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UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey

GROUND WATER IN CENTRAL ST. CROIX, U. S. VIRGIN ISLANDS

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

1972

PREFACE

This report and the investigation upon which it is based were done under a cooperative program of the U.S. Geological Survey and the Virgin Islands Government. Water is precious in chronically water-short St. Croix. Knowledge of the occurrence, availability, utilization, and chemical quality of the island's water, therefore, is more than valuable; it is essential. This report is confined to a discussion of the central part of the island, for there are few places outside this area where high-yielding wells can be obtained.

Much of the report is based upon estimates that, although rough, should prove useful in preliminary planning. Data from 237 wells form the basis for the estimates. Complete chemical analyses were made of water from 91 of these wells in addition to partial field and laboratory analyses of water from many other wells. Cuttings from several wells were examined. Specific-capacity data were correlated with lithologic data to obtain transmissivity values.

Many persons aided in the investigation, but special recognition is given to Mr. Albert Nelthropp, Assistant Director of Public Works, and to the drillers, Mr. Robert Clark and the late Mr. Eugene Schuster. Also, much is owed to the previous investigations mentioned in the body of the report or in the selected references at the end of the report.

SUMMARY OF PRINCIPAL FINDINGS

1. The principal aquifer in central St. Croix consists of the Kingshill Marl and associated alluvium. In one area, well yields of a few hundred gallons per minute are possible. In other places, however, well yields are ~~much less~~--5 to 40 gpm (gallons per minute) from the alluvium and 10 to 40 gpm from the marl.

2. Ground-water recharge is estimated to be 3 percent of rainfall or about 1 3/4 mgd (million gallons per day).

3. Pumpage is estimated to be less than 1 mgd.

4. The water available at typical well depth is brackish and is high in sodium chloride and sodium bicarbonate. There are two areas where salinity is anomalously high, which may be caused by salty connate water being squeezed from a compacting clay formation that underlies the aquifer.

5. The total water stored in the aquifer is estimated to be 130 billion gallons. Of this water, about 35 billion gallons could be recovered and desalted by electrodialysis. At projected levels of water use, this water of better quality--water capable of being desalted by electrodialysis, with 6,000 mg/l (milligrams per liter) or less dissolved-solids content--would be exhausted in about 29 years. Replenishing the aquifer with treated sewage would extend the time to about 38 years. More water of poorer quality, of course, could be desalted by currently more expensive methods, such as distillation.

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HYDROGEOGRAPHY

Location

The island of St. Croix is in the Lesser Antilles of the West Indies. It is the largest and southernmost of the U.S. Virgin Islands and is the easternmost possession of the United States. It lies about 55 miles east-southeast of Puerto Rico and about 40 miles south of St. Thomas and St. John (fig. 1).

Topography and Drainage

Central St. Croix, as identified in this report, occupies about 28 square miles of the island's 82 square miles. The larger part of the area is ringed on the north by rugged, deeply incised hills, giving the effect of part of an amphitheater. The interstream areas to the south are occupied by steep to gently rolling low limestone hills. With the exception of Salt River in the north, the major streams converge toward the south-central coast. The streams are intermittent, dry for long periods in most reaches or flowing only briefly after heavy rainfall. Their intermittent character is especially noticeable in the east, where the drainage areas are small. As a consequence, the streams in the east have poorly defined stream channels. Valley gradients are low to moderate in the lower reaches, being high only near the valley heads. There are no natural lakes, but there are several artificial impoundments and a small swamp.

Climate

The climate is tropical marine. Average annual temperature is 78° F, and temperature variation is only minor from season to season. Average annual rainfall is 44 inches, the greatest rainfall being in May and in August through November. Winter is the driest period. Northeast trade winds blow most of the year.

Industrial, Agricultural, and Urban Development

Central St. Croix is in a period of rapid population and industrial growth. The largest industrial plants are a petroleum refinery, an alumina plant, and a rum distillery. Several smaller plants are engaged in watch assembly, pharmaceutical manufacturing, soft-drink bottling, slaughtering, and cement-block manufacturing. There are numerous wholesale and retail stores. Public and private housing and tourist facilities are increasing rapidly. The busy Alexander Hamilton Airport is in the south-central part of the area.

Raising and processing sugarcane once was the principal industry, but because of economic

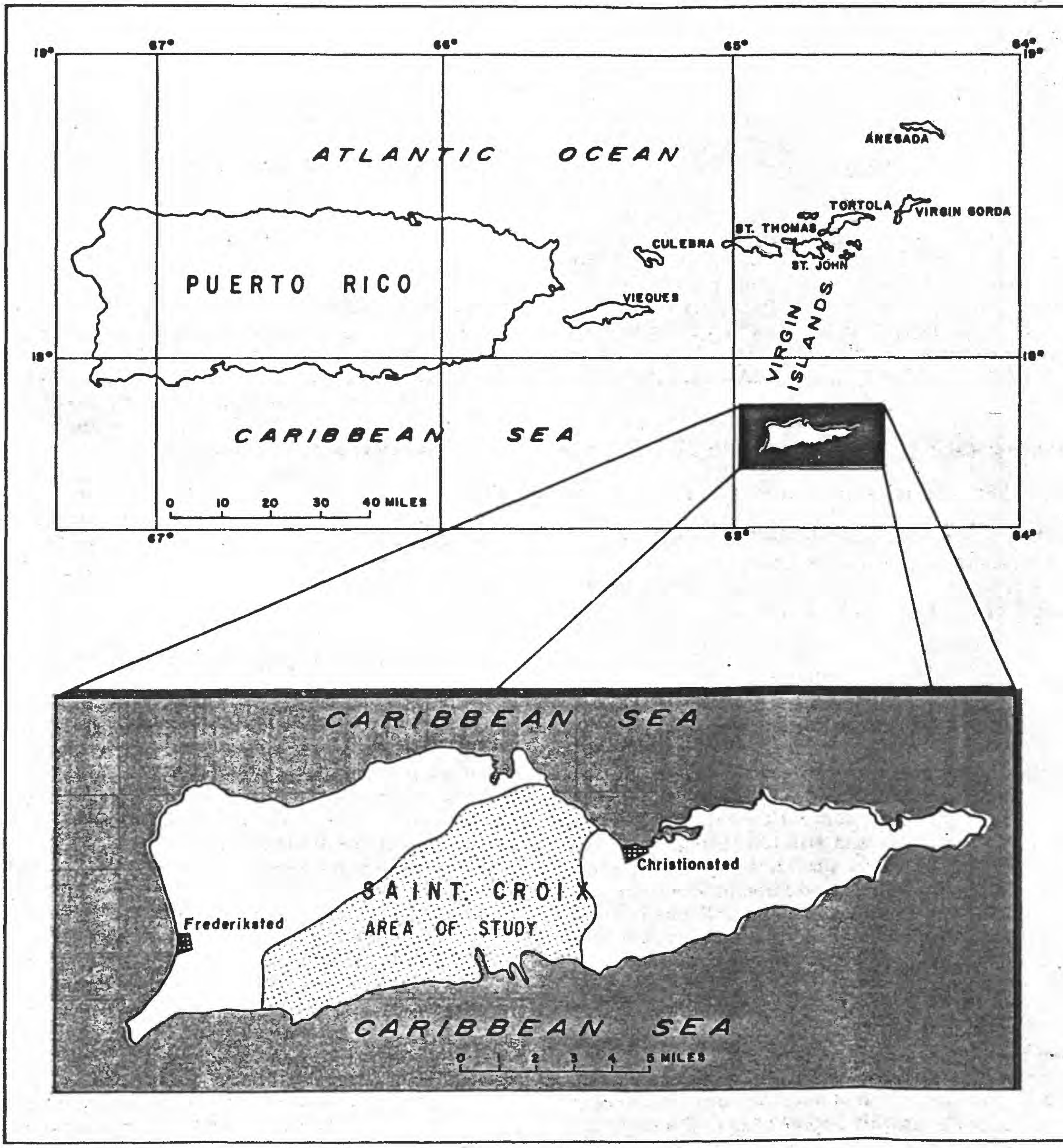

Figure 1.--Location of the area studied for this report.

factors the sugar industry has disappeared. With the exception of a few truck and experimental farms, agriculture is largely restricted to the grazing of goats, sheep, and cattle. There is an experimental forest in the Sion Hill area.

HYDROGEOLOGY

Volcanic Rocks

Volcanic rocks underlie all of St. Croix. These rocks are not discussed in the present study because, with the exception of a well field north of Frederiksted, well yields from the volcanic rocks are not considered adequate for public supply. Descriptions of these rocks can be found in reports by Cederstrom (1950), Whetten (1966), and others. (See Selected References.)

Jealousy Formation (" Blue Clay")

The Jealousy Formation consists of an unknown thickness of gray to bluish or greenish-gray clay and a few thin beds of limestone. Although the formation is not known to be water bearing, it is significant because it underlies the Kingshill Marl aquifer (figs. 2 and 3--in pocket).

Kingshill Marl

Central St. Croix was once occupied by a shallow sea in which there was abundant coral life. The corals and the debris derived from them make up much of the Kingshill Marl. The formation consists of beds of soft yellow-orange to white sandy, limey clay and siltstone alternating with nearly pure to clayey limestone. Volcanic pebbles are common. Oölites and foraminifers also are common. Its maximum known thickness is about 500 feet. Its estimated maximum saturated thickness, however, is somewhat over 200 feet (fig. 4--in pocket).

The Kingshill Marl is an aquifer and is capable of yielding several hundred gallons per minute to wells drilled through its maximum saturated thickness, but drilling that deep has been discouraged by the progressively poorer chemical quality of water with depth. The Kingshill Marl is the principal aquifer in the Barren Spot and Concordia well fields (fig. 2--in pocket).

Alluvium

Except for the absence of limestone beds and the greater number of sand and gravel beds, the alluvium may be difficult to distinguish from the Kingshill Marl. As in the Kingshill, soft sandy, silty buff to white marl is common. The alluvium is generally somewhat lighter in color than the underlying Kingshill Marl. But in the northwestern and north-central parts of the study area, the alluvium consists almost entirely of gray to brown clay (fig. 2--in pocket). Where the streams emerge from the mountains, however, pockets of sand and gravel are not uncommon. Alluvium is the principal aquifer in the Adventure and Fair Plain well fields.

Natural Recharge, Discharge, and Storage

Most of the rainfall is evaporated and transpired. A much smaller amount runs off as streamflow. The rest percolates to the water table, where it becomes part of the ground-water body. This part of the rainfall is called ground-water recharge. There is no accurate method of measuring the volume of recharge, but the author has made some rough approximations by two methods.

In the first method, it was assumed that the connate water, over the years, had been completely flushed out of the formation from its surface down to the water table and slightly below it by infiltrating precipitation. It was further assumed that all chloride ions in water at and slightly below the water table are derived from bulk precipitation--that is, a combination of dry fallout and rainwater. The chloride content of the rain (actually bulk precipitation) was assumed to be the same as in St. Thomas, V.I., or 7 mg/l (milligrams per liter), as reported in a U.S.

Geological Survey news release (April 13, 1969). Runoff was assumed to be such a small percentage of rainfall that it was ignored. As all rainfall under these conditions would, therefore, evaporate, transpire, or become ground-water recharge, the concentration of the chloride ion in water at or near the water table should give a rough estimation of the relative proportions of rainfall used by evapotranspiration and that part contributing to ground-water recharge. For this estimation, wells subject to chloride contamination or close to stream channels were excluded. The median chloride concentration in water near the water table was found to be 210 mg/l, a 30-fold concentration of the 7 mg/l of chloride in the rainfall. This indicates that ground-water recharge is derived from slightly more than 3 percent of total rainfall, or about 1 3/4 mgd (million gallons per day) over the area.

The second method assumed that average ground-water discharge to the sea was equal to the average recharge from rainfall. By considering the slope of the water table (fig. 5--in pocket), the ability of the aquifer to transmit water (fig. 6--in pocket), and the length of the cross section through which discharge takes place, it was estimated that 1 1/2 mgd is discharged along the south coast. The amount discharged along the north coast would be small in comparison. Here again, a recharge of about 3 percent of total rainfall is indicated, or about 1 3/4 mgd for the area of study.

The total amount of water stored in the Kingshill Marl and associated alluvium is estimated to be 130 billion gallons. Very little of this is potable. Only about one-third is considered to be usable (6,000 mg/l or less dissolved solids--author's standard) for electrodialytic-plant feed water (fig. 7--in pocket). The average dissolved solids in this water of better quality is about 1,500 mg/l.

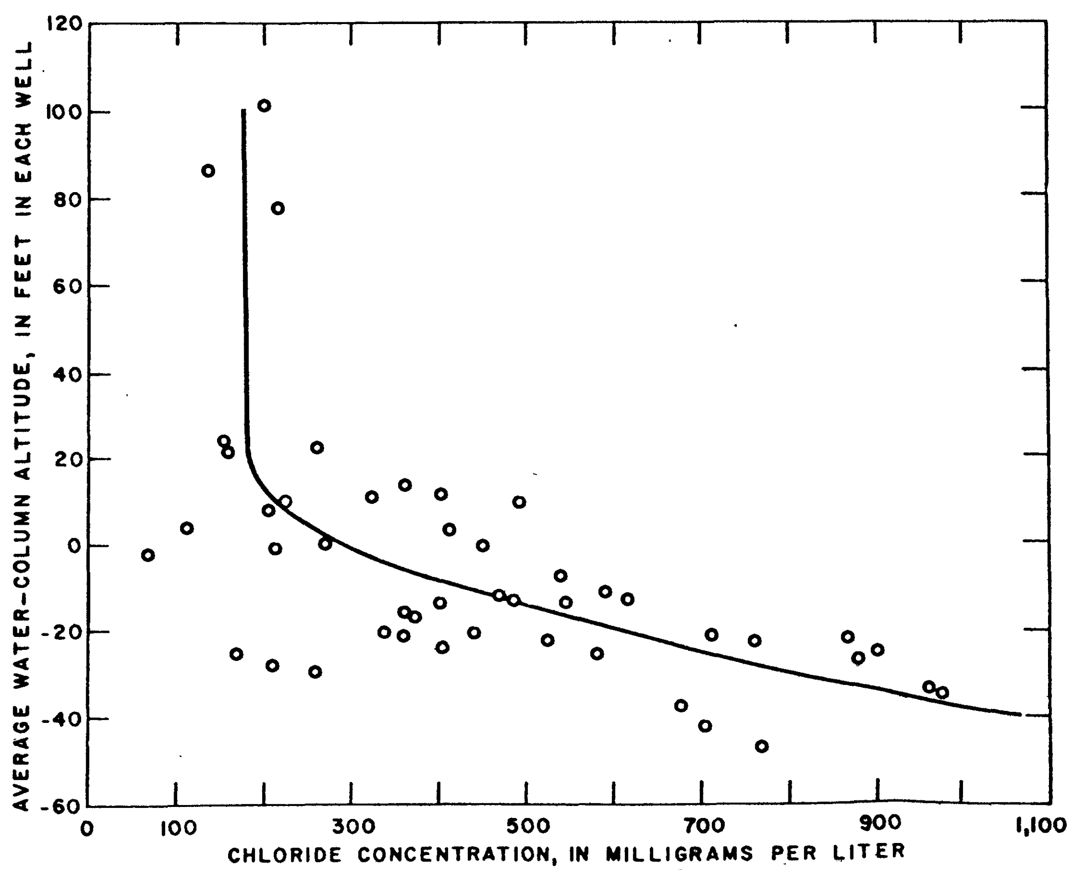

Figure 8.--Generalized curve showing increase in chloride concentration with decreasing altitude in "normal water" area. Note change near sea level. The method assumes that water enters each well uniformly between the water table and the bottom of the well.

The Kingshill Marl was originally filled with sea water. Since these deposits were elevated above sea level, the water in them has been progressively diluted by rainfall. Dilution has been greatest in the upper part of the aquifer, especially where the water table is well above sea level. As shown in figure 8, mineralization increases rapidly with depth below sea level. The classic island hydrologic situation, where fresh water floats upon sea water, is not present in the area because the situation demands an aquifer of fair uniformity. The lack of uniformity in the Kingshill Marl has caused the recharge water to follow circuitous permeable paths, which has permitted much physical mixing and some ionic diffusion between it and sea water. Water-table fluctuations caused by changes in the relative positions of land and sea have accelerated the mixing process. Upward seepage of salty connate water from the underlying Jealousy Formation has further complicated the situation.

Two areas are designated as "high-saline areas," in which the ground water (hereafter referred to as "high-saline water") has unusually high mineral concentration at shallow depth. In the following discussion, ground water from outside the high-saline area and from customary well depths will be referred to as "normal water."

There are at least three possible reasons for the high-saline areas. (1) Circulation of ground water may be restricted by faults, but there is little evidence to support this. (2) The high-saline areas may have underlain lagoons in which sea water was concentrated. The fact that the

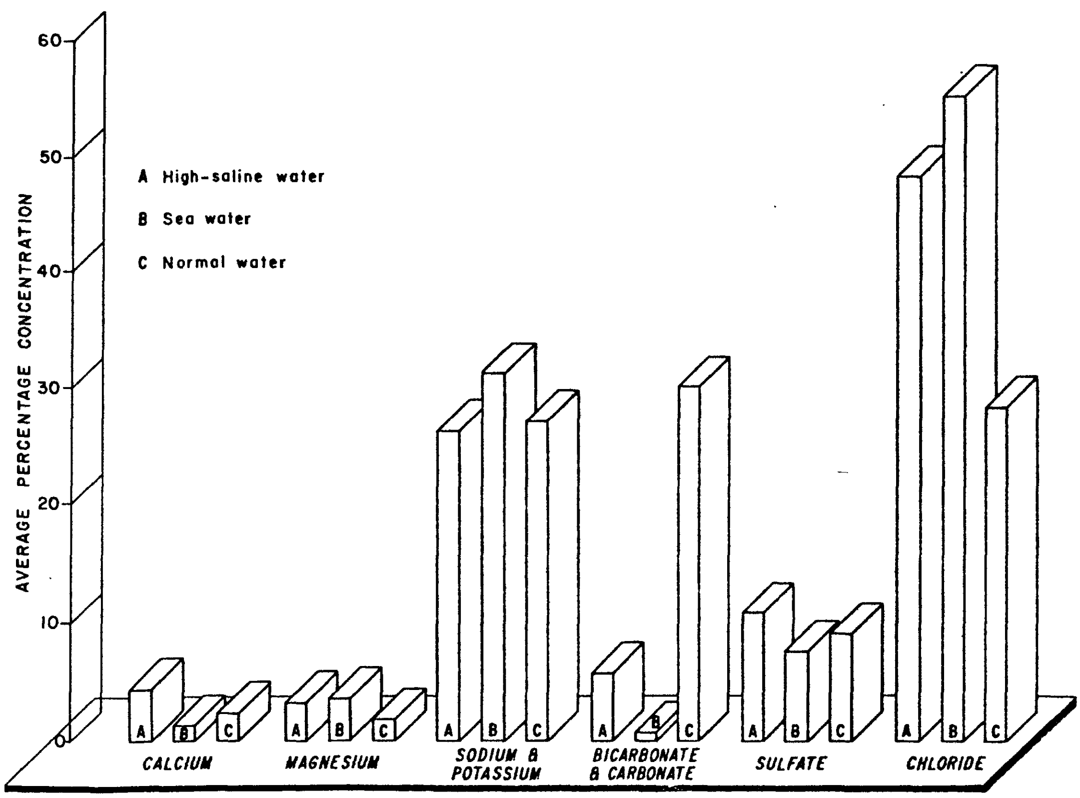

Figure 9.--Average percentage concentrations of inorganic ions in three types of water (total 100 percent; trace ions excluded).

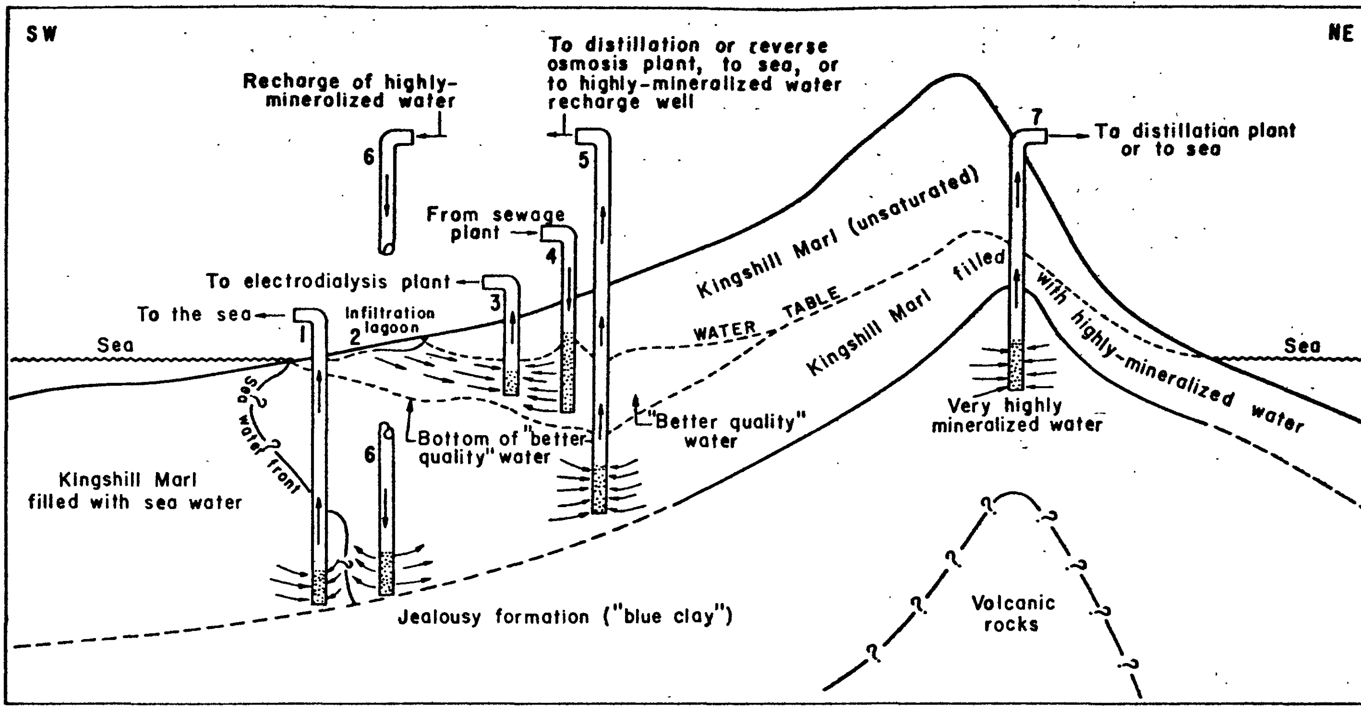

Figure 10.--Diagrammatic southwest to northeast hydrogeologic section across St. Croix. Some of the ground-water development and management alternatives are shown: (1) Sea-water pumping to minimize encroachment; (2) Artificial recharge by surface infiltration; (3) Electrodialysis plant raw-water supply; (4) Injection of treated sewage; (5) Counterpumping to prevent upward movement of highly-mineralized water; (6) Recharge well to prevent sea-water encroachment using counterpumped water; (7) Pressure-relief well to prevent contamination of overlying water by very highly-mineralized water.

average percentage concentrations of calcium and sulfate are somewhat higher than in the normal water or sea water (fig. 9) tends to support this assumption, as hydrated calcium sulfate (gypsum) is precipitated at an early stage of sea-water concentration. Precipitated gypsum would have subsequently been dissolved by ground water. The considerable variation in altitude of the water-bearing beds within the main high-saline area, however, casts doubt on this hypothesis. Also, no ground water more concentrated than sea water has been found. (3) High-saline areas roughly correspond to higher altitudes of the Jealousy Formation ("blue clay"). The formation may be underlain by a ridge of volcanic rock in the same area (fig. 10). With the unyielding volcanic rocks below and a heavy burden of rock above, the clay would become compacted over long periods of time and would lose some of its connate water to the more permeable overlying rocks.

As shown on figure 9 and table 1, the normal water is high in sodium chloride and sodium bicarbonate, whereas the high-saline water is high in sodium chloride and sodium sulfate.

Table 1.--Water quality in central St. Croix, V.I.

Constituent	Significance	Type of water	Number of analyses	Milligrams per liter			
				Minimum	Maximum	Median	Average
Calcium	Calcium and magnesium are the principal causes of hardness. (See hardness.)	High-saline	15	34	1,120	224	365
		Normal	66	6	168	41	53
		Sea water*	--	--	--	--	416
Magnesium		High-saline	15	77	1,400	151	260
		Normal	66	1	126	35	37
		Sea water*	--	--	--	--	1,280
Sodium	High concentration may cause water to be unsuitable for agriculture.	High-saline	15	962	6,020	1,600	2,020
		Normal	65	125	1,090	496	536
		Sea water*	--	--	--	--	10,800
Bicarbonate + carbonate	Principal alkaline factors in water.	High-saline	14	94	602	491	443
		Normal	65	292	852	584	588
		Sea water*	--	--	--	--	152
Sulfate	Gives bitter taste to water. USPHS recommended maximum is 250 mg/l.**	High-saline	15	216	2,440	632	830
		Normal	65	16	752	157	176
		Sea water*	--	--	--	--	2,660
Chloride	Increases corrosiveness of water. USPHS recommended maximum is 250 mg/l, based upon taste.**	High-saline	15	1,360	13,600	2,200	3,700
		Normal	66	70	1,680	487	556
		Sea water*	--	--	--	--	19,200
Fluoride	In low concentration reduces tooth decay; higher concentration may cause tooth mottling. Recommended limits for the Virgin Islands are: minimum = 0.6, optimum = 0.7, maximum = 0.8.**	High-saline	15	.2	4.0	1.0	1.1
		Normal	66	.2	2.4	.7	.8
		Sea water*	--	--	--	--	1.3
Dissolved solids	USPHS recommends a limit of 500 mg/l.**	High-saline	15	3,190	24,500	5,430	7,460
		Normal	65	738	3,470	1,590	1,610
		Sea water*	--	--	--	--	34,800
Hardness as $CaCO_3$	Primarily due to calcium and magnesium. Consumes soap by formation of scum.	High-saline	15	560	8,340	1,140	1,990
		Normal	65	22	1,240	238	289
		Sea water*	--	--	--	--	6,300

* Sea water sample taken from the Caribbean Sea on the south coast of Puerto Rico.

** U.S. Public Health Service (1962).

PRESENT WATER-SUPPLY METHODS IN CENTRAL ST. CROIX

The water-supply methods used at present (1970) include pumping ground water and sea water, desalting sea water, and roof catchments. Water was also barged until recently. There are a few small dams on the island, but because of a long drought that did not end until 1969 these dams have fallen into disuse.

Ground Water

Pumpage of brackish ground water for the public supply system is about 700,000 gpd (gallons per day). Of this, more than 600,000 gpd is produced from central St. Croix. Private pumpage is estimated to be about 300,000 gpd, a total of about 1 mgd.

Desalting

There are three sea-water distillation plants in the area of study, each with a reported capacity of 1 mgd. One of the plants is used for public supply; the other two are used for the refinery and the alumina plant. Outside the area, near the east end of the island, there is a distillin plant with a reported capacity of 100,000 gpd.

Sea Water

Sea water is used for firefighting and sanitary use in both Christiansted and Frederiksted. The total use for these purposes is a little less than 1 mgd. Some homes and hotels have their own sea-water systems.

Roof Catchment

It is customary to store rainwater caught on the roofs of buildings. In addition to private catchments, there is a municipal catchment in Christiansted. The usual capacity of cisterns is 10 gallons for each square foot of roof space. Before the municipal distillation plant was operational, roof-caught water was the primary source of drinking water. The total rainfall catch by this method is not known.

WATER-SUPPLY POTENTIAL OF CENTRAL ST. CROIX

Central St. Croix has a unique and critical value to the future economy of the island. It is the only area where large supplies of fresh-to-brackish ground water are readily obtainable. To determine the optimum use of this water requires careful study of methods of water withdrawal, desalting, blending, waste-water reclamation, recharge, storage, and the selection of the most advantageous combination of methods. Because the amount of available, usable water is finite, the pattern of best utilization of the water resources may vary with time.

The author has made every effort to report the hydrologic characteristics of these ground-water supplies in a format most useful to the water-resources planner. In this reporting, it has been necessary to include appraisal of the anticipated effects of development and management alternatives on the water resource and the natural water-storage facility. Management alternatives identified are those that have been considered by local officials and others, including the author.

Certain assumptions have been made in order to assess the various alternatives:

1. That future water-supply requirements of St. Croix will be met by integrated islandwide facilities.

2. That the local economy will be able to support production of water at higher cost than comparable production on the mainland.

3. That seasonal and other variations in water use could be sufficiently large to warrant storage of fresh water in the ground. This would assume that the cost of storage in the ground would be offset by producing water at optimum economic plant capacity or by avoiding the necessity of barging water.

4. That having an adequate ground-water supply system would be a valuable asset in the event that desalting operations were forced to shut down.

5. That land ownership and land-use patterns will not preclude the use of land for ground-water recharge in the study area.

6. That sewage will be treated.

7. That use of properly treated and stored waste water for public supply will be acceptable to island residents.

8. That aquifers will be protected from pollution.

9. That best solutions to the water-supply problem for the next 20 to 50 years might differ from the ultimate solution.

10. That surface reservoirs, catchments, and water barging are evaluated with and against the alternatives presented in this report.

11. That the population of St. Croix will increase at rates comparable with an informal and provisional projection by C. V. Lyle of the Environmental Protection Agency. Although there are other projections available, they are either obsolete or cover too short a time span to be useful in this study. The projection, as follows, was adapted from a written communication by Mr. Lyle (1970):

1970	- 31,200	1995	- 108,000
1975	- 40,000	2000	- 137,000
1980	- 51,000	2005	- 150,000
1985	- 65,000	2010	- 163,000
1990	- 84,000	2015	- 181,000

12. That per capita water consumption (exclusive of major industrial use) will reach 125 gpd by the year 2015 (author's estimate). This assumption and assumption 11 were used to construct the public-water-use projection shown in figure 11.

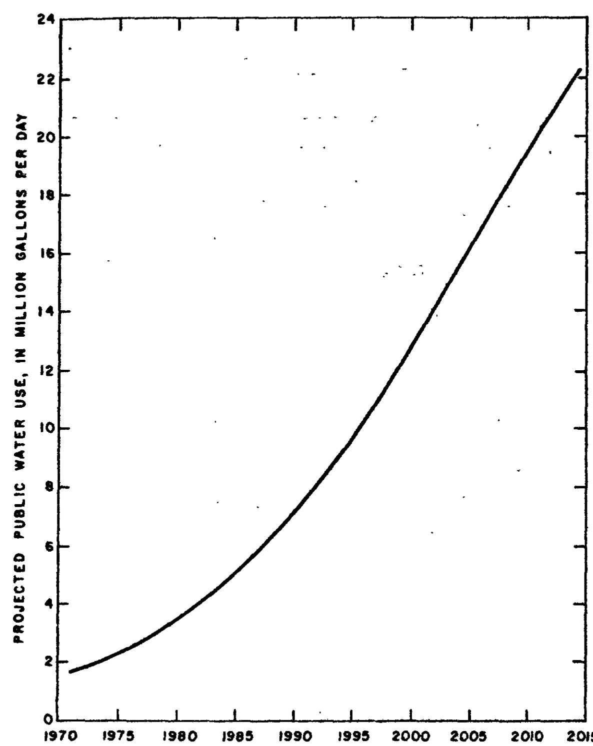

Figure 11.--Projected public water use in St. Croix, V.I. to year 2015.

The Brackish-Water Body-- Its Utility and Limitations

The Kingshill Marl and the associated alluvium contain about 130 billion gallons of water. Near the water table the water is fresh to slightly brackish. With depth, especially below sea level, mineralization of the water tends to increase greatly (fig. 8). The position of the brackish water-sea water interface is unknown. About 35 billion gallons of the water in this aquifer contains less than 6,000 mg/l dissolved solids and could probably be desalted economically by electrodialysis. Of course, reverse osmosis systems may be developed that can desalt even higher concentrations economically.

The alternatives outlined in the following paragraphs are only possible alternatives. Further investigation would be needed to determine their technical and economic feasibility.

If the "better quality" water (6,000 mg/l or less dissolved solids) is pumped at high rates, water of higher mineral content will tend to rise upward to replace the water withdrawn. This can be prevented by pumping the water of higher mineral content and removing it from the area (figs. 10 and 12). This more mineralized water might be usable in a reverse osmosis process or as distillation-plant feedwater. If the total water removed exceeds natural regional recharge, encroachment by sea water will result. Encroachment can be minimized, however, by pumping out the sea water as fast as it moves into the aquifer (figs. 10 and 12).

Artificial recharge of fresh water to the aquifer would have the same effect as an increase in natural recharge. Possible sources of recharge water would be treated sewage, impounded runoff, or surplus fresh water from a desalting plant.

Thus, pumping ("better quality water"), counterpumping (water of higher mineral content), backpumping of encroached sea water, and artificial recharge of the Kingshill Marl and associated alluvium all might be simultaneous. The technical feasibility of such a system, although speculative at best, is worth investigation. Hydrologic programs applicable to feasibility studies are treated in the section "Further Studies Needed."

Three major stages in ground-water development may be envisioned. In the first stage, present distilled-water production combined with brackish-water desalting would be adequate for the island's needs without exceeding natural and artificial recharge. Under such a regimen, the

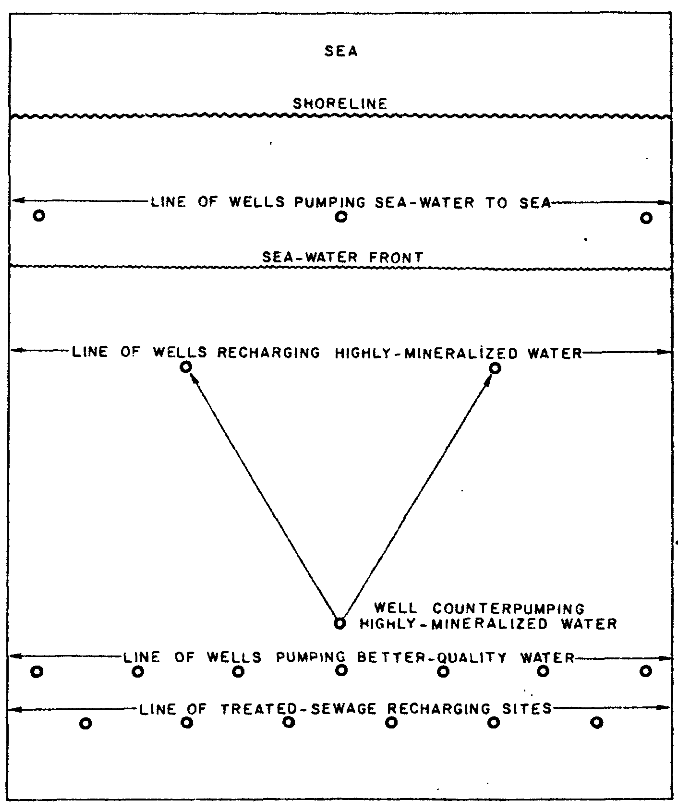

Figure 12.--Hypothetical well array showing a composite method of sea-water front stabilization. It is assumed that the array is repeated to the left and right of the illustrated area.

brackish water-sea water interface would advance only minimally and would later stabilize. It would be hydrologically feasible to use low-yielding relatively shallow wells during this stage without the necessity of counterpumping, provided that the pumped wells were paired with recharge facilities. The fact that the recharge water is less mineralized than the pumped water should cause the average mineralization of the "better quality" water to decrease with time.

In the second stage, distillation and natural and artificial recharge would no longer be adequate to balance the water used but not returned to the ground-water system. This would occur in about 1980, if the water-use projection (fig. 11) is correct. Systematic depletion of the brackish water then would begin. As the demand on the "better quality" water increased, the water table would decline, facilitating upward movement of the underlying highly-mineralized water. This tendency could be largely overcome by the use of counterpumping. To achieve the greatest effect with the fewest wells, counterpumping should be done at high rate from the lowest feasible part of the aquifer, causing it to be effective over a wide area. If the counterpumped water were to be used as reverse-osmosis feed water, however, it might be desirable to counterpump more wells at a higher interval to obtain less mineralized water.

Heavy pumping of the better quality water combined with counterpumping would depress water levels in the area of pumping and would cause the sea-water front to advance. This advance could be stopped or slowed by the use of wells pumping sea water back to the sea (figs. 10 and 12). The counterpumped water also could be recharged to wells on the landward side of the front, producing a similar effect, or the combined system shown on the figures could be used. The straight sea-water front shown on figure 12 is based on the unproved assumption that the potential cusp-and-parabola front generated by the wells backpumping sea water would be cancelled by the opposing cusps and parabolas that would be generated by wells being recharged by counterpumped water. It is assumed that no water would flow through the front.

In the third stage, as the better quality water neared depletion, perhaps between the years 2005 and 2010, some alternate supply of water would have to be introduced--probably increased sea-water distillation. It might then be desirable to partly or fully restore the water table to its present level in the major pumping areas. Here the value of counterpumping becomes obvious. If the highly mineralized water removed by counterpumping had been allowed to occupy the part of the aquifer previously occupied by the better quality water, flushing of the highly mineralized water would require large volumes of good water, for much of the highly mineralized water would remain in the rock pores to contaminate the invading good water.

In the third stage, counterpumping and the efforts to stabilize the sea-water front could be relaxed in proportion to the degree of restoration of the water table to its present level.

The Ground-Water Storage Facility--Its Value and Limitations

In addition to the large amount of stored water below the water table, the Kingshill Marl and the alluvium contain a great volume of unsaturated rock above the water table. At some places, such as Castle Coakley (fig. 5), the water table lies more than 75 feet below the valley floor. The space above the water table could be used to store surplus fresh water in times of low demand in order to augment the supply in times of high demand. The stored water also could serve as an emergency supplv. Of course, any adequate ground-water supply system could serve in an emergency, even if it were necessary to use brackish water in its natural state for nonpotable use.

Some advantages of storage in the aquifer are:

1. Low cost compared with tank storage.
2. Minimal interference with other land use.
3. Negligible evaporation.

Items (2) and (3) assume injection in wells, as compared with surface spreading.

Some disadvantages are:

1. The mineral content of the stored water may be increased by mixing with the native water or by contact with the aquifer.

2. The stored water cannot be totally recovered.

3. If water is injected through wells, it must be free of suspended solids and must be chemically compatible with the receiving formation.

Some of the Water-Supply-Treatment Alternatives to be Considered

In seeking to meet the island's water needs, all feasible methods were considered. Some of the methods are discussed and compared in this section. Comparison of methods without consideration of cost, however, would be less meaningful. For cost comparisons, the author has relied heavily upon a consulting report titled, "Water Reclamation Study of the U.S. Virgin Islands" (October 1968), prepared for the Virgin Islands Government by Engineering-Science, Inc. Where the above report is the source of a cost figure, the figure is followed by the initials "ES" in parentheses. Other figures are the author's estimates, based on various sources. The cost figures will soon be outdated but still will have some validity relative to one another. In time, of course, uneven technologic progress may negate the present relativity.

Distillation

The distillation method uses sea water, a virtually unlimited resource. Therefore, only cost of production will be considered. A 2 mgd plant would produce water at $1.18 per 1,000 gallons (ES cost curve). However, being almost totally demineralized, distilled water dilutes brackish water or recycled sewage to half concentration when mixed in equal parts. Therefore, the diluting ability of distilled water has the same economic value as single-stage electrodialysis, or 27 cents per 1,000 gallons (ES). If distilled water's dilutant value is considered, its net cost is 91 cents per 1,000 gallons. Mixing ground water with distilled water can produce a mixture superior to either in its unmixed state. Distilled water has a flat taste, may be corrosive, and lacks valuable trace elements. To obtain maximum economic benefit, if water from the Concordia well field is taken as an example, a mixture of about 2 parts distilled water to 1 part ground water would be used. This mixture should meet U.S. Public Health Service (1962) criteria. To achieve optimum water quality, however, a much lower proportion of ground water would be used.

Electrodialysis

As of this writing (1970), electrodialysis of brackish ground water provides the least costly source of potable water. Assuming a brackish-water production cost of about 10 cents per 1,000 gallons and multistage electrodialytic desalting from 1,500 mg/l to 500 mg/l of about 40 cents per 1,000 gallons, total cost would be about 50 cents per 1,000 gallons. In this report electrodialysis is considered to be uneconomic for water having more than 6,000 mg/l dissolved solids, the cost being nearly a dollar per 1,000 gallons. The distribution of stored ground water having less than 6,000 mg/l dissolved solids ("better quality water") is shown in figure 8. The average dissolved-solids content of the better quality water and the estimated altitude of the bottom of the better quality water are shown on figure 13 and 14 (both in pocket).

The quantity of better quality water is estimated to be less than 45 billion gallons. Of this amount, only about 35 billion gallons is economically recoverable. Of the natural recharge to the aquifer, about 1 1/4 million gpd is recoverable. In conjunction with the output of the public distillation plant, the recoverable recharge alone would be adequate for present needs. The projected increase in water use, however, as shown in figure 11, would require removal of more water from aquifer storage and would accelerate depletion of the better quality water.

Extending the life of the ground-water supply is highly desirable. One method would be artificial recharge with treated sewage, which is discussed in the following section.

Aquifer Recharge with Treated Sewage

Sewage is increasingly being regarded as a resource rather than a nuisance in water-short areas. One method of reuse is to recharge aquifers with secondary-treated or tertiary-treated effluent, either by surface infiltration or direct injection, and then to withdraw the water from acceptably distant wells.

For reuse of treated sewage by injection, the total cost would probably be about 79 cents per 1,000 gallons, which includes 36 cents (ES) for secondary treatment, 6 cents (ES) for partial tertiary treatment (multimedia filtration), 10 cents for recharge and withdrawal, and 27 cents (ES) for one-stage electrodialysis. The electrodialysis is to prevent buildup of inorganic solutes. In addition to its original 500 mg/l, the water picks up about 250 mg/l (ES) of inorganic solutes in use and would probably pick up another 250 mg/l in its passage through the ground--making a total of 1,000 mg/l. Tertiary treatment could be eliminated if surface spreading were used, but land cost and evapotranspiration loss would have to be considered.

If the sewage from Frederiksted and Christiansted is to be reclaimed, then sanitary use of sea water in the cities would have to be discontinued. The high mineralization of sea water would cause reclamation of the sewage to be uneconomic.

The amount of available sewage varies directly with water use. Therefore, sewage is a resource that is very responsive to need. Exfiltration from sewer lines in addition to losses in distribution and in the sewage-reclamation process might be greater than half the water supply. Part of the losses from the water and sewage system, however, would become ground-water recharge and would eventually be available for recycling.

The principal reason for recharging the aquifer artificially is to prevent accelerated depletion of the better quality water. The depletion rate with and without artificial recharge is shown on figure 15. To construct the depletion curves, the following assumptions were made: (1) public water use will increase as shown on figure 11, (2) recoverable natural recharge is 1 1/4 mgd, (3) distillation for public use is 1 mgd, (4) artificial recharge would be equal to half of public water use.

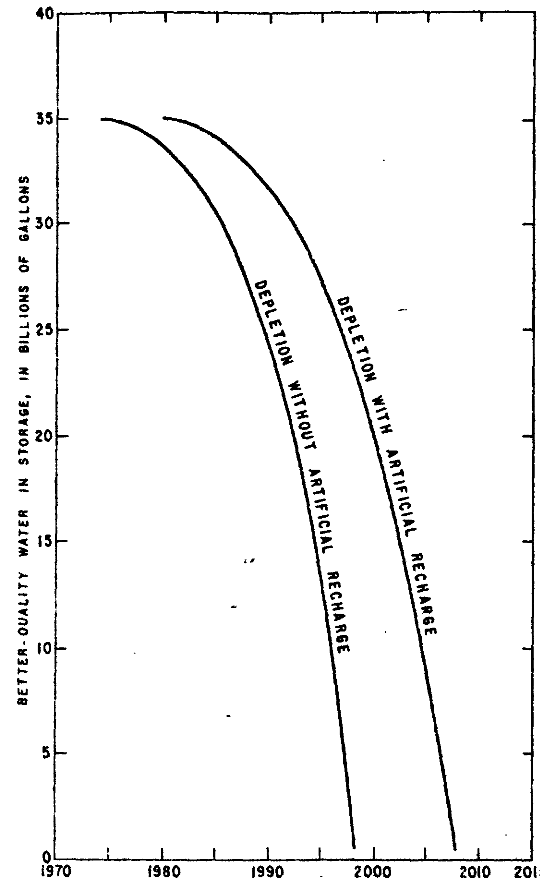

Figure 15.--Projected depletion of the better quality water in central St. Croix, V.I., with and without artificial recharge.

Reverse Osmosis

Only recently has the reverse-osmosis process moved from the laboratory to commercial use. Although restricted to small-scale plants at present, large-scale plants may be constructed in the future. Reliable cost estimates for this process cannot be made at this time. It will probably, however, become economic to use this process for higher levels of mineralization than is practical for electrodialysis. Electrodialysis may remain more economic at lower levels of mineralization.

GROUND — WATER SITES

The most promising sites for public-water-supply development are discussed below and are shown on figure 16 (in pocket). These sites could serve as centers for pumping and artificial recharge. Some wells between these sites as well as west of the airport and east of Estate Pearl, however, would be necessary for optimum coverage.

Concordia

The Kingshill Marl is the principal aquifer at Concordia (Site 1). Alluvium also contributes water to wells and aids in the infiltration of stream water to the aquifer. Small dams to retard streamflow would increase infiltration.

This site already is a major supplier of water to the public system. The water is mixed with distilled water from the plant at Christiansted.

River Gut and Bethlehem Gut

River Gut and Bethlehem Gut (Site 2) includes two well fields and one proven but undeveloped field. One of the well fields is at Fair Plain, and the other is at Adventure (where the west branch of River Gut crosses Centerline Road). The aquifer in both fields consists of alluvium and Kingshill Marl. The Fair Plain well field is yielding less than its potential. The Adventure well field was pumped beyond its capacity, resulting in considerable dewatering of the aquifer, which caused well yields to decline. The aquifer contains better quality water throughout its thickness in this field, so that there has been no upwelling of excessively mineralized water in spite of the heavy pumping. This field would be well suited to recharge and withdrawal of treated sewage.

Test drilling indicates the presence of an excellent undeveloped aquifer near the southeast corner of the airport. Yields of 50 to 70 gpm were obtained in pumping tests of undeveloped wells. Nearness to the sea, however, could make counter-pumping and sea-water pumping necessary (figs. 10 and 12).

Any well field near a stream would be benefited by low dams to retain a part of storm runoff, which promotes infiltration to the aquifer. A low dam, also, where River Gut enters the sea, would exclude sea water from the lower reach of the stream and would help to prevent contamination of the aquifer if the water table is lowered below sea level.

Barren Spot

Site 3, at Barren Spot, is a major source of water for public supply and industry. The aquifer consists of the Kingshill Marl and alluvium. In spite of heavy pumping for several years, there has been little deterioration of water quality. This suggests that, with counterpumping and artificial recharge, even heavier draft is possible.

Castle Coakley

Three test wells drilled at Castle Coakley (Site 4) indicate that wells tapping the reef limestone of the Kingshill Marl could yield much water--a few hundreds of gallons per minute each. Counterpumping would be essential at such high yield. One or two scavenger wells 300 to 350 feet deep could serve an extensive well field. The water table in the area is more than 75 feet below the land surface. This would reduce injection costs (because of the weight of the injection-water column) but would increase withdrawal costs. All considered, this is the most promising undeveloped site in central St. Croix.

Pearl

Site 5, at Pearl, has never been test-drilled. It resembles the Barren Spot and Castle Coakley sites in many ways. Production probably would be from reef limestone of the Kingshill Marl.

FURTHER STUDIES NEEDED

The diagrams on figures 10 and 12 are simple and the discussions relative thereto are, thus, simplified. The possible approaches to management illustrated on the figures certainly would apply under certain conditions, but whether these conditions obtain on St. Croix remains untested and unproven. Several complicating physical parameters are possible, and the possibility is more likely than conjectural. The ground-water reservoir is small; thus, simultaneous pumping, counterpumping, backpumping, and artificial recharge would tend to be less effective and more likely to interfere, one with another, than in a large ground-water reservoir. Permeability stratification is likely, as are facies changes downdip, which would limit downdip circulation. Transmissivity is generally small, which might result in a lack of flushing of high saline water from rocks of low permeability. Salinity stratification is generally unknown. Other complications are the known heterogeneity of aquifer materials and marked changes in vertical permeability.

Any solution to the water-supply problem involving ground water thus requires further studies. If large withdrawals are contemplated, the position of sea water in the aquifer would have to be determined by test drilling before withdrawal starts and then should be monitored as withdrawal proceeds. The resulting test holes and other test holes might also help resolve some of the complications outlined in the preceding paragraph. Electrical resistivity surveys might be used to obtain information between observation wells. A lessening of the electrical resistivity of the formation, as measured in successive surveys, would indicate advance of sea water.

Before the Kingshill Marl is recharged artificially on a large scale, pilot studies could determined the best method--surface infiltration, galleries, injection wells, or some combination thereof. As part of the studies, the compatibility of the recharge water with the formation and with the native water should be evaluated.

Drilling a few exploratory holes in the valleys near the ridgeline of the Kingshill Marl might help define the source of the salts in the high-saline areas. Measures to prevent further contamination then could be taken.

A large-scale withdrawal-recharge system might justify modeling the system by electric analog, digital computer, or other appropriate means. An effective model could predict the effects of withdrawal and recharge on the system and, therefore, would aid in making decisions. A cost-analysis model could also be constructed, which would include cost data and treatment of water for the recharge-discharge system, within the limits imposed by the hydrologic model.

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GLOSSARY

(The words in this glossary are defined, as used in this report. The definitions are not necessarily standard or complete.)

Aquifer.--A rock unit that yields water in sufficient quantity to be of value as a source of water.

Connate water.--Water that was deposited simultaneously with the containing sediments; salty in marine deposits.

Counterpumping.--When an aquifer is pumped, deeper, more mineralized water may rise in response to the reduced head in the producing zone. Pumping water to waste at an appropriate rate from a deeper zone will reduce the head on the more mineralized water, preventing it from rising to the producing zone.

Electrodialysis.--A method of demineralizing water using spaced membranes with charged electrodes behind them. The water between the membranes loses minerals as the ions in solution are attracted to the electrodes and pass through the membranes. The water behind the membranes becomes enriched with minerals and is either recycled or discarded.

Evapotranspiration.--The loss of water both by evaporation at or near the ground surface and by transpiration by plants.

Foraminifer.--A type of shelled protozoan.

gpd.--Gallons per day.

gpm.--Gallons per minute.

Marl.--Limey claystone or siltstone.

mgd.--Million gallons per day.

mg/l.--Milligrams per liter; equivalent to parts per million (ppm) in dilute solutions; mg/l and ppm values diverge as the density of a solution increases.

Oölite.--A small white round limey particle.

Reverse osmosis.--In the normal osmotic process a less concentrated solution passes through a semipermeable membrane into a more concentrated solution. By applying pressure on the more concentrated solution the flow can be reversed, with dissolved ions being rejected by the membrane and being left behind in the more concentrated solution. In essence, the ions are filtered out of the more concentrated solution producing a filtrate of reduced concentration.

Scavenger well.--A well used for counterpumping.

Transmissivity.--The measure of an aquifer's water-bearing ability. It is the rate of flow of water (gallons per day) at the prevailing water temperature, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot.

TOPOGRAPHIC MAPS OF THE AREA OF STUDY

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