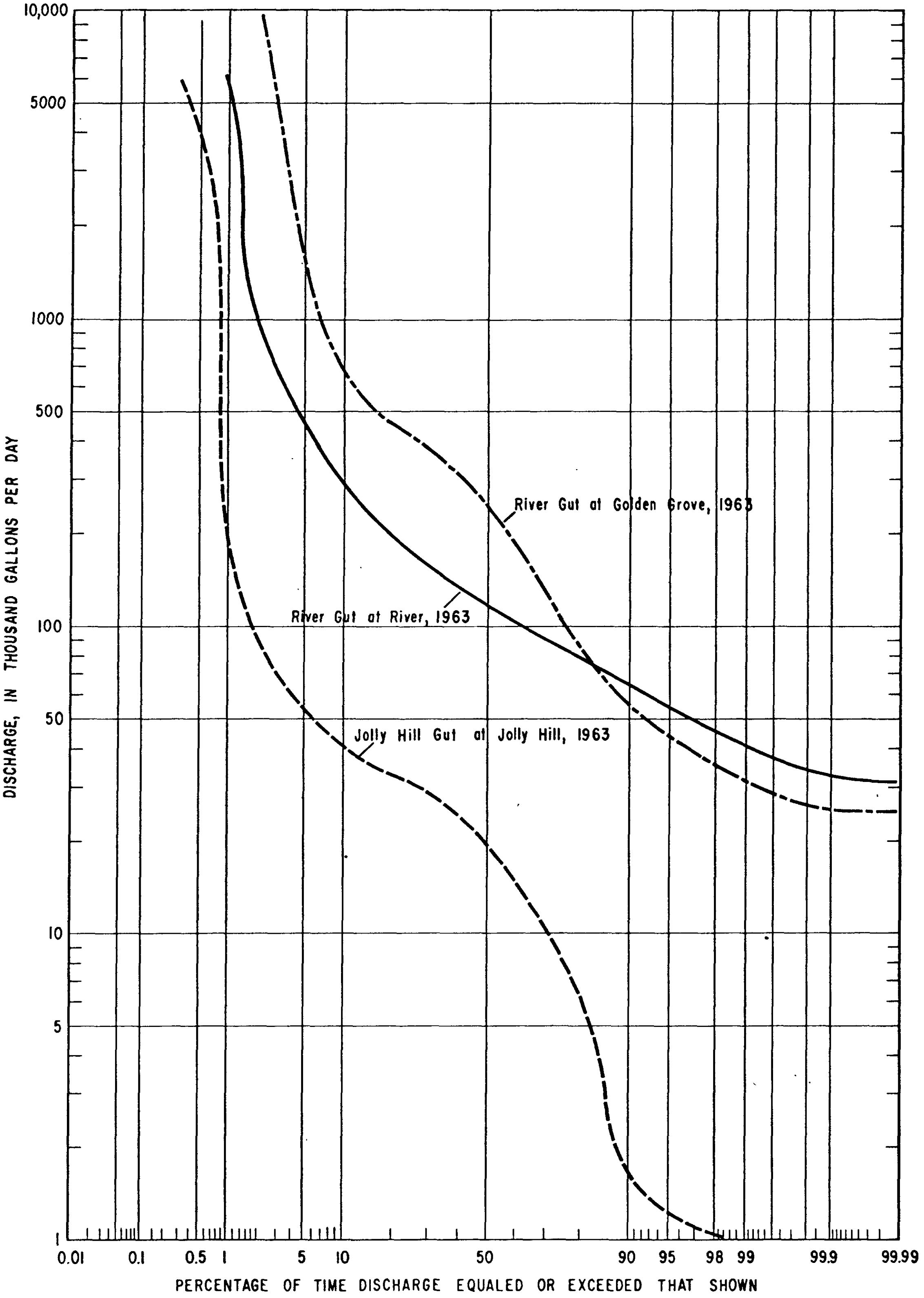


Figure 13.--Duration curves of daily flow in River Gut and Jolly Hill Gut, 1963.

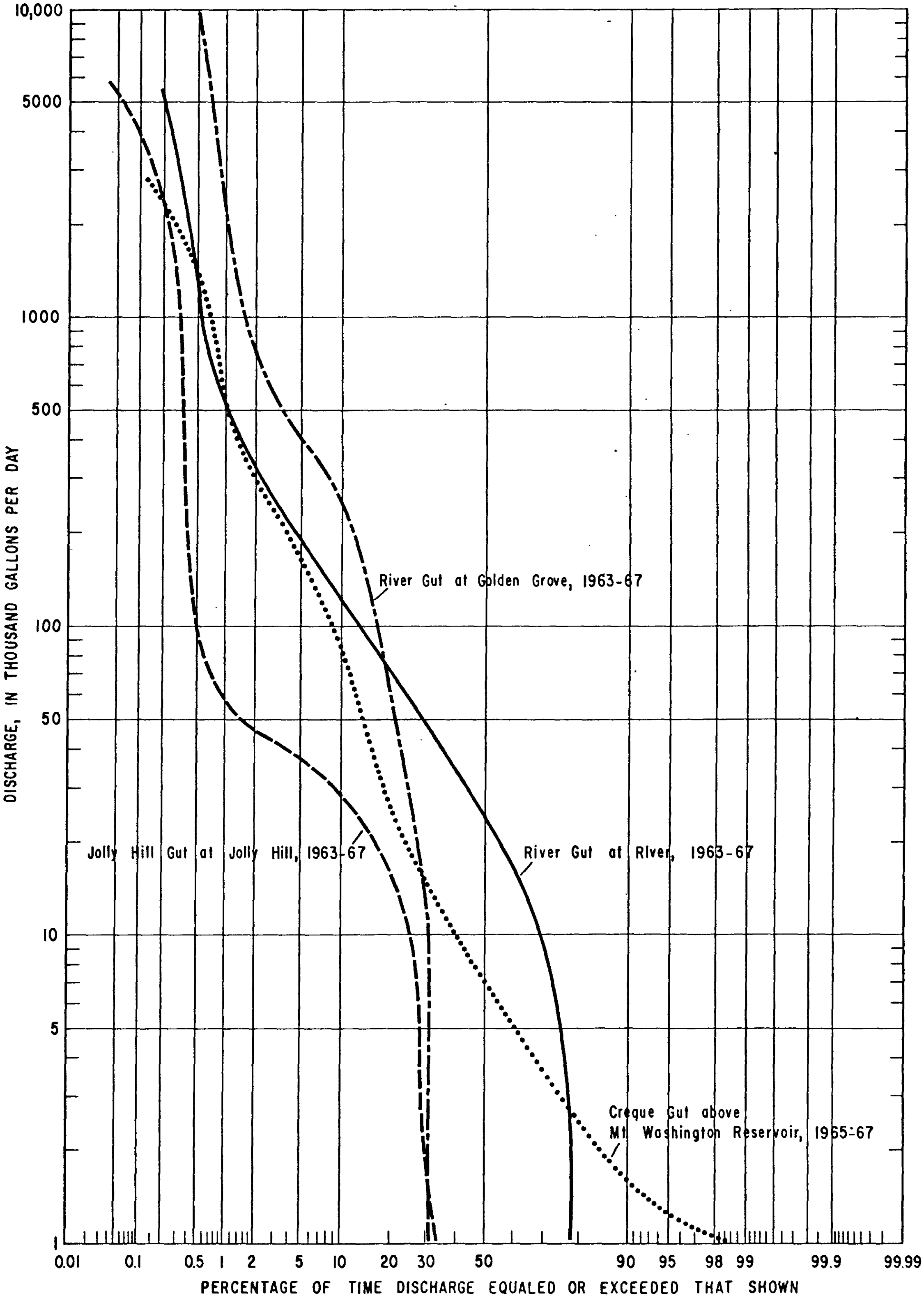


Figure 14.--Duration curves of daily flow in River Gut and Jolly Hill Gut, 1963-67 and Creque Gut, 1965-67.

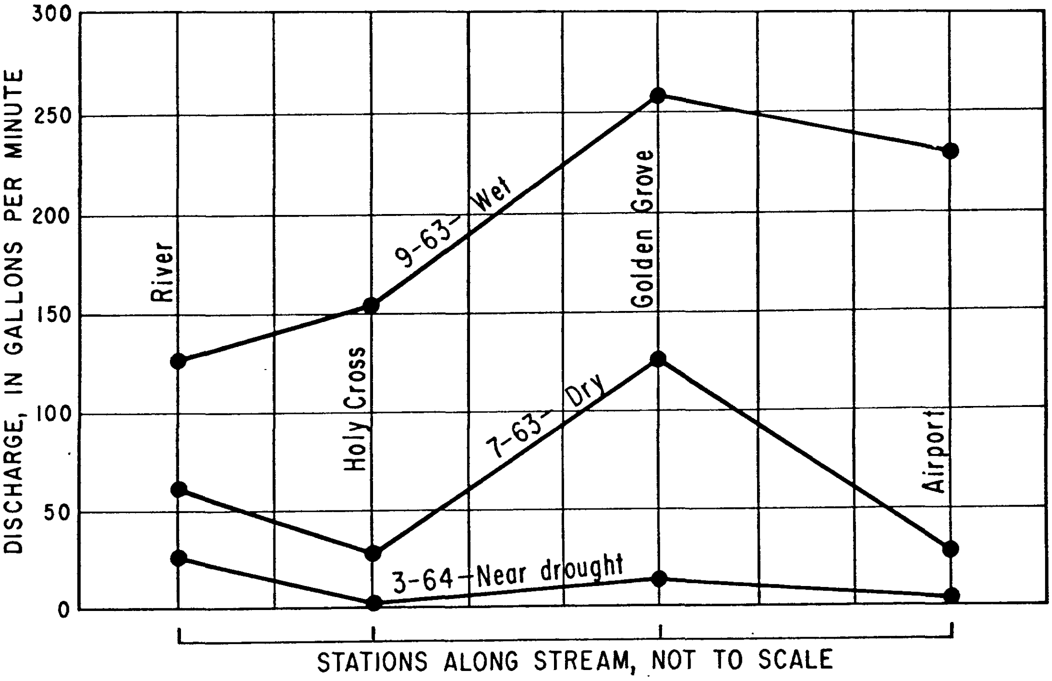


Figure 15.--Examples of base flow regimen of River Gut, 1963-64.

may be characterized by three types of climatic conditions--wet, dry, and drought. During wet periods, base flow gains slightly between River and Holy Cross Church, gains significantly from Holy Cross Church to Golden Grove, and declines between Golden Grove and the airport. In dry periods, flow declines between River and Holy Cross Church and declines more sharply between Golden Grove and the airport. Flow during drought declines without recovery from River to the airport.

Decreases in flow upstream from Holy Cross Church during dry periods and droughts are attributed to evapotranspiration from several acres of swamp. The swamp lies on the Jealousy Formation, which has very low permeability, so leakage is believed by the author to be small. In addition, chemical analyses of water taken from River Gut during dry periods indicates contribution of water to the stream from the Jealousy Formation. In wet periods, evapotranspiration from the swamp is more than offset by increased ground-water discharge to base flow upstream.

Ground-water discharges to River Gut from the thin alluvium between Holy Cross Church and Centerline Road, but frequent replenishment of the aquifer is necessary to maintain base flow. In the 1964 drought, studies revealed that this alluvial aquifer, without replenishment, contributed a total of about 10 million gallons to base flow in ever-diminishing quantities during a 6-month period. From Centerline Road to the tidal estuary at the airport, River Gut loses flow to the alluvium almost continuously.

Ground Water

St. Croix has three major ground-water provinces, corresponding in general to the geologic characteristics described previously. In the northwestern and eastern parts of the island most of the ground water is found in the Mount Eagle Group of epiclastic and pyroclastic volcanic rocks and associated intrusive rocks. Between these two provinces, in the central and southwestern parts, ground water is generally found in the Kingshill Marl composed of calcareous rocks--limestone, sandstone, and marl. The Jealousy Formation, a conglomerate in outcrop and an impermeable blue clay in the subsurface, underlies the Kingshill Marl. Alluvial valley fill is associated with all three provinces. Large alluvial deposits are found only in the valleys of Central St. Croix, but small deposits of local significance are scattered throughout the island. These small deposits yield little water directly to wells; they principally serve as sinks through which recharge from rainfall and streamflow can reach the underlying rock aquifers.

Figures 5a and 5b show the distribution of these materials and table 1 briefly describes them and their water-bearing properties.

The hydrologic properties of the volcanic and associated intrusive rocks are similar. The principal water-bearing zone can be visualized as a mantle 200 to 300 feet thick following the general topographic relief. Compaction and cementation have eliminated much of the original porosity of these rocks and ground water is largely confined to openings formed by fractures and joints and by chemical weathering. The water-bearing and yielding capabilities, therefore, depend on the extent of the interconnection of the openings. Valleys are often expressions of fracturing and jointing or of unusual susceptibility of chemical weathering and so are areas of potentially good ground-water yield. Because of the low permeability of the volcanic terrane, the water table has a high relief, standing hundreds of feet above sea level in the mountains and sloping steeply toward the valleys and coastal lowlands. Ground water in the volcanic rocks funnels through the valleys to discharge to sea, to other water-bearing rocks, or to streams.

The intrusive plugs associated with the volcanic rocks are thoroughly weathered to depths of as much as 50 feet; below this layer the rock is weathered along fractures and joints to depths of at least 150 feet. The upper part of the weathered zone is very friable and contains a large amount of granular material.

Few wells have been drilled in the volcanic areas because of generally low yield and, until recently (1960), the lack of suitable drilling equipment. Specific capacity of wells penetrating water-bearing zones is usually about 0.2 gpm (gallons per minute) per foot of drawdown, and ranges from less than 0.1 to 5. Wells having the greater specific capacities are rare and are usually located in the lower ends of valleys where saturated alluvium overlies the bedrock.

In the central ground-water province the hydrologic properties of the Kingshill Marl are closely associated with those of alluvial deposits, which mantle large areas and fill the valleys. A thin rocky soil has developed in the hills and upland areas not mantled by alluvium. Figure 16 shows the general distribution of the water-bearing rocks in this province. The ground-water level ranges from more than 100 feet above sea level in the upland limestone areas to less than 10 feet in a band about a mile wide along the south coast.

The water-bearing properties of the Kingshill Marl vary widely. The marl is relatively soft and plastic. Joints are tight and infrequent permeable zones are generally localized in beds of limestone or sand and gravel. Well yields are seldom more than a few hundred gallons per day. Where limestone beds form a large part of these sections, permeability is greater. Wells may yield as much as 5 to 10 gpm with specific capacities of about 0.5 gpm per foot of drawdown. The reef-associated limestone and calcarenite have the greatest permeability in this province. Yield of wells from these rocks ranges from 10 to 300 gpm with specific capacity from about 0.5 to 50 gpm per foot of drawdown.

Alluvium, filling valleys and forming alluvial plains, is composed predominantly of clay, silt, and fine sand. These deposits serve principally as sinks and temporary storage zones through which recharge from rainfall and streamflow can reach the underlying rock aquifers. Significant beds of sand and gravel are found locally, such as in the valleys of Salt River, Barren Spot, and the River Gut system (figs. 5a, 5b). Wells tapping these sand and gravel beds have yields ranging from 10 to 50 gpm, with specific capacities up to 10 gpm per foot of drawdown.

The Fresh-Water Lens

In an island aquifer, fresh water accumulates as a lens that floats on and displaces the slightly heavier sea water in the aquifer below sea level. Its basic shape is convex downward, extending

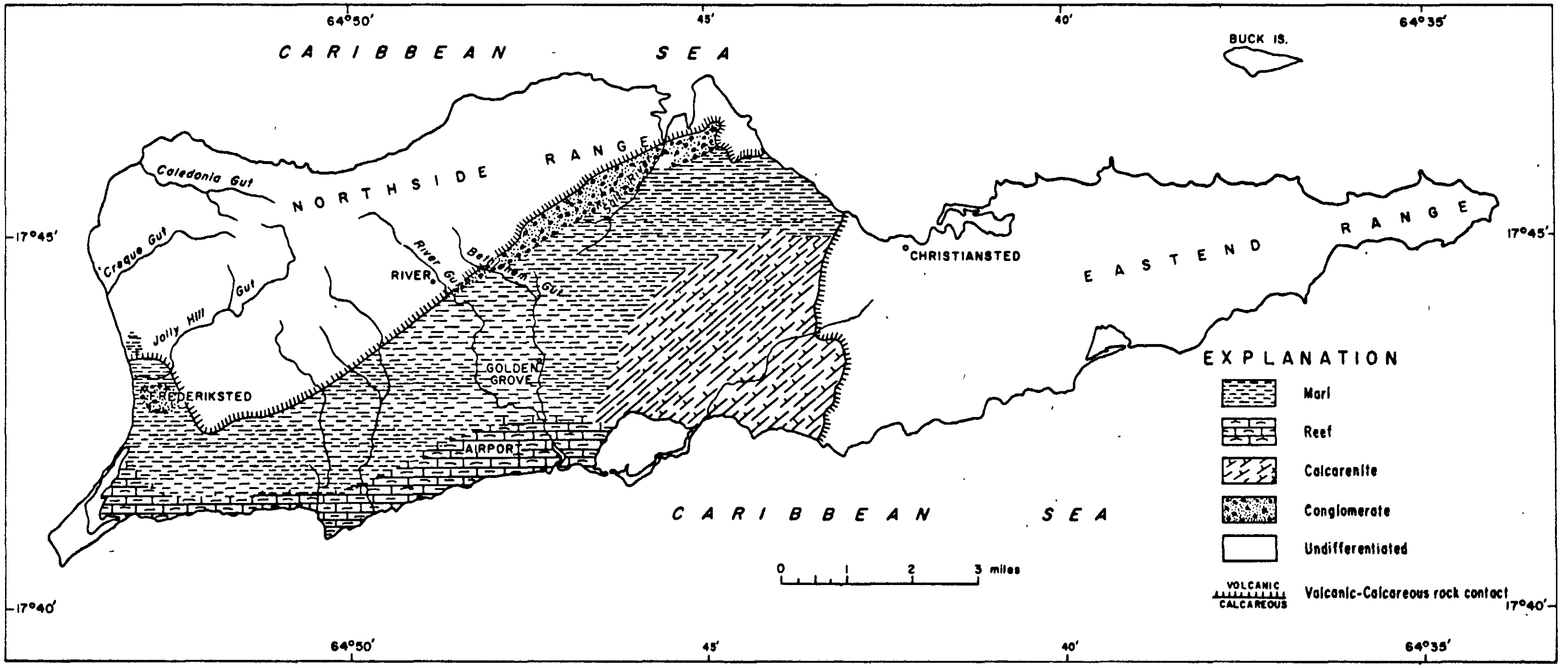


Figure 16.--Dominant lithology of water-bearing zones in the Kingshill Marl.

inland approximately from the shoreline. On St. Croix the shape of the lens is modified in that it is terminated in the subsurface by the impermeable blue clay in Central St. Croix and the decreasing permeability of the volcanic rocks on the remainder of the island.

The lens is a dynamic system through which water is constantly in motion from areas of recharge to areas of discharge. Fluctuations in recharge, discharge, and sea level cause oscillatory movements in the fresh-salt water interface creating a mixing or transition zone between fresh and salt water that becomes more saline downward and seaward.

Development of an island aquifer must take into consideration the position and potential fluctuations of the fresh-water lens imposed by stresses due to development.

Water Levels

Figure 17 (in pocket) shows the approximate configuration of the ground-water surface in the spring of 1962 for areas where sufficient data are available. In the mountains sparse data indicate that the water surface generally is a subdued expression of the topography. At the base of the mountains and in the large mountain valleys, the water surface usually is within 50 feet of the land surface but is about 200 feet below land surface on the valley slopes and near the crest of the mountains.

The gradient of the ground-water surface in the Kingshill Marl reflects the permeability of the rock. In the vicinity of Fredensborg and Bethlehem Old Works, the ground-water surface forms a plateau about 100 feet above sea level. The rock in the area is predominantly marl of low permeability. The steep ground-water gradients immediately to the south and east indicate a rock of relatively low permeability but greater than that underlying the aforementioned plateau. In a strip one-half mile to a mile in width along the south coast, ground-water levels are less than 10 feet above sea level. The underlying rocks are the most permeable of the Kingshill Marl and the low gradient reflects the free movement of ground water and hydrostatic adjustment to the base level of the sea.

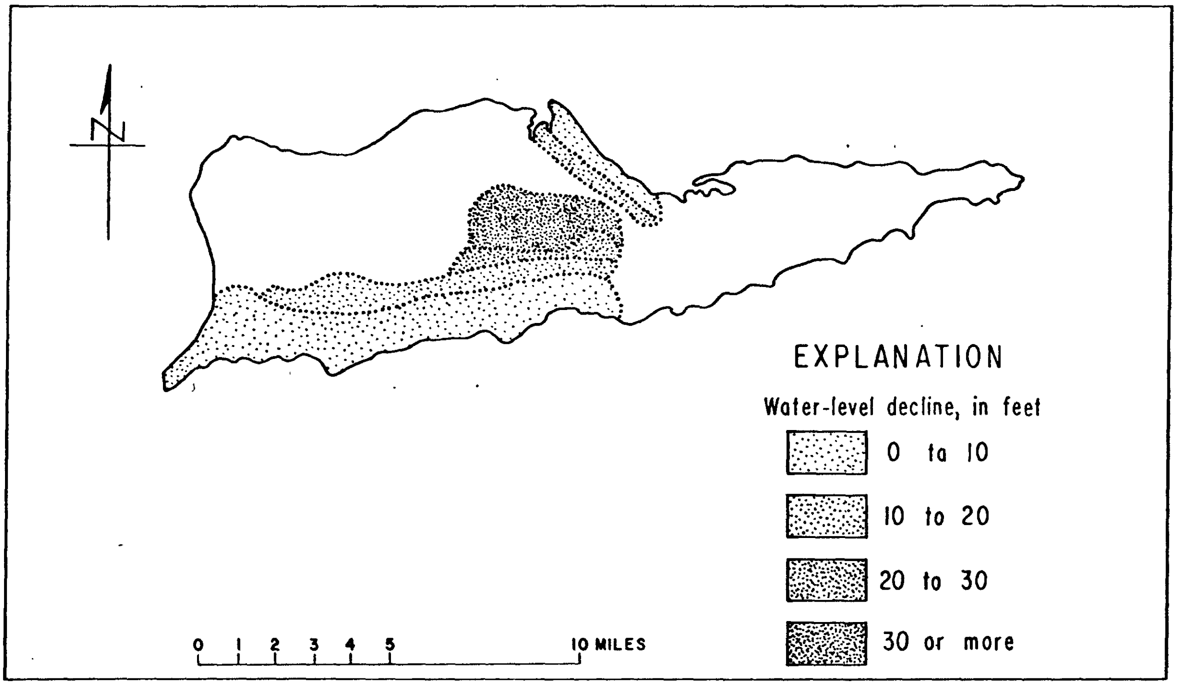


Figure 18.--Approximate decline in ground-water level in Central St. Croix, 1940-67.

Sparse records beginning in 1919 show that water levels have fluctuated considerably in response to variations in rainfall and change in land use. The drought of the 1920's was marked by severe declines; water levels recovered somewhat by the 1940's but then began a steady decline, which has continued to 1967. The current trend probably is caused by increased evapotranspiration intercepting potential recharge as the result of abandoned farm and pastureland reverting to brush and trees. Figure 18 shows the approximate decline in water levels from 1940 to 1967 where data are available. Water levels have probably declined 20 feet or more in the mountain areas, which would account for the reduction in base flow of streams.

The fluctuation of water levels in wells reflects recharge, discharge, local permeability and storage characteristics of the aquifer and the overlying soil and rock. Figure 19 shows that water levels fluctuated during the study but are marked by a general decline. Well 39 taps the limestone of the south coast, and has high permeability that tends to dampen fluctuations. Small amounts of rain produce rapid recharge, but discharge takes place rapidly also. Well 72, in the interior of the island, taps alluvium and limestone of low permeability and small storage. Recharge takes place only during very wet periods because most of the potential recharge either runs off or is retained in the soil and alluvium where it is discharged by evapotranspiration. Well 73 taps a fractured volcanic rock aquifer that is overlain by alluvium, and both deposits have low permeability. Water levels are depressed to or below sea level by nearby pumping. Recharge follows only prolonged wet periods that exceed the demands of evapotranspiration on the alluvium. Peak water levels may lag two months or more behind the rain that produces recharge, reflecting the slow movement of water through the alluvium to the bedrock.

The mean tidal range of the sea is only 0.6 foot and no water-level fluctuations attributable to tides have been observed in wells as close as 1,500 feet to shore. Estuaries and salt ponds along the coast do respond to tidal action and This undoubtedly affects the ground water in the near vicinity.

Availability and Suitability for Supply

The three ground-water provinces of St. Croix have been divided into several smaller areas for ease of discussing hydrologic conditions and the availability and suitability for supply (fig. 5a). The areas were arbitrarily selected on the basis of drainage boundaries as well as geologic and hydrologic characteristics.

Areas 1-a, 1-b, 1-c, and 1-d comprise the ground-water province located in the northwestern mountains of St. Croix.

Areas 2-a, 2-b, and 2-c comprise the ground-water province in the volcanic and associated intrusive rocks of the mountains in the eastern part of the island.

Areas 3-a, 3-b, and 3-c comprise the ground-water province located in the central and southwestern part of the island. Robison (1972) describes availability and potential for development of ground water in most of this province in considerable detail. The following discussion is presented herein to provide continuity for this report.

Area 1-a

This area includes the mountains of the Northside Range that drain to the west coast and the small coastal plain north of Frederiksted. It is underlain by rocks of the Mount Eagle Group and a small outcrop of Kingshill Marl on the coastal plain near Estate William. The coastal plain is mantled by pebbly, silty alluvium as much as 50 feet thick.

Wells completed in the fractured rock underlying the alluvium of the coastal plain where Jolly Hill and Creque Guts enter the coastal plain yield as much as 30,000 gpd. The productivity of these areas is attributed in part to the thick overlying alluvium that acts as a recharge and temporary water storage area for the bedrock. Elsewhere in the coastal plain bedrock wells generally yield about 1,000 gpd.

The most favorable location for wells in the mountains is near the center of the valleys.

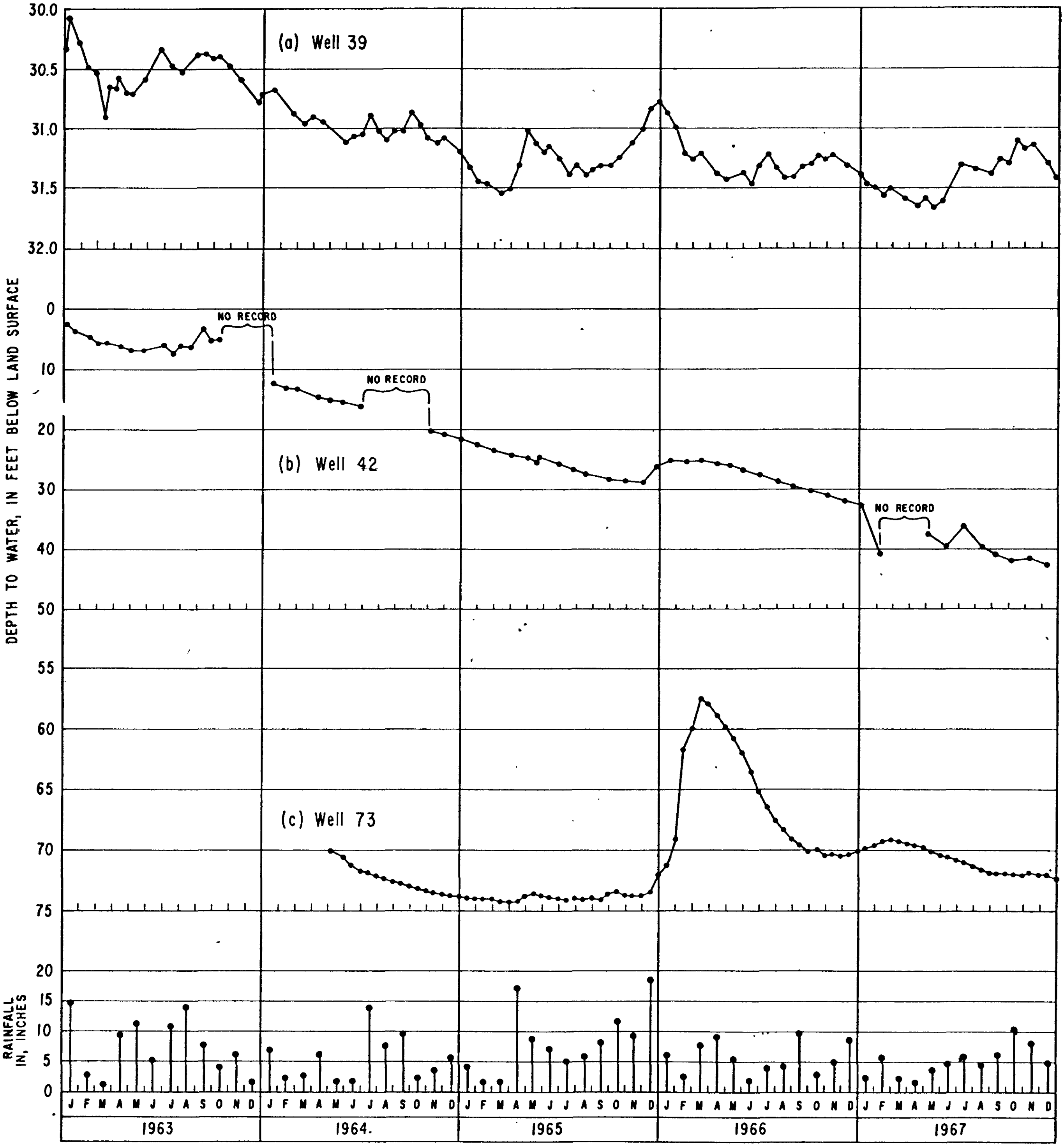


Figure 19.--Water levels in selected wells: a) limestone, coastal; b) alluvium and limestone, interior; c) volcanic, coastal valley. Rainfall: National Weather Service gage at Alexander Hamilton Airport. See figure 5 (in pocket) for location.

Yields of 500 to 1,000 gpd can usually be developed in wells 300 feet or less in depth.

Overall well-water quality is the best in St. Croix. Dissolved solids seldom exceed 1,000 mg/l (milligrams per liter) and chloride is usually less than 150 mg/l. The ground-water reservoir in the coastal plain is highly susceptible to salt-water encroachment as demonstrated in the Mahogany Road well field north of Frederiksted. Excessive pumping in the well field during drought in 1965 caused the salt-fresh water interface to move inland nearly one-half mile. As a result, the chloride content of water from the well field increased from 150 mg/l to more than 1,000 mg/l.

Area 1-b

This area includes the volcanic rocks and the fingers of gabbro lying north of the central ridge of the Northside Range from Hams Bay to Judith Fancy, east of Salt River Bay.

The north coast is a poor area for the development of ground-water supplies. Little or no water can be obtained along Maroon Ridge, from half a mile west of Davis Beach east to Prosperity, and along Barons Bluff. Water quality would probably deteriorate rapidly during pumping because of salt-water encroachment. Wells yielding as much as 1,000 gpd likely can be developed in the larger valleys near Annaly Bay, between Prosperity and La Vallee, and at Belvedere, Rust-up-twist, and Greig Hill. The most favorable location is between altitudes of 100 and 300 feet. Wells drilled to, or slightly below, sea level would be in position to intercept ground water moving through the valleys to the sea and should be safe from sea-water encroachment. The volcanic rock at Judith Fancy yields 1,000 gpd or more to wells.

At La Vallee, as much as 50 feet of alluvium may overlie the bedrock. The alluvium readily accepts recharge and, when saturated, is a source of water to the bedrock. In the upper part of the valley bedrock wells yield about 1,000 gpd and in the lower part where alluvium overlies the bedrock, wells yield about 5,000 gpd. The chloride content of the water is about 300 mg/l but sea-water encroachment could be a problem in the lower part of the valley.

In general, the quality of the water along the north coast is poor because of salt-water encroachment, sea spray, and other soluble salts that fall on the land surface from the atmosphere and are carried to the ground-water reservoir during recharge. The chloride content of well waters ranges from about 300 mg/l in upland valleys, above an altitude of 300 feet, to 1,000 mg/l or more along the coast.

Area 1-c

This area has two sections, which are underlain by volcanic rocks on the south flank of the Northside Range, separated by the intrusive rocks of the gabbro. The west section lies between the basins of Jolly Hill Gut and River Gut and is drained by narrow, southward-trending valleys. The east section is essentially the upper Salt River drainage basin.

In the west section, yields as much as 5,000 gpd can be obtained from wells up to 300 feet deep in the lower parts of the valleys. On the flanks and in the upper parts of the valleys, yields probably are less than 1,000 gpd. In the lower part of the large valley at Grove Place there are several wells that yield as much as 10,000 gpd from the bedrock underlying the alluvium.

In the east section wells in the Salt River valley yield as much as 5,000 gpd at depths of 50 to 300 feet; yields are variable but are generally greater in the lower part of the valley. It is estimated that wells drilled in the small south-trending valleys east of the Salt River valley would yield 500 to 1,000 gpd.

The chloride content of typical well water of both sections is generally less than 150 mg/l. Along the south edge of the area, however, where the volcanic rocks are in contact with the Jealousy conglomerate or the Kingshill Marl, chloride content may be as high as 500 mg/l. Sea-water encroachment is a problem only near Salt River Bay.

Area 1-d

Located in the center of the Northside Range, this area is underlain by fractured and deeply weathered gabbro surrounded by volcanic rock in the adjacent hills. Alluvium as much as 60 feet deep and containing extensive beds of sand and gravel overlies the gabbro along River Gut. Alluvium as much as 20 feet deep lies along Bethlehem Gut. Ancestral stream channels draining these basins along the south part of the area also contain deposits of sand and gravel 20 to 50 feet in depth (figs. 5a and 5b).

Wells tapping the alluvium and underlying gabbro will yield as much as 40,000 gpd at depths ranging from 50 to 200 feet. The volcanic rocks surrounding the gabbro will yield an estimated 500 to 1,000 gpd to wells as much as 300 feet deep.

The chloride content of typical well water from the alluvium and gabbro ranges from 150 to 350 mg/l. The quality of the water from the volcanic rocks is probably similar, although along the north edge of the area ground water may be more mineralized from airborne sea spray.

Area 2-a

This area lies west of the diorite intrusive and its center is marked by rounded hills of volcanic rocks. East of Christiansted, two small alluviated valleys discharge to the north coast. To the south is an alluvial plain as much as a mile wide between the hills and the sea.

The alluvium in the valleys to the north is 25 feet thick or more and contains silt and sand with some beds of gravel. Water can be obtained from the gravel beds in the alluvium and from the underlying bedrock. Yield from wells is as much as 10,000 gpd, although prolonged pumping at this rate probably would result in lowering water levels considerably and might cause sea-water encroachment.

The alluvial plain to the south is generally about 20 feet thick and contains silt, sand, and probably some gravel beds. Usually, these deposits are above the water table except near the coast and in possible buried valleys. All existing wells penetrate bedrock and yield to individual wells is about 500 gpd.

In the bedrock of the hills, wells as much as 300 feet deep yield less than 500 gpd. It is estimated that 1 of 10 wells drilled will be dry.

The quality of the typical well water is best in the hills where the chloride content is 500 mg/l or less, and the dissolved-solids content is about 1,000 mg/l. Nearer to the north coast, the water becomes brackish in the alluvium and bedrock--chloride exceeds 1,000 mg/l north of the main road to the east of Christiansted and in the lower-lying parts of the town. A similar condition exists on the south coast--water where a chloride content of 1,000 mg/l is found about a mile inland and becomes more brackish nearer the coast.

Area 2-b

This area is underlain by diorite that is well fractured and extensively weathered. North and south of a low saddle in the central ridge, which marks the position of the intrusive, the diorite is overlain by thin alluvium.

The alluvium yields 500 to 1,000 gpd to dug wells along the coast. In the uplands the alluvium is above the water table, but wells tapping the diorite yield as much as 10,000 gpd. In general, the deeper the well, the greater the yield. Depths of wells are as much as 200 feet on the central saddle but wells are shallower close to the coast because of possible salt-water encroachment.

The chloride content of typical well water is about 500 mg/l in the central part of the area. Water quality generally is poorer near the coast, and particularly in the vicinity of the salt ponds. Both alluvium and diorite are affected by salt-water encroachment.

Area 2-c

This area, underlain by volcanic rocks, is the almost desert-like eastern part of the island. In the larger valleys on the north coast alluvial deposits of sand and clay may reach a thickness of 40 feet.

In the valleys west of a line from Knight Bay to Grapetree Bay, wells tapping volcanic rock yield about 500 gpd. East of this line, the small amount of ground water available is brackish. Water in the coastal areas is also brackish, thus potentially potable supplies are limited to the upper parts of the western valleys. Even in the mountains the quality of the water is poor--the chloride content ranges from about 500 to 1,000 mg/l.

Area 3-a

This area is underlain by Kingshill Marl and is composed of a coastal terrace to the north mantled by alluvium and an arc of limestone and marl hills west and south of Christiansted. Beneath the Kingshill Marl of the center ridge, the "blue clay" of the Jealousy Formation stands well above sea level (fig. 6).

The surface of the "blue clay" is near sea level at the foot of the northern slope and dips seaward to about 50 feet below sea level at the coast thus limiting the depth of productive wells in the coastal terrace to about 100 feet. Yields to wells in the rocks overlying the "blue clay" range from 1,000 to 5,000 gpd at the foot of the slope to as much as 40,000 gpd at the coast. The quality of the water, however, becomes poorer seaward because of salt-water encroachment. Near the foot of the slope the chloride content of the water is about 1,000 mg/l but increases to 5,000 mg/l or more half a mile toward the coast.

Wells drilled in the conglomerate outcrop of the Jealousy Formation south of Salt River Bay generally yield less than 500 gpd of brackish water.

The surface of the "blue clay" slopes steeply from about 100 feet above sea level under the central divide, to about 100 feet or more below sea level in the southern and southeastern section of the area. The permeability is low in the predominantly marl rocks near the central divide and in the deposits abutting the volcanic rocks to the east. Along the southern edge of the area, the permeability increases where more limestone and calcarenite are found. The few wells that penetrate the Kingshill Marl to the "blue clay" show a marked increase of calcarenite with depth.

Yields to wells of about 1,000 gpd can be obtained on the southern flanks of the "blue clay" high. Yields increase toward the south coastal lowland to about 5,000 gpd. Adjacent to the central lowlands, yields of about 5,000 gpd of water with 1,000 mg/l chloride can be obtained from wells tapping the upper 50 feet of the aquifer. If the full section of the aquifer is tapped, yields up to 30,000 gpd are possible but the chloride content of the water will increase to 3,000-5,000 mg/l.

Ground water immediately south of the "blue clay" high has a hardness of only about 100 mg/l.

Area 3-b

This area is constituted of a lowland, 1 to 2 miles wide, along the foot of the Northside Range. In the northeast, the lowland converges on the lower drainage basin of Salt River; to the southwest it broadens to the sea and extends along the west coast to Frederiksted. The ground water in the lowland has been described by eastern, central, and western sections.

The eastern section is the lower drainage basin of Salt River. The northwestern and northern part of the basin are underlain by the conglomerate member of the Jealousy Formation. Through the central part of the basin the "blue clay" underlies the Kingshill Marl at a depth of about 60 feet below sea level near Salt River Bay and about 40 feet below sea level to the south (fig. 6). The ancestral Salt River channel in the marl is filled with as much as 60 feet of fine-grained alluvium, which contains some beds of sand and gravel.

Wells may yield 1,000 to 3,000 gpd from the conglomerate of Jealousy Formation in the valley of Salt River near the contact with the volcanic rocks. Wells in the vicinity of Friedensfeld and Glynn that tap the Kingshill Marl yield about 5,000 gpd of brackish water. Both yield and quality of water from the limestone improve toward Salt River Bay because of interchange of water from the alluvium filling the central part of the valley. Along the periphery of the alluvium, wells in the limestone yield 10,000 gpd; wells tapping the alluvial fill in the center of the valley yield as much as 15,000 gpd.

Water from wells in the conglomerate near the contact with the volcanic rocks has a chloride content of about 1,000 mg/l but is more mineralized toward the center of the valley. In the south near Glynn, water in the upper part of the limestone has a chloride content of about 1,000 mg/l whereas at the base of the aquifer, chloride content is 5,000 mg/l or more. Elsewhere, the chloride content of water from wells in the limestone is about 1,500 mg/l. Water in the alluvium in the central part of the valley has a chloride content of about 500 mg/l.

The central section of Area 3-b is about a mile in width and parallels the foot of the Northside Range. At its western end, it swings southward to the sea at Good Hope. Covering the lowland is an alluvial mantle consisting of pebbly sand, silt and clay. The mantle is about 40 feet thick at the foot of the mountains but to the south it averages about 10 feet thick. Along the foot of the mountains are small outcrops of Jealousy Formation conglomerate and Kingshill Marl. In the subsurface, the Jealousy Formation's "blue clay" dips southward from about 60 feet above sea level at the foot of the mountains to 100 feet or more below sea level at the south margin of the area. Overlying the "blue clay" and abutting the conglomerate is the Kingshill Marl.

Beds of sand and gravel in the subsurface are occasionally found where present-day streams leave the mountains and apparently are channel or fan deposits from ancestral streams. Wells tapping these deposits yield about 5,000 gpd; water is of good quality with a chloride content of less than 500 mg/l. Because these deposits are limited in volume and areal extent, their water-storage capacity is small. In times of drought when there is no recharge, the water level declines rapidly and chloride content increases as highly mineralized water from the adjacent calcareous rocks moves into these deposits.

The underlying marl has a very low permeability and generally yields little water. Locally, however, the marl is more indurated and water-bearing fractures and joints in the marl, usually near the contact with the "blue clay," will yield as much as 5,000 gpd to wells. A chloride content of 2,000 to 10,000 mg/l or more can be expected from the water-bearing zones in the marl.

The western section of Area 3-b encompasses the limestone terrace of the southwestern corner of the island; the limestone is mantled by a thin soil, and alluvium is absent except along the larger stream channels. Under the limestone, the surface of the "blue clay" is about at sea level near the foot of the mountains from where it dips westward and southward to 100 feet or more below sea level along the coastline.

The solution openings that are present in the limestone are most numerous in the southwestern part of this section. Water levels are only a few feet above sea level where permeability is greatest. Sea water circulates through these openings in the aquifer and ground water, therefore, is generally brackish as much as half a mile inland.

Water containing less than 1,000 mg/l chloride can only be obtained inland near the foot of the mountains where wells yield about 3,000 gpd. Close to the coast, wells yield as much as 30,000 gpd of brackish water.

Wells tapping the sand and gravel in the alluviated valley immediately east of Frederiksted yield up to 30,000 gpd. Chloride content of water in the alluvium is about 500 mg/l and that of the adjacent limestone, 1,000 mg/l or more. The quantity of alluvium is so small, however, that pumping from the alluvial aquifer causes influx of the poorer quality water from the limestone.

<u>Area 3-c</u>

This area consists of a strip of the south coast about 2 miles wide and 6 miles long, between Estate Good Hope and Cassava Garden. The western two-thirds of the area is marked by a wave-cut coastal terrace, about half a mile wide, that slopes seaward from the foot of the limestone upland. The upland is crossed by several alluvium-filled valleys; (from west to east, these are) the valleys of River Gut and Bethlehem Gut, the streamless valleys through Barren Spot and Castle Coakley, and the valley through Cassava Garden.

The western half of the coastal terrace, near the sea, is underlain principally by limestone and calcareous sandstone associated with reef development; inland, the proportion of marl increases.

The eastern half of the terrace is underlain by as much as 100 feet of alluvium filling a buried channel that parallels the coast. The underlying "blue clay" is 150 feet or more below sea level (fig. 6), and thus exerts little influence on either the yield or water quality.

The limestone forming the hills and underlying the alluvial valleys inland of the coastal terrace can be separated by a north-south line roughly following the divide between Bethlehem Gut and the valley through Barren Spot (fig. 16). West of the line the rock is predominantly marl whereas to the east calcarenite and other limestone predominate.

Wells in limestone in the western part of the terrace yield about 10 gpm in the vicinity of Betty's Hope, but yield increases to 100 gpm near River Gut. Two sea-level limestone springs, one at Envy and another about half a mile to the east flow as much as 40 gpm.

The alluvium of the buried channel along the coast yields as much as 100 gpm to wells in the vicinity of River Gut. Yields diminish eastward to a maximum of about 30 gpm northeast of Krause Lagoon.

Yields to wells tapping the marl of the western part of the uplands generally are less than 10 gpm, whereas those tapping the limestone and sandstone to the east yield up to 30 gpm. Yields of 100 gpm are possible locally in the eastern part of the upland from wells tapping the full section of the Kingshill Marl; however, water is of poor quality and generally unusable for most purposes.

Ground-water levels in the coastal terrace are only a few feet above sea level and reflect the relatively high permeability of the aquifer. The quality of water from wells is controlled by the location and the depth of the wells in relation to the fresh-sea water interface. Along the coastline the fresh water zone is but a few feet thick. A half mile inland, the chloride content of the water generally is less than 500 mg/l in the upper 50 feet of the water-bearing zone but increases to about 1,000 mg/l within the next 50 feet of penetration. The chloride content of the water continues to increase with depth to as much as 3,000 mg/l or more at 150 feet. Dissolved solids shows a corresponding increase, being more than 5,000 mg/l in the deeper water-bearing zones. Wells near the inland edge of Area 3-c show a similar relation of quality with depth but it is believed by the author that this is partly because of drainage of highly mineralized water from the marl and limestone areas to the north.

The alluvial deposits of the River Gut and Bethlehem Gut valleys consist of clay, silt, and sand and gravel predominantly of volcanic rock origin. The deposits increase in thickness from about 25 feet at Centerline Road to more than 100 feet near the sea (figs. 5a and 5b). The percentage of sand and gravel also increases seaward from about 10 percent of the total thickness in the vicinity of Centerline Road to about 50 percent where River Gut passes through the constriction formed by the limestone hills near the airport. The streams are in hydraulic connection with the aquifer, and depending upon the altitude of the water level in the aquifer, gain or lose water.

Yield to wells ranges from about 20 gpm in the upper part of the valleys to about 100 gpm on the coastal terrace. Water quality varies depending on contributions from the streams or from the surrounding limestone. In general, dissolved-solids content is about 1,000 mg/l and chloride content is between 250 and 500 mg/l.

The alluviated valleys passing through Barren Spot and Castle Coakley are unique in that they have no surface drainage. The alluvium, which approaches 100 feet in thickness near Krause Lagoon, is predominantly fine grained and consists of sand, silt, and clay derived mainly from limestone and marl, with only a few thin beds of sand and gravel. Wells tapping the sand and gravel zones yield as much as 30 gpm of water with a dissolved-solids content of about 1,000 mg/l and a chloride content of 500 mg/l. Wells are usually drilled to tap both the alluvium and the bedrock to obtain greater yields, even though water in the underlying limestone is twice as mineralized as that in the alluvium.

An ephemeral stream heads in the eastern volcanic uplands joining the Barren Spot drainage on the east at Cassava Garden. Alluvium is generally less than 25 feet thick in the upper valley and wells yield only a few gallons per minute. Water quality will vary--in a wet period, the ground water may have a chloride content of 250 mg/l;

in a dry period, when ground-water levels are low the chloride content may be as much as 1,000 mg/l.

Alluvium is estimated to be 50 feet thick in the lower valley where wells probably would yield up to 30 gpm, and the chloride content ranges from about 500 to 1,000 mg/l.

Water Quality

Water quality in St. Croix has two basic groupings--that associated with the volcanic and igneous rocks, and that with the calcareous rocks. The quality of water from the alluvium lies somewhere between the two basic groupings taking its characteristics from the parent material of the alluvium, areas of recharge, and the type of bedrock with which it is hydraulically connected. Water quality of the streams reflects the quality of the ground water which contributes to their base flow and, during storm runoff, the effect of dilution and leaching from the soils of the stream basin.

The mineral content of the water of St. Croix reflects the influence of the sea and the land. In shallow ground water, calcium and bicarbonate are almost wholely land-derived, whereas chloride either directly or indirectly is sea-derived. Other major ions, magnesium, sodium, and sulfate are derived about equally from both sources.

The principal source of minerals in the shallow ground water is assumed to be bulk precipitation. Bulk precipitation is the term for the aggregate of ocean and land-derived salts deposited on the land surface. Ocean-derived salts reach the land surface in rainfall, as dry fallout of salt crystals, and from wind-carried sea spray. The island itself is the major source of land-derived airborne salts picked up by the wind as dust and then redeposited, although there probably is contribution from distant land masses as well. Table 3 shows the average concentration of major constituents in precipitation for samples collected in St. Thomas; it is assumed that the composition is similar in St. Croix. Also shown are average concentrations for samples of ground water from different sources in St. Croix, and for a sample from the Atlantic Ocean near St. John.

Table 3.--Average concentration of selected constituents in bulk precipitation on St. Thomas; ground water from volcanics, alluvium, and limestone, St. Croix; and sea water near St. John

	Milligrams per liter					
	Calcium	Magnesium	Sodium, Potassium	Bicarbonate	Sulfate	Chloride
Bulk precipitation, St. Thomas	2.06	0.65	5.28 0.32	11.1	1.68	7.11
Volcanics, St. Croix	83	38	162	440	53	204
Alluvium, St. Croix	53	37	354	595	105	317
Limestone, St. Croix	48	33	529	580	159	532
Sea water, St. John	300	1,460	10,600 500	156	2,900	19,800

A comparison of sea water and ground water to bulk precipitation made by equating the major ions of the former to the chloride ion of bulk precipitation is shown in table 4.

Table 4.--Average concentration of selected constituents in ground water, St. Croix, and sea water, St. John, equated to the chloride content of bulk precipitation, St. Thomas

	Milligrams per liter and milli-equivalents per liter												
	Calcium		Magnesium		Sodium Potassium		Bicarbonate		Sulfate		Chloride		Total
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	
Bulk precipitation, St. Thomas	2.06	0.092	0.65	0.53	5.47	0.238	11.1	0.182	1.68	0.035	7.11	0.200	0.900
Volcanics, St. Croix	2.89	.130	1.32	.108	5.65	.246	15.3	.251	1.85	.038	7.11	.200	.973
Alluvium, St. Croix	1.19	.053	.83	.068	7.95	.346	13.10	.214	2.35	.049	7.11	.200	.930
Limestone, St. Croix	.64	.029	.44	.036	7.08	.308	7.75	.127	2.12	.044	7.11	.200	.746
Sea water, St. John	.11	.005	.52	.043	3.80	.165	.05	.001	1.04	.022	7.11	.200	.436

Robison (1972) assumed that bulk precipitation was the source of all chloride ions in the Kingshill Marl at, or slightly below, the ground-water surface where the influences of sea-water encroachment and connate water were not present. For water in the Kingshill Marl (chloride about 210 mg/l at water surface), this assumption indicated that a 30-fold increase of the chloride content of bulk precipitation (7 mg/l) would be required. The mechanics of this increase is believed to be a process of concentration. Minor rains, which do not cause runoff, carry the salts accumulated on the land surface into the soil zone. Major rains, resulting in runoff, tend to wash away accumulated salts on the surface, but since the major rainstorms are also the source of recharge to the aquifer, salts earlier concentrated deep in the soil zone are carried along with recharge to the aquifer. Within the zone of areation, the vadose zone and the upper part of the aquifer, evaporation or transpiration removes water but leaves soluble salts behind, further concentrating the mineral content of the ground water. Following the initial concentration, however, the mineral content of the water is further altered by solution, ion exchange, and connate water within the aquifer.

From the premise of the mineral content of the water from calcareous rocks, it can be postulated that a similar concentration of bulk precipitation occurs in the water of the alluvial and volcanic aquifers.

Selected chemical analyses of water from various sources are given in table 5. Included are wells tapping the volcanic rock, limestone, gabbro, and alluvium as well as samples of springs, streams, and the Atlantic Ocean. With the exception of ground water from isolated areas in the volcanic rock and water from streams in the Northside Range, little of the water of St. Croix meets quality standards for drinking water (U.S. Public Health Service, 1962) as far as chloride content is concerned. In local practice, water is generally considered potable if chloride is less than about 500 mg/l. The content of other constituents, generally, is within U.S. Public Health Service's limits. Fluoride ranges from 0.1 to 1.0 mg/l; iron and manganese are present in very small quantities, if at all; and nitrate ranges from near zero to 24 mg/l, but averages about 5 mg/l. Wells tapping the upper part of the aquifer produce water with a lower mineral content than those tapping the deeper water-bearing zones.

Figures 20 through 27 show the general distribution of dissolved solids, hardness, chloride, sulfate, bicarbonate, calcium, magnesium, and sodium and potassium in ground water from wells tapping the upper 50 to 100 feet of the water-bearing zone of the aquifers.

Water in the volcanic rock is basically a calcium bicarbonate sodium chloride type. Dissolved solids ranges from about 500 to 1,000 mg/l. In the Northside Range, chloride is generally less than 200 mg/l and hardness is about 300 mg/l; in the Eastside Range, chloride is generally less than 300 mg/l and hardness is about 100 mg/l.

Water in the limestone and marl is a sodium bicarbonate sodium chloride type with mineral concentrations that vary considerably with depth and location. The dissolved-solids content is generally from 1,500 to 3,000 mg/l but exceeds 20,000 mg/l in places (fig. 20). A zone of highly mineralized water extends from the coast west of Christiansted southwestward along the foot of the Northside Range to the vicinity of River Gut. This may result in part from water discharged from the conglomerate and clay of the Jealousy Formation. The quantity of the water in the most highly mineralized zone resembles sea water and may be connate water trapped in the Kingshill Marl during deposition.

The quality of water in the alluvium reflects the types of materials from which the alluvium was derived, the bedrock with which it is in hydraulic connection, and the source and quantity of recharge. Similarly, quality of streamflow depends on the quality of ground-water discharge to the channels and the proportion and source of surface runoff.

In table 5, the analyses of samples for River Gut show that dissolved solids increases downstream and the water-quality characteristics change from those of volcanic rock to those of the limestone, marl, and alluvium aquifers.

Table 5.--Selected chemical analyses of ground and surface water, St. Croix. (See figure 17 for sample location)

CHEMICAL ANALYSES

Date of collection	Sample number	Milligrams per Liter														Specific conductance (micromhos at 25°C)	pH	Manganese (Mn)	Temperature, °C
		Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$					
														Calcium magnesium	Non-carbonate				
04-02-64	1	26	0.00	88	38	69		362	28	140	0.3	3.4	596	376	79	1,010	7.8	--	--
07-16-65	1a	27	.00	520	153	124		354	52	1,312	.5	.7	2,720	1,926	1,636	4,420	7.4	--	27
04-29-68	2	28	.00	64	40	1,384	20	588	294	1,840	.8	--	3,960	324	0	6,770	8.0	0.00	31
05-15-68	3	28	.00	46	21	44	.6	212	15	79	.2	1.2	339	202	28	540	8.1	.01	26
04-15-68	4	32	--	71	49	110	3.2	485	59	118	.3	.0	683	378	0	1,220	7.8	--	24
03-22-68	5	20	.00	200	151	1,600	13	540	996	2,200	1.0	--	5,446	1,120	677	8,400	7.9	.01	28
03-12-68	6	42	.00	76	46	125	2.0	510	60	135	.5	.2	737	390	0	1,240	7.6	.11	33
04-12-68	7	39	--	20	52	498	2.1	386	167	592	.4	10	1,600	264	0	2,780	8.7	.00	27
02-19-63	8	42	.00	40	24	461		690	108	362	.9	12	1,380	198	0	2,310	8.0	--	--
10-05-64	9	34	.00	104	74	328		420	122	570	.5	.5	1,440	564	220	2,600	7.9	--	--
03-07-68	10	47	.00	592	244	3,100	20	506	1,660	5,000	.9	--	10,900	2,480	2,065	--	7.8	.04	--
07-16-65	11	27	.00	64	35	934		546	316	1,100	.8	5.4	2,770	304	0	4,690	7.9	--	27
07-21-65	12	14	.00	26	12	537		662	138	415	1.0	8.7	1,500	114	0	2,540	8.3	--	27
03-01-68	13	28	.01	29	37	695	8.4	456	88	860	.9	.8	1,971	224	0	3,510	8.6	.00	--
06-23-63	14	24	.00	20	11	512		590	102	435	.5	5.3	1,430	95	0	2,450	7.8	--	--
10-04-68	15	29	--	1,100	358	1,860	23	75	1,080	4,980	.5	--	9,470	4,220	4,160	14,900	7.9	--	--
03-26-68	16	10	.00	40	22	80	1.1	182	20	132	.2	.8	396	190	41	749	7.9	.00	26
05-23-68	17	32	--	41	61	480	9.5	220	177	710	.6	8.6	1,630	353	163	3,020	8.3	.00	28
02-18-63	18	26	.00	82	11	82		398	1.2	71	0.4	.4	470	250	0	797	8.0	--	24
02-18-63	19	28	.00	109	15	101		474	8.4	110	.3	.1	583	389	0	1,000	7.4	--	--
02-18-63	20	38	.00	36	22	82		318	11	62	.1	.2	404	180	0	609	7.3	--	--
02-18-63	21	36	.00	57	25	146		446	19	125	.2	.2	628	245	0	1,040	8.0	--	--
02-18-63	22	38	.02	62	28	225		550	49	182	.4	.2	856	270	0	1,400	7.9	--	--
02-18-63	23	40	.42	87	26	407		780	41	372	.6	.7	1,360	324	0	2,290	7.8	--	--
05-28-68	24	.5	--	300	1,460	10,600	500	156	2,900	19,800	.9	--	35,600	6,770	6,640	46,600	7.7	--	--

EXPLANATION (Sample numbers)

1 = Mahogany Road, Public Works Dept., Well 1, volcanic.
1a = Mahogany Road, Public Works Dept., Well 1, volcanic, after sea-water encroachment.
2 = Whites Bay, H. Sugden, limestone and marl.
3 = Oxford, H. Lavaetz, volcanic.
4 = Coble, S. Lloyd, gabbro.
5 = Mon Bijou, O. Skov, Jealousy conglomerate?
6 = Castle Buck, E. Benjamin, alluvium.
7 = Fair Plains, Public Works Dept., Well 1, alluvium.
8 = Envy, Government of Virgin Islands, sea-level limestone spring.
9 = Concordia, Public Works Dept., Well 7, alluvium and limestone.
10 = Limetree, R. Tierney, limestone and marl.
11 = Barren Spot, Public Works Dept., Well 4a, limestone.
12 = Barren Spot, Public Works Dept., Well 6a, alluvium and limestone.
13 = Little Princess, C. Austin, limestone.
14 = Sion Farm, National Park Service, limestone.
15 = Castle Coakley, USGS Well 44, limestone deep aquifer.
16 = Catherines Rest, PanAm Distributing Co., volcanic.
17 = Solitude, W. Roebuck, volcanic.
18 = Creque Gut above Mt. Washington Reservoir.
19 = Jolly Hill Gut at Jolly Hill.
20 = River Gut at River.
21 = River Gut at Holy Cross Church.
22 = River Gut at Golden Grove.
23 = River Gut at airport.
24 = Sea water, Atlantic Ocean, St. John, Virgin Islands.

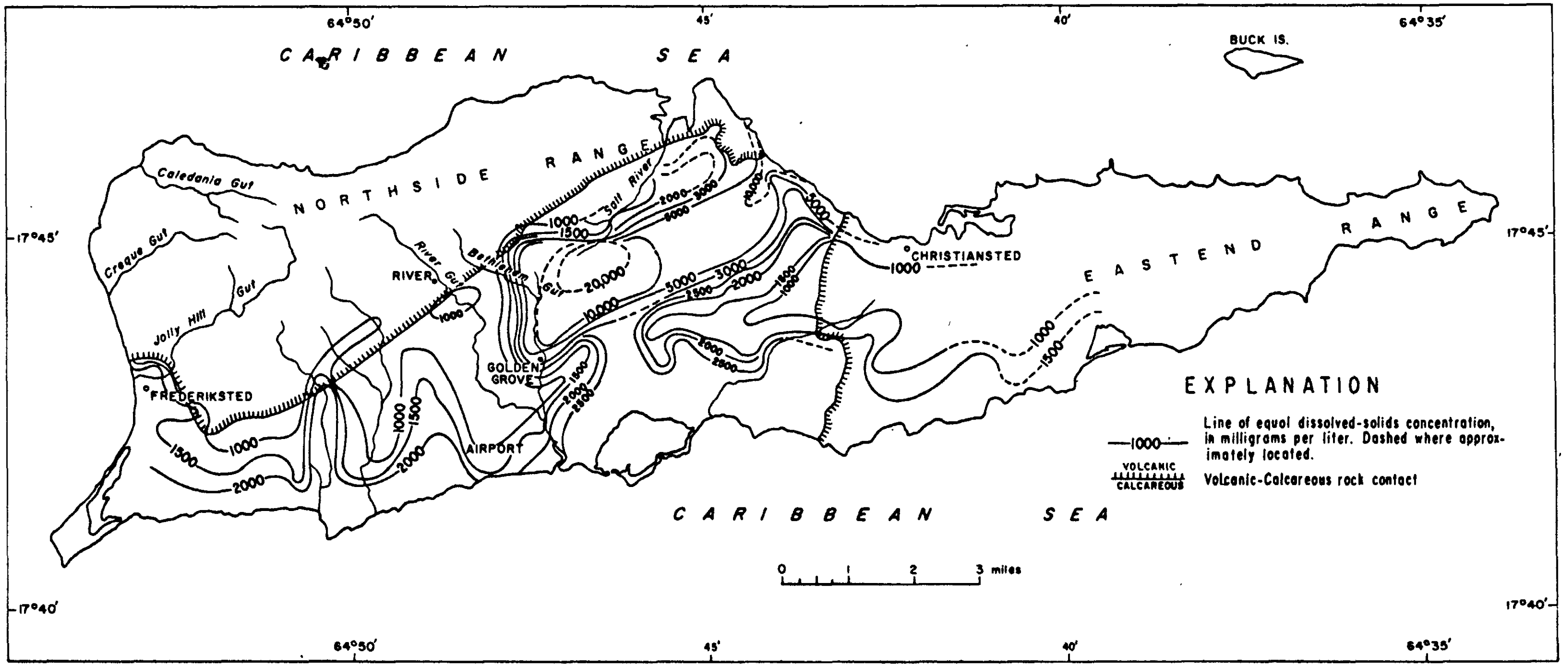


Figure 20.--Dissolved-solids concentration of typical well water.

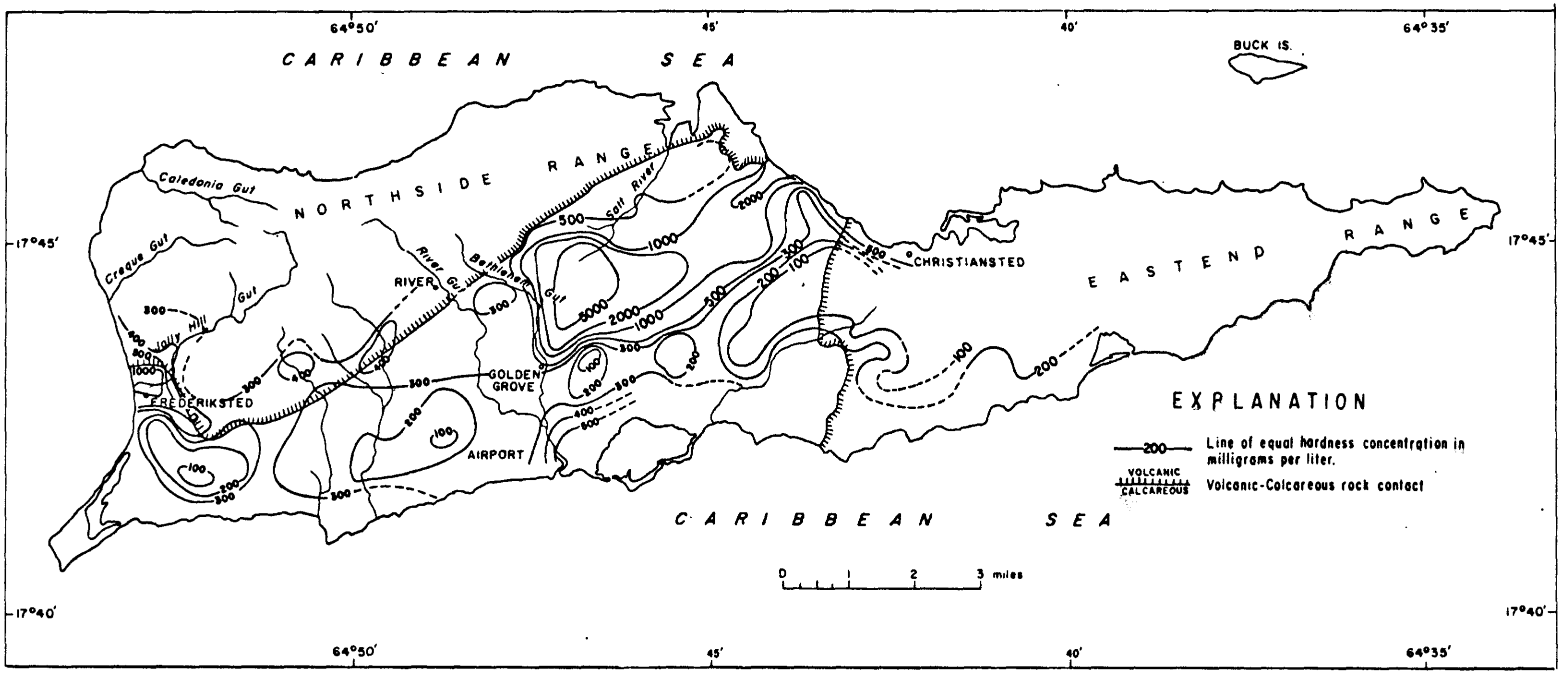


Figure 21.--Hardness concentration of typical well water.

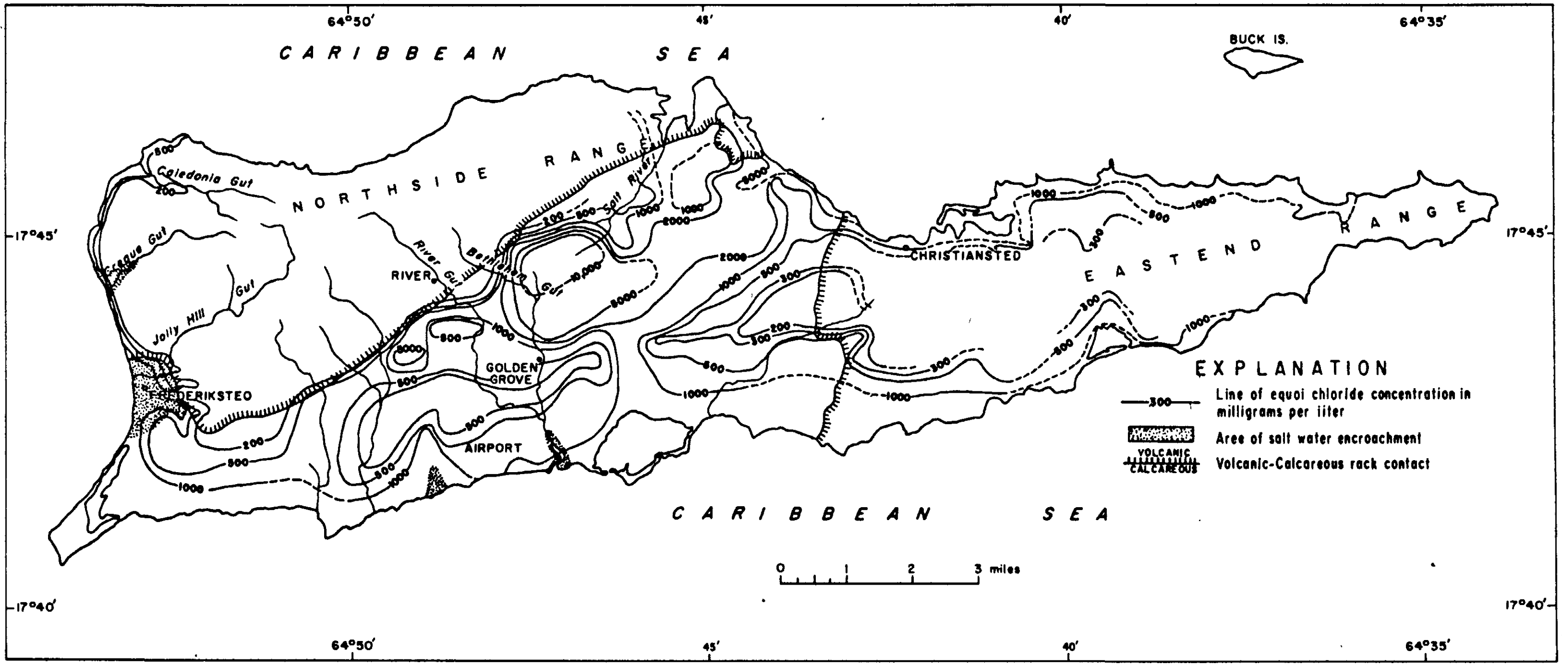


Figure 22.--Chloride concentration of typical well water.

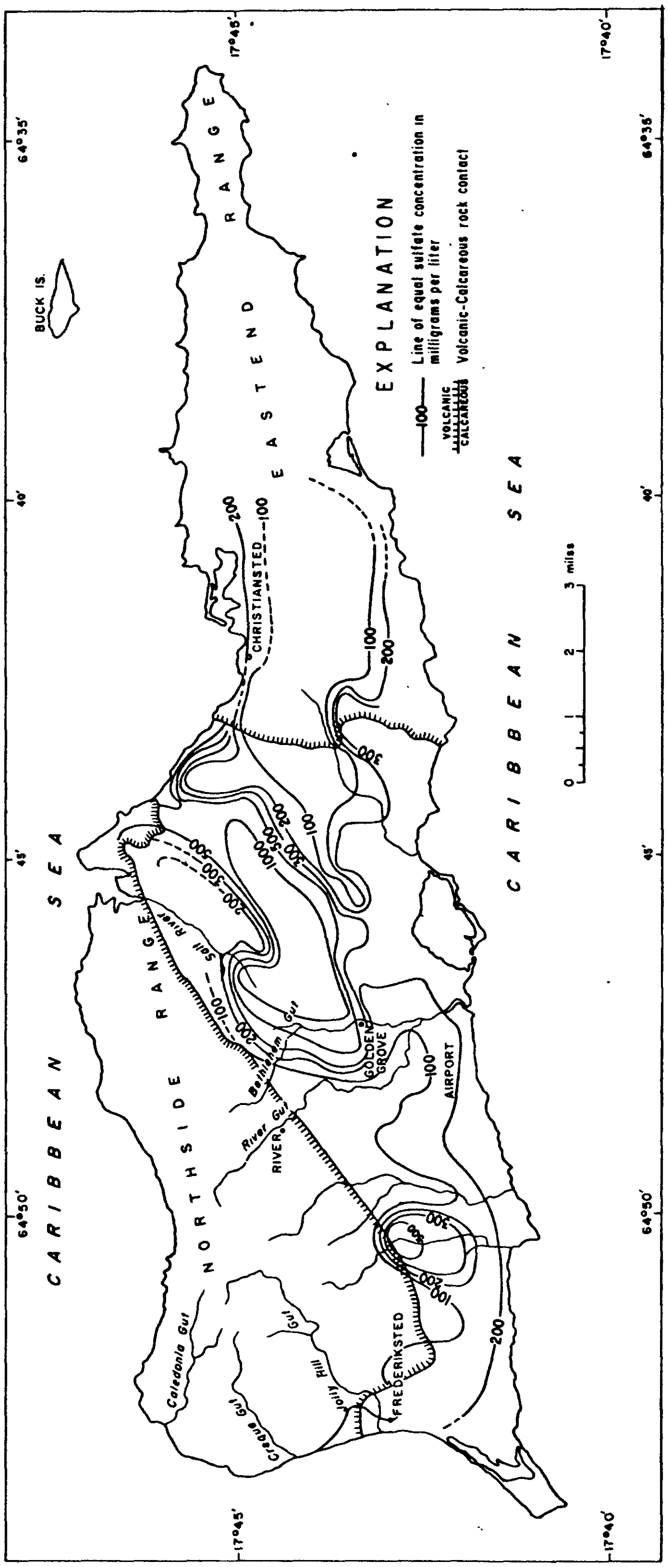


Figure 23.--Sulfate concentration of typical well water.

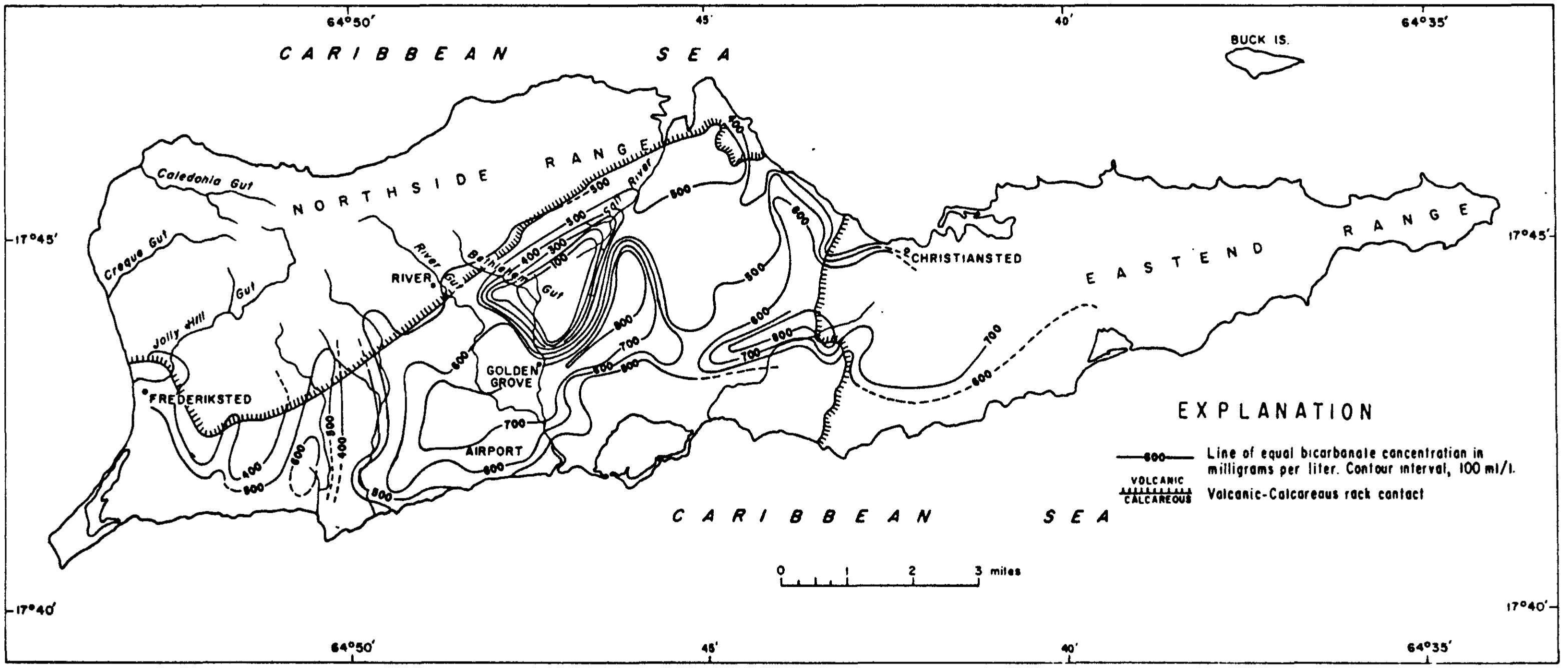


Figure 24.--Bicarbonate concentration of typical well water.

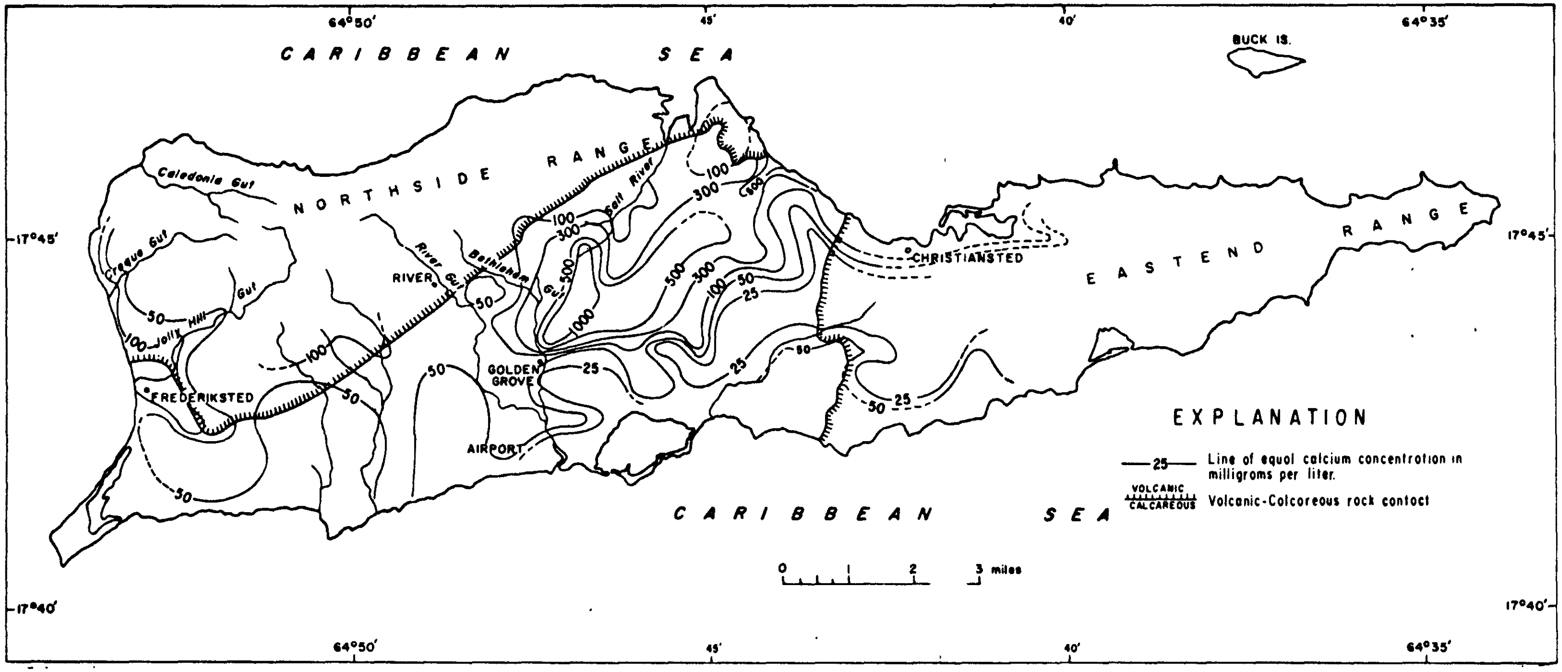


Figure 25.--Calcium concentration of typical well water.

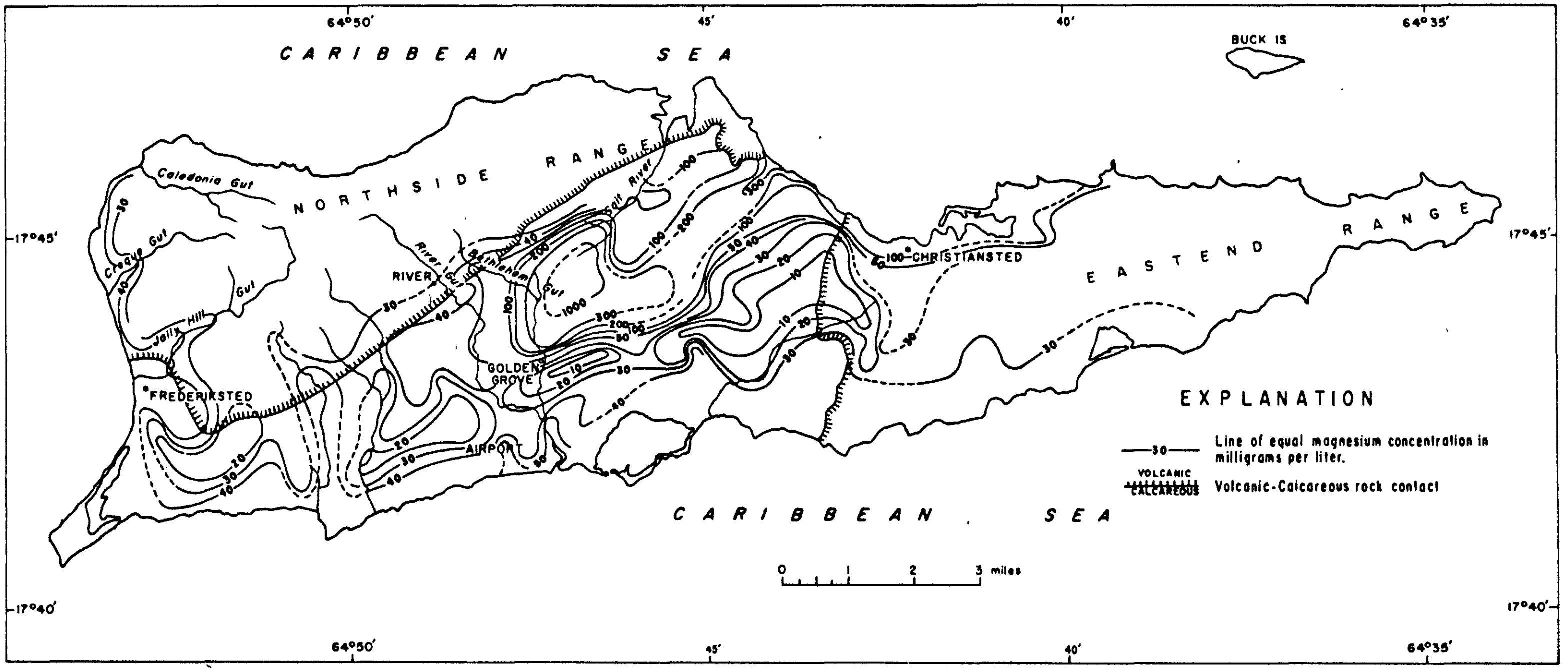


Figure 26.--Magnesium concentration of typical well water.

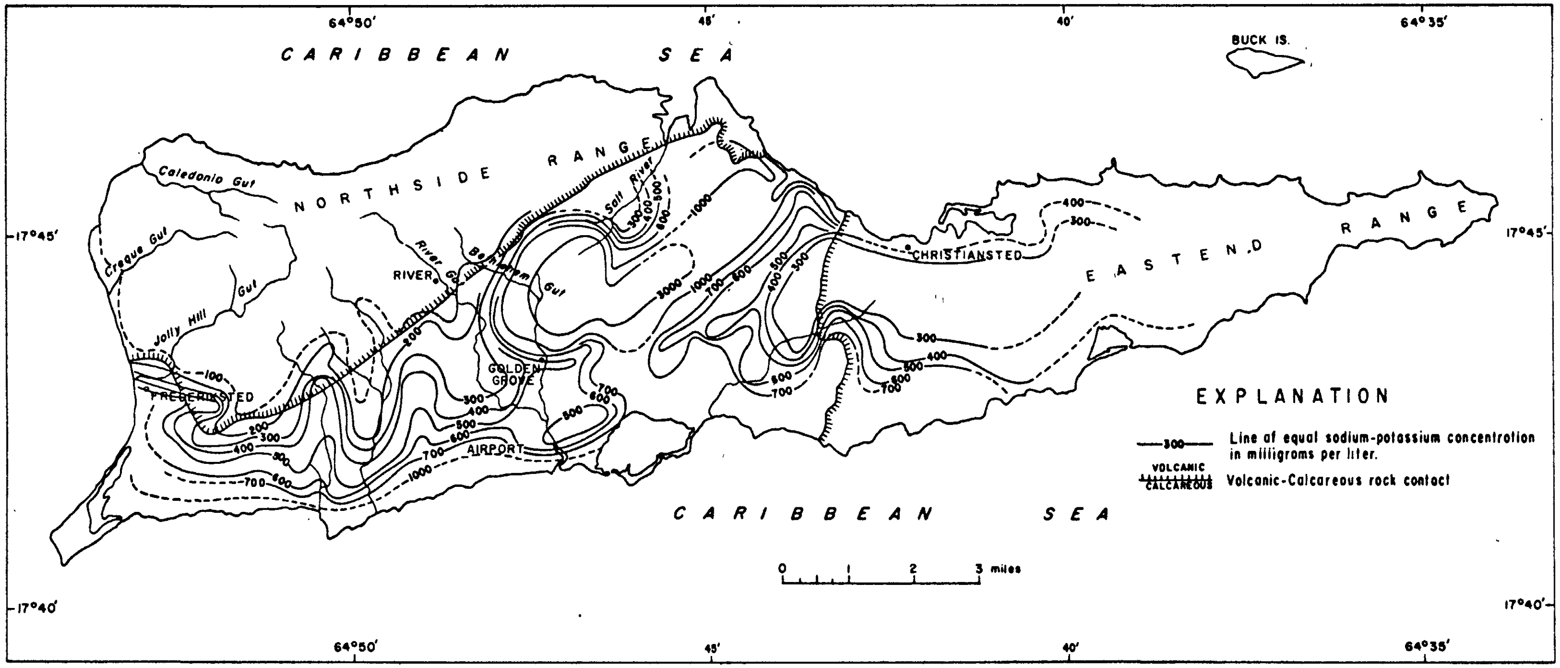


Figure 27.--Sodium potassium concentration of typical well water.

POTENTIAL DEVELOPMENT OF WATER SUPPLIES

Rainfall catchments, ponds, streams, and underground water have been utilized for water supply in the past and are still potential sources of water for the future.

Rainfall Catchments

Rainfall catchments have been proven to be a good source of water, as long as the demand is small as has been shown by centuries of use for domestic supplies. Catchments are seldom feasible for large or even moderate water demands because of space requirements and the large water-storage facilities needed. Studies in St. John (Cosner, 1972) and St. Thomas (Jordan and Cosner, 1973) have shown that large hillside catchments have a recovery efficiency of about 70 percent. In addition, only about 90 percent of the annual rainfall recovered can feasibly be stored--to store all rainfall recovered would more than triple storage requirements. For example, a catchment yielding 100,000 gpd would require an area of about 50 acres and storage of 13 million gallons.

Surface Water

Historical evidence indicates that streamflow was once substantially greater than at present. The decline in streamflow appears to be directly related to the reversion of pasture and cropland to brush and forest.

Flow, even in years of normal rainfall, is small and at least half the annual flow can be expected as runoff from two or three major rainstorms. Reservoir storage requirements to retain the occasional storm runoff would be large in terms of potential daily yield. In addition evaporation losses incurred during long-term storage could be as much as 60 inches per year (Jordan and Cosner, 1973) as indicated by studies in St. Thomas.

The many small ponds and reservoirs on the island have been of beneficial use in that they retain storm runoff water that might be lost to the sea and can be a source of water for stock, supplementary irrigation, and minor industrial use.

Streamflow could be a source of recharge to the aquifers of the island--a possibility that will be discussed later.

Ground Water

The estimated average use of ground water from major well fields in 1967, as shown in table 6, was about 0.9 mgd (million gallons per day). Production was principally from the Barren Spot, Concordia, and Upper River-Bethlehem Gut areas. Several major fields were not in production or were producing at reduced yields. The well fields at Golden Grove and Manning that supplied about 100,000 gpd each were out of production due to the closing of the Bethlehem sugar factory. Pumping from the Mahogany Road well field supplying Frederiksted was reduced in late 1967 from about 100,000 to 30,000 gpd because of salt-water encroachment. Extremely low ground-water levels reduced the yield of the Adventure well field from an estimated potential yield of 100,000 to 10,000 gpd.

Other wells concentrated principally in Central St. Croix supply local domestic, industrial, agricultural, and public water-supply users. Total water use for these consumers is estimated to be about 0.8 mgd.

Table 6.--Development of ground water for major public and industrial supplies on St. Croix. (See fig. 17 for well field location.)

Location of well field	Supplies water to	Estimated average use, 1967, gallons per day
Property (Mahogany Road)	Frederiksted	30,000 [1]
Adventure	do	10,000
Manning	do	30,000
Concordia	Christiansted	100,000
Barren Spot	do	500,000
Barren Spot	Hess Oil Co. housing area	100,000
Golden Grove	Bethlehem sugar factory	100,000 [2]
Manning	Bethlehem sugar factory	100,000 [2]
Upper River and Bethlehem Gut basins	Fountain golf course	150,000
		1,120,000

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[1] Production reduced in 1967 from 100,000 to 30,000.

[2] Factory closed in 1966; wells no longer used.

Estimates of potential yield reveal that as much as 3.9 mgd of ground water may be available for development, or 2.2 mgd more than is being used now. Of the 3.9 mgd, it is estimated that the northwestern ground-water province has a potential of 0.9 mgd; the eastern province, 0.4 mgd; and the central province, 2.6 mgd. The estimates were made for a year of average rainfall and assume no net change in ground-water storage; that is, recharge equals discharge.

Calculations of aquifer transmissivity from pumping tests, specific capacity data, and records of streamflow and rainfall were used for estimates of yield. Data are extremely sparse for most places on the island, so the estimates are far from definitive. They do provide, however, a basis to compare the potential for ground water from place to place, once the existing development is considered. The estimated production and potential yield for each of the ground-water areas, described previously, is shown in figure 28.

The estimates of potential yield are based on conditions of recharge, evapotranspiration, and water use as they currently exist. In part, these conditions result from only about 1 to 6 percent of the annual rainfall reaching the water table. Means of increasing recharge, decreasing evapotranspiration, or varying patterns of water use may be effective in providing more water in places than the potential estimated.

Yield by Ground-Water Area

Area 1

The potential ground-water yield from Area 1 is estimated to be 0.9 mgd in times of average rainfall. Because of the low storage capacity of the rocks in the area, there is little carryover storage available to sustain the bedrock-aquifer during periods of drought greater than a year duration. Hence, the yield of the aquifer is closely related to the rainfall available to replenish it.

The potential ground-water yield of subarea 1-a is about 360,000 gpd--an average effective recharge of about 0.8 inch annually. The fractured bedrock underlying the alluvial plain at the

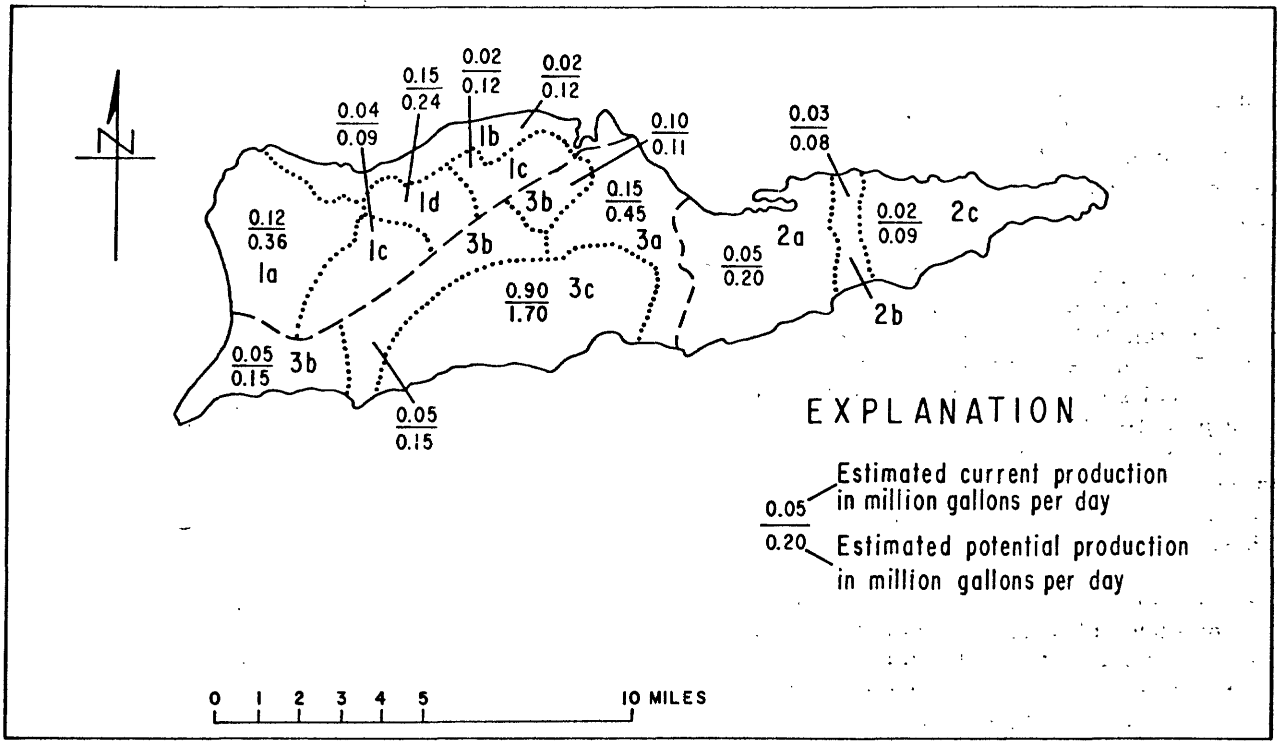

Figure 28.--Estimated current production and potential yield from ground-water areas, 1967.

mouths of Creque Gut and Jolly Hill Gut will yield about 60,000 and 100,000 gpd, respectively. Development of the mountain basins of these streams would yield about 70,000 gpd each. Such development would reduce base flow in the streams, but it is believed that it would not adversely affect recharge to the coastal plain.

The remainder of the potential yield of the subarea can be developed in the small mountain valleys and coastal plain adjacent to Creque and Jolly Hill Guts.

As mentioned earlier, the potential yield of the bedrock underlying the alluvial plain of Jolly Hill Gut could be increased by selective deforestation of the basin to increase base flow and also by utilizing water from Mt. Washington Reservoir or Creque Gut for recharge. An estimated 200,000 gpd for recharge could be realized from increased base flow in Jolly Hill Gut. Artificial recharge utilizing water from Mt. Washington Reservoir could add an additional 30,000 gpd to the potential yield.

The potential ground-water yield of subarea 1-b is estimated to be about 120,000 gpd, the equivalent of about 0.5 inch of recharge annually. Steep slopes and bluffs which descend from altitudes of 800 feet or more to sea level in the distance of a mile or less preclude a large volume of recharge or of storage. Bedrock underlying the alluviated valley of La Vallee will yield an estimated 40,000 gpd. The adjacent valley, to the east of Rust-Up-Twist, probably will yield an equivalent amount of water. An additional 40,000 gpd probably can be obtained from the remaining valleys scattered along the north coast.

Ground-water yields from the alluviated valley at La Vallee could be improved slightly by the construction of leaky retention dams in the ephemeral stream channel to delay stream runoff, thus allowing it to infiltrate the alluvium rather than run off to the sea.

Much of subarea 1-c lies in the high rainfall area of St. Croix. Steep slopes are detrimental to recharge, but much of the potential recharge and ground-water yield is lost through interception by the dense vegetation which blankets the slopes.

Annual recharge to the eastern and western parts of Area 1-c is about 0.6 inch. Under different conditions of land use the ground-water yield of the area probably could be doubled. Historical evidence indicates that perennial or at least intermittent streams supplied by ground-water discharge once flowed in the valleys when the area was in pasture or cropland. The eastern part of the area will yield about 120,000 gpd. Estimated yield of the western area is 70,000 gpd of which 45,000 gpd is obtainable in the valley in the vicinity of Grove Place. The valleys passing through Hope, Cane Valley, and Robe Hill have estimated yields of 8,000, 12,000, and 5,000 gpd, respectively.

The Fountain and Hermitage basins, Area 1-d, have a potential ground-water yield of about 240,000 gpd in a year of normal rainfall. The yield is equivalent to about 1.8 inches of recharge annually.

The area offers an excellent opportunity for water management. The potential ground-water yield can be increased by 30 percent or possibly more by controlled mining of water from the aquifer and the retention of storm runoff in small reservoirs for later recharging to the aquifer.

Recharge to the basins occurs in periods of one or two days, during infrequent major rainstorms. Both the weathered gabbro and alluvium readily infiltrate rainfall, but if ground-water levels are high, due to previous recharge, much of the infiltrating water is rejected and discharged to the streams. Mining water would provide greater storage below stream base level for infiltrating water, and thus makes more water available for later use. Immediate results, particularly if storm runoff retention reservoirs were used in conjunction with the mining operations, would be a reduction in storm runoff. Long-term results would be a reduction in the base flow and very likely the elimination of base flow in the streams. Streamflow would be limited to the occasional storm runoff of sufficient volume to overwhelm the infiltration capacity of the aquifer and the storage of the retention reservoirs.

With proper management, the ground-water yield of the area could be increased to a minimum of 320,000 gpd. Average effective recharge over the basins would be only 2.3 inches annually, which is not deemed excessive in terms of average rainfall and the infiltration capacity of the basins.

Area 2

Rainfall on eastern St. Croix ranges from less than 40 inches annually in the hills south of Christiansted to about 30 inches on the easternmost end of the island.

The lack of rainfall and dense brush covering most of the area contribute to the small ground-water potential of the area estimated to be about 370,000 gpd.

Subarea 2-a has an estimated potential yield of 200,000 gpd, the equivalent of less than 0.4 inch of recharge annually. The ground-water yield, almost all from volcanic rocks, is about equally divided between the areas north and south of the central east-west ridge. The three major valleys east of Christiansted will each yield about 25,000 gpd and the one west of Christiansted about 15,000 gpd. The remaining 10,000 gpd probably can be gleaned from the small valleys in and south of the town proper. Increasing urbanization of these valleys probably will reduce the natural recharge to the aquifers, but as sanitary services for the dwellings are provided for by septic tanks, it is very possible that as the number of dwellings increase, supplemental recharge by increased effluent from septic tanks will actually increase the ground-water yield in the valley aquifer. The usability of the water, however, may be questionable.

The 100,000 gpd ground-water yield from the southern part of the area is believed to be relatively well distributed. The area of the broad alluvial plain, which covers much of the southern part, offers a good potential for recharge to the underlying bedrock.

Subarea 2-b is underlain by diorite and covered with an extensive alluvial mantle. The granular nature of the alluvium and relatively low relief is beneficial to recharge when major rains occur. Effective recharge is about 1 inch annually. Potential yield of the area, nearly all from the diorite, is about 80,000 gpd of which about 50,000 gpd can be obtained north of the central divide and the remainder to the south of the divide.

The general lack of rainfall and the corresponding lack of storm runoff does not offer much opportunity to increase the ground-water yield by retention of storm runoff and allowing it to infiltrate into the alluvium.

Subarea 2-c has a potential ground-water yield of about 90,000 gpd or about 0.2 inch effective recharge annually. Nearly all available ground water is from volcanic rocks west of a line from Knight Bay to Grapetree Bay. About two-thirds of the potential yield is in the major alluviated valleys of the north coast. The remainder, about 30,000 gpd, is available in the hills of the central ridge and in the major valleys of the south coast.

Area 3

Area 3 not only has the greatest ground-water potential on St. Croix but also has the greatest potential for management and development of its water resources. An estimated 1.2 mgd of ground water is being used at present, nearly half of the 2.6 mgd estimated ground-water potential of the area. The ground water in the area is slightly brackish to saline--water in the alluvium ranging from 250 to 500 mg/l chloride, while that in the limestone is greater than 500 mg/l. The water being of poor quality does not prohibit its use. The very fact that the estimated ground-water pumpage from the area tripled between 1960 and 1967 would indicate that the water is usable.

The ground-water potential in parts of Area 3 varies widely. Estimates of effective recharge ranges from about 0.50 inch in the relatively flat central lowland underlain by marl and mantled by thin alluvium, to nearly six times that amount in the south coast area with its permeable reef limestone calcarenite, and broad alluvium-filled valleys. In the alluvial valleys streamflow, whether storm runoff or base flow, exerts considerable influence in the development of the ground-water resources.

Subarea 3-a, which comprises the arc of limestone hills of the northeastern and eastern part of the limestone block, has an estimated potential ground-water yield of 450,000 gpd.

The limestone of the hills and coastal terrace north of the central divide has an estimated yield of 150,000 gpd, the equivalent of about 1 inch of recharge annually. Most of the usable water is found in limestones underlying the coastal terrace. Development of the area is limited to drilling additional wells to totally utilize the natural recharge from rainfall.

The arc of limestone hills and valleys to the south of the central ridge has a potential yield of about 300,000 gpd, the equivalent of 1.2 inches of recharge annually. The greatest potential for development lies in the valleys, as ground-water movement is to and through the valleys.

Small leaky reservoirs in the valleys to trap storm runoff for recharge are feasible and could enhance the local ground-water potential. It has been observed, however, the storm runoff from these valleys infiltrated the alluvium of the larger streamless valleys to the south. In terms of increasing the overall ground-water potential, retention-recharge reservoirs in the upper valleys are not necessary as long as the recharge areas in the major valleys are not destroyed.

That part of the area lying south of Annas Hope to the sea lacks the extensive valley development of the more northern area. The broad valley through Humbug appears to offer the greatest possibility for development of ground water.

The lowland lying at the foot of the Northside Range (subarea 3-b) has a potential ground-water yield of 420,000 gpd. The development of what could be considered potable supplies, however, is limited.

The eastern part of the lowland, essentially the alluviated valley of Salt River, has an estimated ground-water yield of 110,000 gpd, the equivalent of 1.3 inches of recharge annually. As approximately 100,000 gpd is pumped from the Concordia well field located in the valley, the ground-water potential under present conditions must be considered as being fully developed.

Should conditions in the watershed change so that storm runoff were increased, or the stream was once again perennial, the ground-water potential would increase proportionally.

The central part of the lowland is underlain by marl covered by a thin mantle of alluvium. A buried channel filled with silt and clay is believed to run through the area from east to west turning south to the sea. The ground-water potential of the area is estimated to be about 150,000 gpd, the equivalent of about 0.50 inch of recharge. Ground water throughout most of the area is brackish. Potable ground water and practically the entire potential of the area lies along the foot of the Northside Range where sand and gravel deposits, presumably fossil fans, are present in the subsurface. Some ground water is available in the western part of the area near the sea.

There is little opportunity for supplementing the ground-water potential of the area. The overlying alluvium in most places readily accepts recharge but is too thin to retain water, losing most of it by evapotranspiration or discharge to streams.

The area is very favorable for the construction of small-storm runoff retention ponds in the stream channels. Water thus retained could be released for recharge to downstream alluvial aquifers.

The western part of the lowland has a potential yield of about 150,000 gpd, the equivalent of about 0.65 inch of recharge annually. The greatest potential lies in an east-west strip comprising the middle third of the area. The rocks of the northern third of the area are predominantly marl and as such have little potential, whereas the rocks of the southern third of the area are predominantly reef-type limestone and have a high potential yield but generally produce brackish water due to encroachment from the sea.

The area offers little or no potential to supplement the ground-water yield by artificial means.

Subarea 3-c is the principal area of actual and potential water development in St. Croix. Ground-water pumpage is approaching 1 mgd of which an estimated 600,000 gpd is from the Barren Spot area. The estimated potential yield of the area is about 1.7 mgd, the equivalent of about

2.90 inches of rainfall annually. Actual effective recharge to the limestone hills probably is about 1 inch annually, whereas recharge to the alluvium from rainfall and streamflow probably is 5 inches or more annually. Recharge to the porous limestone and alluvium of the coastal terrace is estimated to be about 5 inches annually, principally from rainfall.

Major areas of actual and potential development of potable water are the alluvial valleys of River Gut and Bethlehem Gut, the alluvium and underlying limestone of the streamless valleys at Barren Spot and Castle Coakley, and the valley through Annas Hope-Cassava Garden. The coastal terrace in the vicinity of the airport and Krause Lagoon has minor potential as does the limestone upland. The basal part of the Kingshill Marl in the vicinity of Barren Spot and Castle Coakley has potential as a source of brackish water for desalting operations.

Storage in the alluvium of River and Bethlehem Guts is estimated to total 400 million gallons when saturated to stream level. About 100 million gallons is estimated to be recoverable without causing serious salt-water encroachment.

The potential yield of the alluvium is dependent upon recharge from rainfall and streamflow. In years when rainfall and streamflow are near or greater than average, the yield would approach 500,000 gpd, whereas in dry years the yield would be about 200,000 gpd. A prolonged dry period of more than a year would reduce the potential yield to near zero.

The yield of the alluvium could be enhanced by utilizing retention-recharge ponds in the stream channel downstream of Centerline Road to retard base flow and minor storm runoff, thus facilitating recharge. Major storm runoff that would overwhelm the reservoir capacity could be diverted by the retention dams over the valley floors utilizing them as temporary water-spreading areas.

Induced infiltration of streamflow into the alluvial aquifer is feasible, as is shown by the loss in flow of River Gut (fig. 29) between Golden Grove and the airport. Dry period flow showed about a 90 percent loss to the aquifer at discharges up to 350,000 gpd, the maximum measured, whereas wet period losses are variable reflecting storage in the aquifer. The key to infiltration, therefore, is storage space available in the aquifer.

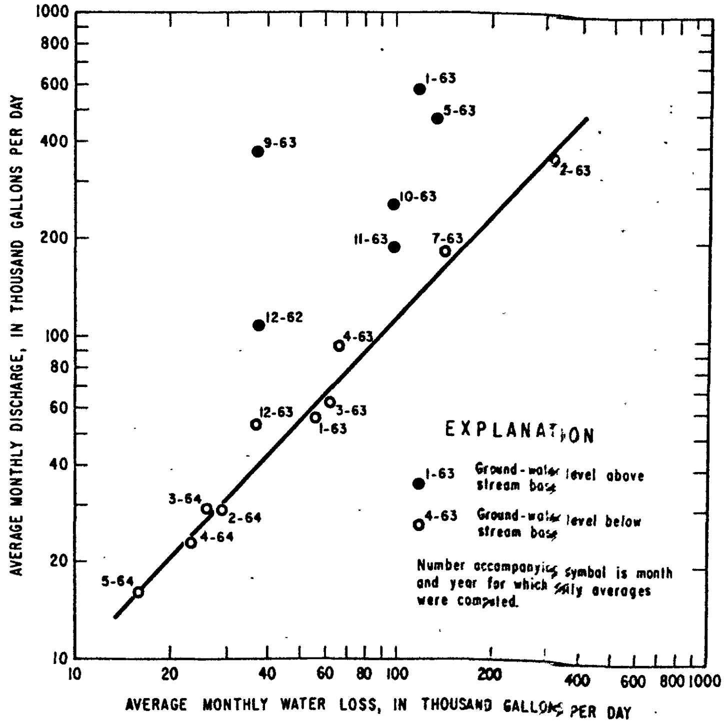

Figure 29.--Water loss from River Gut to valley alluvium between Golden Grove and Alexander Hamilton Airport.

Wet year base flow of about 200,000 and 100,000 gpd for River Gut and Bethlehem Gut respectively could be recovered by retention-infiltration ponds as could minor storm runoff of about 200,000 and 100,000 gpd respectively for River Gut and Bethlehem Gut. If aquifer storage were made available through controlled pumping the flow would infiltrate the aquifer without the benefit of the recharge ponds, but it is assumed that temporary surface storage would be required approximately half the time. The recharge ponds would have little effect on the yield of the aquifer in dry years except for the additional water made available through retention of major storm runoff.

Maximum development of recharge structures in the valleys could increase the potential yield to about 800,000 gpd in wet years. In dry years, however, the potential yield would be about the same as under natural conditions or about 200,000 gpd except for the possible advantage of carryover storage.

A possible source of supplemental recharge water is treated sewage effluent. Several means of application could be utilized, dependent upon degree of treatment. The effluent could be used for irrigation of crops, the excess water from irrigation being contributed to the aquifer.

Treated sewage could also be applied through permanent recharge ponds, water-spreading areas, or recharge wells provided objectionable mineral or organic material were removed prior to application. Any method utilizing sewage effluent should be thoroughly investigated for applicability.

The alluvium filling the three major valleys of Barren Spot, Castle Coakley, and Cassava Garden in the eastern part of Area 3-c has an estimated 500 million gallons of water in storage, of which about 200 million gallons could be recovered without excessive salt-water encroachment. The average potential yield of the alluvium is about 250,000 gpd, but total recovery would be difficult due to the overall low yield of wells. The principal water-bearing zones are thin discontinuous beds of sand and gravel and tapping these zones would be a hit-or-miss operation. It may not be feasible to develop the alluvium as a unit although it is quite feasible to develop the alluvium in conjunction with the underlying Kingshill Marl.

The principal benefit derived from the alluvium is its capability to accept large volumes of water and replenish the underlying Kingshill Marl aquifer. Maximum development of the limestone aquifer, therefore, depends upon maintaining the recharge capabilities of the alluvium. As long as the alluvial valleys are in cropland or pasture, rainfall and storm runoff from the surrounding hills will infiltrate the alluvium with no loss to the sea (there is occasional storm runoff to the sea in the stream passing through Cassava Garden). It is likely, however, that these valleys will be developed as residential or industrial sites. Such development could destroy the infiltration capabilities of the alluvium, thus reducing the potential yield of the alluvium and limestone aquifer. A compromise could be reached by utilizing green belts in the valleys as artificial recharge sites. Storm runoff from the hills and developed areas could be funneled to retention ponds and water-spreading areas in the green belts. The same system could also be used for recharging the aquifer with treated sewage effluent.

A green belt system should be capable of controlling the runoff from an area of about 6 square miles or about 300 acre-feet of water as a major rainstorm under maximum runoff conditions would produce about 65 acre-feet of runoff per square mile.

Retention and recharge of rainfall and storm runoff in the green belts would not increase the potential yield of the alluvial or limestone aquifers, but could serve to maintain the recharge that would naturally occur on crop or pastureland. Artificial recharge utilizing treated sewage effluent could increase the potential yield of the aquifers.

The Kingshill Marl underlying the alluvium is the principal source of water to wells in the valleys. About 500,000 gpd are being pumped from the Kingshill Marl and 100,000 gpd from the alluvial aquifer underlying the lower Barren Spot valley. It is likely that little potential remains for developing additional water of usable quality from this area as ground-water levels have been depressed to or slightly below sea level in the vicinity of the major well fields and water quality is in the range of 1,000 mg/l chloride and 2,500 mg/l dissolved solids.

Ground water in the adjacent valley of Castle Coakley has been but slightly developed--primarily for domestic and stock use. An estimated 100,000 gpd could be developed from the alluvium and 300,000 gpd from the underlying Kingshill Marl in the valley.

The area of major ground-water development in the valley through Cassava Garden lies in the middle reach. The potential yield of the alluvium is probably less than 50,000 gpd but the underlying Kingshill Marl has a potential yield of about 150,000 gpd.

The coastal terrace is underlain by alluvium filling a buried channel to depths of over 100 feet from Krause Lagoon to the vicinity of River Gut and porous reef-type limestone west of River Gut. The alluvium east of River Gut and adjacent to Krause Lagoon had little fresh-water potential due to the lagoon. Dredging of a harbor and salt-water canals in the lagoon has further reduced the fresh ground-water potential to essentially zero.

The potential yield from alluvium and limestone of the coastal terrace west of River Gut is small because of the danger of salt-water encroachment although well yields are as great as 150 gpm. West of River Gut 100,000 gpd of water containing 500 to 1,000 mg/l chloride could be obtained. Greater yields are possible but only at the expense of poorer water quality. If the alluvium of River Gut is fully developed, ground-water flow to the sea through the limestone ridge west of River Gut and north of the airport would be reduced and salt-water encroachment could occur in the aquifer underlying the coastal terrace.

Artificial recharge areas could be developed in the vicinity of the airport and River Gut to create a fresh-water barrier to protect inland well fields developed in River Gut and Bethlehem Gut. Either storm runoff from the airport runway and paved areas or treated sewage effluent could be used.

The limestone uplands bisecting the area appear to have little potential other than for domestic wells. A combination of topography and subsurface geology may be a factor. Wells in the hills generally tap only the upper part of the Kingshill Marl, a mixture of limestone and marl beds yielding little water. Deeper wells, of 300 to 400 feet, east of River Gut, likely would tap the basal calcarenite (fig. 16) of much higher yield. West of River Gut the basal calcarenite is absent, marl is predominant, and yield would be small of even the deep wells.

The overall potential of the uplands for the development of water of usable quality probably does not exceed 150,000 gpd if the basal calcarenite is excluded.

The basal Kingshill Marl, underlying much of the area, contains a large volume of brackish water ranging in quality from 1,000 to more than 20,000 mg/l dissolved solids. In general the water becomes more mineralized with depth. Robison (1972) estimates that nearly 45 billion gallons of water having 6,000 mg/l or less of dissolved solids are in storage. Of this he estimated 35 billion gallons is recoverable.

The brackish water has potential as a source of water if demineralized. A large demineralizing operation would require that the ground water be mined (pumpage exceeding recharge) in view of the inadequate recharge from rainfall. Mining would partly de-water the overlying rocks containing better quality water and also cause salt-water encroachment from the sea. Thus, such an operation could only be undertaken with the foreknowledge that potable water in the overlying rocks and the brackish water in the basal rocks would eventually be depleted.

The utilization of the green belt concept and sewage effluent for recharge to the alluvium, and hence to the underlying rocks of the area would prolong the life of the mining. It is conceivable that the combination of natural and artificial recharge would balance withdrawals, stabilizing salt-water encroachment. It is even possible that if stabilization were achieved water quality in the aquifer would improve as the water applied through artificial recharge likely would be less mineralized than the existing water in the aquifer.

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