Ground Water for Public Supply in St. Croix Virgin Islands

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1663-D

Prepared in cooperation with the Government of the Virgin Islands

Hendrickson

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By G. E. HENDRICKSON

CONTRIBUTIONS TO HYDROLOGY OF LATIN AMERICA AND THE ANTILLES

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GROUND WATER FOR PUBLIC SUPPLY IN ST. CROIX, VIRGIN ISLANDS

By G. E. Hendrickson

ABSTRACT

The ground-water resources of St. Croix, V.I., if properly developed should be adequate to supply the present and near-future demand for water for public supply. Ground water is obtained from weathered volcanic and intrusive rocks (bedrocks), from limestone, and from alluvium. The water obtained from weathered bedrocks and from alluvium in the valleys of the North Side Range is generally of better quality than that obtained elsewhere on the island. The greatest yields are obtained from the limestone and alluvium of the south-central coastal plain, but the water there is generally of poor to only fair quality. In the East End area no water, or salty water, is obtained from wells.

INTRODUCTION

The study described in this report was made during the period March 12 to June 1, 1962, at the request of the Hon. Ralph M. Paiewonsky, Governor of the Virgin Islands. The purpose of the study was to determine the potential yield of several recently drilled test wells that are to be used for public water supply and to obtain information needed to plan further studies of the water resources of the island. A field inventory of more than 130 wells was made, including most of the wells drilled on the island since the study made in 1938–39 by Cederstrom (1950). Depths to water were measured where possible, and field determinations of the chloride content of the water were made wherever samples could be obtained. Pumping tests were made on eight of the test wells intended for the public supply. An open-file report (Hendrickson, 1962) was prepared for early use by Virgin Islands officials. This report contains an appendix which includes data on the wells inventoried, logs of test wells, a summary of pumping tests, and suggestions for obtaining continuous records of ground-water supplies.

Previous reports on the ground-water resources of St. Croix include a published report by Cederstrom (1950), a brief open-file report by

McGuinness (1953), and consulting reports by Malcolm Pirnie (1945) and by Tippets and others (1959). Cederstrom's report includes a description of the geology and a geologic map. His report summarizes literature on physiography and geology and contains almost all the information available on ground-water resources at the time his study was made (1938–39). The reports by Pirnie and by Tippets and others are chiefly summaries of information obtained in earlier studies, but they include specific recommendations for development of water supplies on the island.

Appreciation is expressed for the cooperation of officials of the Virgin Islands Public Works Department in carrying out this study. Mr. Alfonso Paraliticci, Mr. Victor Gibeon, and Mr. Albert Nelthropp provided working space and equipment and assigned Public Works personnel to assist when needed. Mr. Nelthropp helped design the air-lift equipment used to pump the wells and took an active part in some of the tests. Mr. Alfred Ovesen collected samples of well cuttings and prepared logs of test wells. Mr. Leonard Larsen, also of the Public Works Department, worked with the author on pumping tests and inventoried some of the wells. Mr. R. L. Kenan, of R. L. Kenan and Associates, Montgomery, Ala., provided well logs and information on pumping tests made in the Concordia and Mahogany Road well fields when they were installed in 1949–50. Mr. Eugene Schuster, local driller who has put down most of the drilled wells on St. Croix, donated 4 days of his time to accompany the author in a field inventory of wells. His firsthand knowledge of the wells and his friendship with the well owners made it possible to obtain much information that otherwise might not have been available.

GEOGRAPHY AND CLIMATE

The island of St. Croix is the southernmost of the Virgin Islands, about 40 miles south of St. Thomas, site of Charlotte Amalie, the capital of the American Virgin Islands. It is about 100 miles southeast of San Juan, P.R., and about 1,100 miles southeast of Miami, Fla.

The island is about 21 miles long and 6 miles wide at its widest section. The long axis of the island trends about 10° north of east. There are two highland areas, the North Side Range and the East End Range. A broad, rolling lowland makes up the central, south-central, and southwestern parts of the island. There are no perennial, through-flowing streams on the island, but a few of the streams are perennial along short reaches. The major physical features and drainage courses are shown on figure 1.

The population of St. Croix in 1962 was about 16,000. About 5,500 live in Christiansted and 2,500 in Frederiksted. The remainder live in small villages or in the country. Several private housing developments are now being built. These will provide many homes in areas outside the present city limits of Christiansted and Frederiksted.

The average temperature in St. Croix is 78°F and varies only a few degrees between winter and summer. The northeast trade winds, which blow most of the time, contribute to the pleasant climate. The average annual rainfall varies from an estimated 20 inches at the east end of the island to about 54 inches at Annaly, in the mountains at the northwestern part of the island. Rain generally falls in showers lasting from a few minutes to a few hours. Continuous rainfall of a day or more is rare and occurs only during the hurricane season. Torrential rains are not uncommon, as much as 7 inches falling in 24 hours in the north-central part of the island about once every 5 years (U.S. Weather Bureau, 1961, p. 86).

The rainfall is markedly seasonal, generally being concentrated in the "wet season" in May and August–November. Variations from the normal seasonal distribution are common, however, as are large variations in total rainfall from year to year. According to Cederstrom (1950, p. 10), the average based on stations at Christiansted, Frederiksted, and Kings Hill showed for the period 1852–1938 a minimum of 29.10 inches in 1922 and a maximum of 71.44 inches in 1933; the average was 46.34 inches.

GEOLOGIC SETTING

The geology of St. Croix was described and mapped by Cederstrom (1950). A more detailed map and description were prepared by J. T. Whetten in 1961 as a doctoral dissertation for Princeton University. The following brief summary is based on these reports.

The North Side and East End Ranges are composed of dense volcanic-sedimentary rocks of Late Cretaceous age designated the Mount Eagle Volcanics. A large intrusive mass of gabbro is exposed in the central part of the North Side Range and a similar mass of diorite is exposed in the East End Range; the intrusives, also, are probably of Late Cretaceous age. Along part of the southeast flank of the North Side Range are outcrops of the Jealousy Formation, of Oligocene age, which unconformably overlies the Cretaceous bedrock. In outcrop the Jealousy is a calcareous conglomerate, but in the subsurface to the southeast the Jealousy is composed chiefly of gray, green, or "blue" clay. About 1,400 feet of this clay was penetrated in a test hole drilled near Bethlehem (Cederstrom, 1950, p. 19), and the well did not reach the bottom of the formation. The Kingshill Marl, of Oligocene and Miocene age, consisting of limestone and marl, overlies the Jealousy Formation and crops out in a broad area in the central and southwestern parts of the island.

The valleys of major streams are partly filled with alluvial deposits of sand and gravel, silt, and clay of Quaternary age; the deposits are everywhere less than 120 feet in thickness, so far as is known.

SURFACE WATER

No records of surface runoff on St. Croix are available. Apparently, the Danes collected some records on streamflow during the late 19th century, but no one has been able to trace the location of these records. In estimating the quantity of water that could be obtained in surface reservoirs, Tippets and others (1959) assumed that the average annual runoff is 1 percent of the annual rainfall, or less than half an inch. This low value of runoff presumably is based on the high potential rate of evapotranspiration. The average annual evaporation from an open pan at Annas Hope is about 72 inches, and that from larger bodies of water probably is something like two-thirds as high.

The estimate of runoff as 1 percent of the rainfall may be too low. Rainfall records suggest that 3 inches or more can be expected to fall in 24 hours on the average of once each year on the northwestern third of the island (U.S. Weather Bureau, 1961, p. 85). About every 5 years, on the average, 4.5 inches or more can be expected to fall on that area in 12 hours (idem., p. 83). Torrential rains such as these may be expected to produce a high rate of runoff. Floodwaters are reported to flow over the Centerline Road to depths as great as 5 feet at least once every several years. A single flood of this magnitude may discharge more water than would normally flow in a period of a year or more.

It appears that some of the streams in St. Croix may vary in discharge from nothing to perhaps thousands of cubic feet per second. To obtain significant records of surface runoff on St. Croix it will be necessary to measure flood flows as well as those confined to the stream channels.

WATER-BEARING FORMATIONS

The occurrence of ground water in the various geologic units was described in some detail by Cederstrom. The following discussion is based in part on his report but mainly on the results of an extensive test-drilling program carried out during the period 1959–62. Figure 1 shows the general availability of ground water in St. Croix as indicated by the results of drilling.

The following descriptions of ground-water availability apply to the five areas shown in Figure 1.

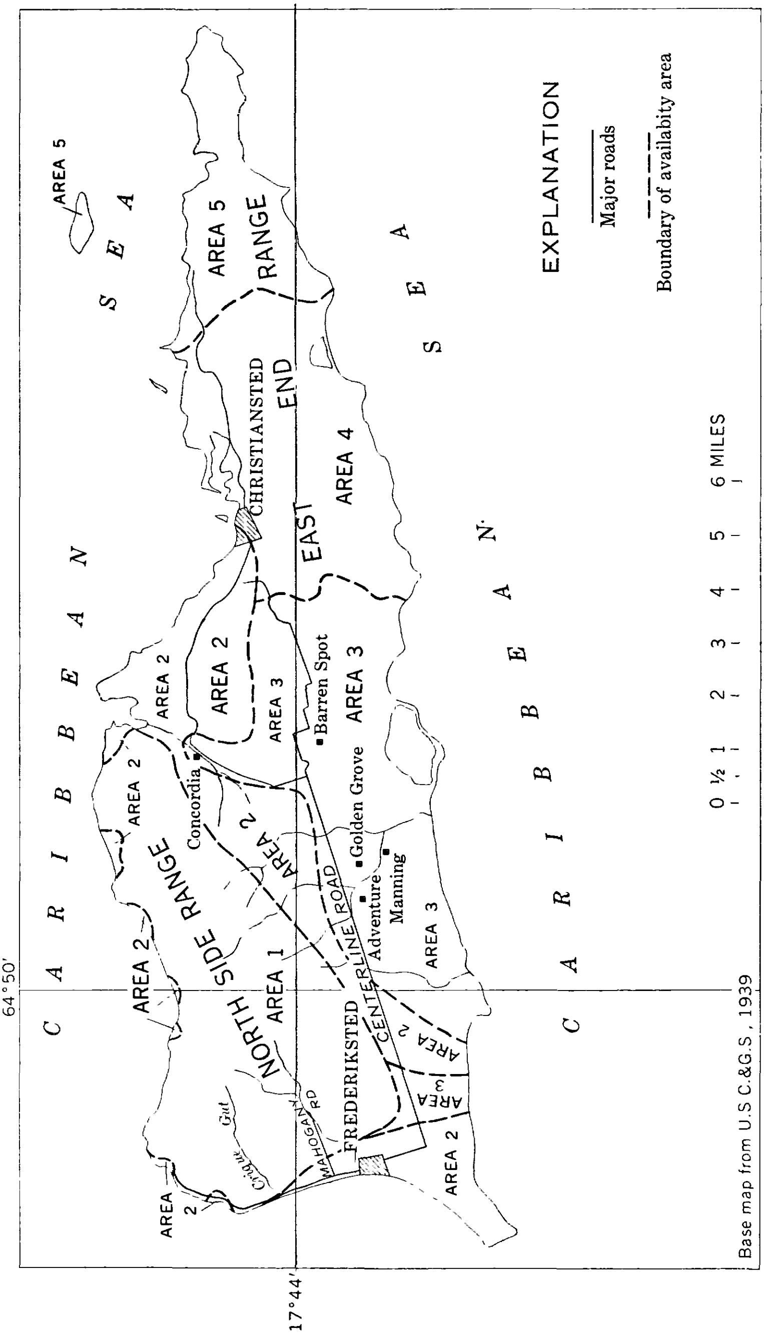

FIGURE 1.—Availability of ground water in St. Croix, Virgin Islands.

Area I: Most wells in valley bottoms will yield 5 to 10 gpm of water of good quality that generally contains less than 300 ppm of chloride. Wells in alluvium-filled valleys draining relatively large areas (more than 1 square mile) may yield as much as 30 gpm. Water is obtained from alluvium or from weathered and fractured rock.

Area II: Most wells will yield little water or salt water.

Area III: Most shallow wells (less than 100 feet deep) will yield as much as 10 gpm of water of fair quality containing generally less than 700 ppm of chloride. Wells in some of the larger valleys may yield 100 gpm or more. Deeper wells and wells near the sea generally will yield saltier water, containing more than 1,000 ppm of chloride. Water is obtained from alluvium and from limestone. Water in the limestone generally is saltier than that in the alluvium.

Area IV: Most wells will yield small supplies (1 to 5 gpm) of water containing less than 500 ppm of chloride. Wells near the sea generally yield saltier water. Water is obtained from alluvium and from weathered and fractured rock.

Area V: Most wells will yield salty water. Wells in the upper parts of the larger valleys may yield water of fair quality (less than 700 ppm of chloride).

MOUNT EAGLE VOLCANICS

The upper and weathered and fractured zone of the Mount Eagle Volcanics yields moderate supplies, 5 to 10 gpm (gallons per minute), of water of generally good quality to a number of wells in the valleys of the North Side Range. Three wells along Mahogany Road yield about 30 gpm each from these rocks. Because of the erratic distribution of fractured zones it may be necessary to drill several test wells for every successful production well.

In the east-central part of the island and in the East End Range, the Mount Eagle Volcanics generally yield only small amounts of water, and the water may be highly mineralized, the chloride content ranging from about 150 to 5,000 ppm or more.

The chance of penetrating permeable zones in the Mount Eagle Volcanics declines with depth. The weathered zone generally does not extend more than 100 feet below the surface, and open fractures pinch out with depth.

Although the Mount Eagle includes limestone beds in places, no evidence of permeability due to solution of the limestone was noted.

INTRUSIVE ROCKS

Cederstrom (1950) reported a successful well in the weathered intrusive rocks in the central part of the North Side Range. This well was pumped for 6 hours at a rate of 19½ gpm with a drawdown of

15 feet. No additional information on the availability of ground water in this area was obtained by the present writer. It is recommended that test wells be drilled into these rocks in the area upstream from River and near Hermitage.

Two drilled wells in the weathered intrusive rocks of the East End Range are reported to yield 10 gpm each. The water is of fair to good quality; the chloride content of water from the two wells is 200 and 300 ppm. Test wells are recommended in the valley south of Southgate Farm.

SEDIMENTARY ROCKS

JEALOUSY FORMATION

Little is known of the water-bearing capacity of the Jealousy Formation. The gray or "blue" clay which underlies the Kingshill Marl in the central and southwestern parts of the island yields little or no water. The calcareous conglomerate at the base of the formation appears to be moderately permeable where exposed in outcrop, but a test hole drilled at Jealousy under the supervision of Cederstrom (1950, p. 66, 68) yielded no water from the Jealousy Formation. J. T. Whetten mapped the rocks in a belt extending from just south of Judiths Fancy to Mon Bijou as possibly belonging to the Jealousy Formation. No records of wells in this outcrop area were obtained. There appears to be a general impression that no water or only salty water can be obtained from the Jealousy. Nevertheless, it may be desirable to try one or more test wells in valleys where the conglomerate of the Jealousy lies below the alluvium.

Although not an aquifer, the relatively impermeable "blue" clay of the Jealousy is of considerable hydrologic importance. It is the lower limit of fresh-water-bearing rocks wherever it occurs. According to drillers' reports, fresh water has never been found in rocks below the "blue" clay. This same "blue" clay, however, performs an important role in restricting the upward migration of salt water. Where fresh-water aquifers are underlain directly by the clay, upward migration of salt water probably is virtually nil.

Because of its important hydrologic effects, the top surface of the "blue" clay should be logged in every test hole where it is reached, and a structure map on the top of the clay should be prepared. This map would show the effective lower limit for fresh-water wells and would also help to determine areas where salt-water encroachment is likely to occur.

KINGSHILL MARL

Probably the most productive aquifer on the island is the Kingshill Marl. Four wells in this formation have been pumped at rates of

100 gpm or more. The permeability of the limestone probably is quite variable. In the Frederiksted area small caves in the limestone are apparent. A break in the main waterline at Frederiksted was unnoticed for several days because all the water drained away through solution channels in the limestone. Unfortunately, water in the Kingshill generally is of poor to only fair quality, the chloride content ranging from about 400 to 1,000 ppm or more.

In most wells drilled into the Kingshill within a mile of the south coast, water stands at elevations less than 10 feet above sea level. Higher water levels in a few wells probably are perched or semiperched. North of the Centerline Road, water levels more than 100 feet above sea level also are probably perched or semiperched. These high water levels are an indication that the limestone below is probably of relatively low permeability.

Water in the Kingshill probably is recharged along the beds of streams discharging southward from the North Side Range and also in the broad outcrops of limestone near the south coast. A favorable recharge area would seem to be along the southeast flank of the range where the streams first cross the Kingshill rocks. However, it is in this area that most wells in the Kingshill are unsuccessful, because little water, or only salty water, is obtained. Possibly the Jealousy Formation, which crops out in places along the edge of this area, contributes salty water to the overlying Kingshill, or perhaps openings related to the fault mapped by Whetten allow upward migration of salt water. The low yield of wells in this area may be due to the shallow depth at which clay of the Jealousy Formation lies.

ALLUVIUM

Deposits of sand and gravel in the alluvium yield 40 gpm or more to several wells along the streambed between Adventure and Manning (fig. 5). Alluvial deposits also provide a part of the water pumped from the Concordia and Barren Spot well fields and may yield some water to the public-supply wells in the Mahogany Road well field. Alluvial deposits along smaller streams yield small supplies to many stock and domestic wells. It is difficult to predict the yield of a well drilled in the alluvium because the character of the alluvial material varies greatly within short distances. Silt and clay make up the greater part of the alluvial section in most areas. Beds of sand and gravel generally are thin and are interbedded with silt and clay. Yields of some wells are greater than would be expected from examination of the drill cuttings. Drill samples that include clay, silt, sand, and gravel in varying amounts probably are obtained from thin sand and gravel beds alternating with silt and clay.

The quality of water obtained from the alluvium in the valleys of the North Side Range and most of the central plains area generally is fair to good, the chloride content ranging from 100 to 700 ppm. In the central plains area the water in the alluvium generally is lower in chloride than that in the underlying limestone. Water in the alluvium along the southeast flank of the North Side Range is reported to be generally salty, and water in alluvial deposits near the coast and at the east end of the island is almost invariably salty.

PUBLIC-SUPPLY WELL FIELDS

As of June 1962 four major well fields for public water supply were active or were being developed. In addition, there are several small public-supply systems for small communities in various parts of the island. These small public supplies generally consist of 1 to 3 wells each and a storage tank from which the local residents haul their water. Plans are now being made to provide pipelines to individual homes in some of these communities.

Wells are identified in this report by field numbers that are shown on the maps (figs. 2–5) and by map coordinates that refer to the 10,000-foot grid on the 1:24,000 U.S. Geological Survey topographic quadrangle maps (1958). The grid is indicated by "tick" marks in the margins of the map. The coordinates are given in thousands of feet, the digit after the decimal point representing the location of the well to the nearest 100 feet. Thus, map coordinates 74.8N, 1079.6E indicate a well located 74,800 feet north and 1,079,600 feet east of the point of origin of the grid.

The four major well fields are described in the following sections.

CONCORDIA WELL FIELD

The Concordia well field is in the Salt River valley near Concordia, about 4 miles west of Christiansted and about 1 mile southwest of Sugar Bay (fig. 2). Of the five wells now pumped in the field, four are equipped with turbine pumps, one with a jet pump. Apparently the water is obtained chiefly from limestone, although some water is obtained from sand and gravel in alluvium overlying the limestone. Records of wells in the Concordia field are listed in table 1.

Pumping tests by R. L. Kenan and Associates on three of the wells indicate specific capacities ranging from 3 to 5 gpm per foot of drawdown. Well 14 (coordinates 74.3N, 1078.7E) was pumped at a rate of 50 gpm for 30 minutes, with a drawdown of 12 feet. Of the five wells, four are now pumped at a rate of about 30 gpm each, and at times of high demand they are pumped 24 hours a day. Pumping-test data also are summarized in table 1.

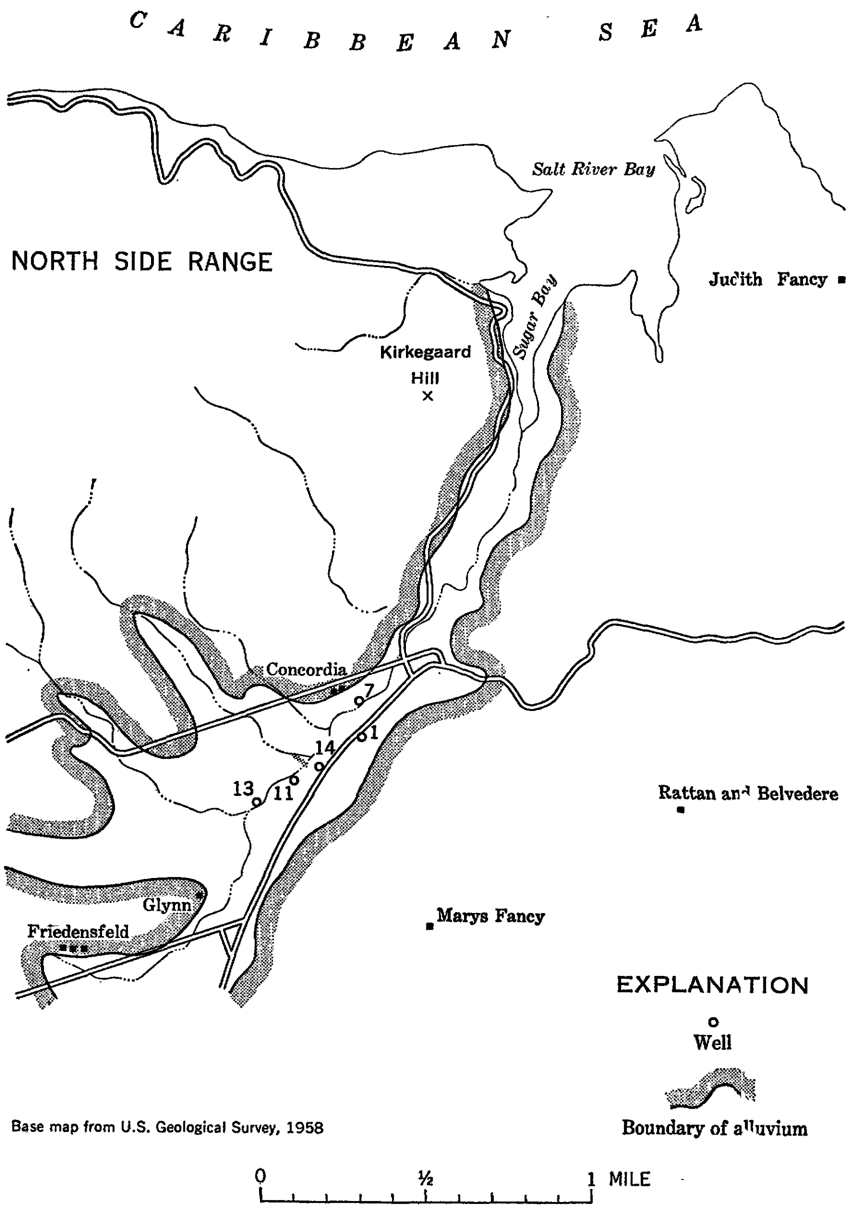

FIGURE 2.—Concordia well field.

TABLE 1.—*Concordia well field*

Records of wells

[Yield: M, measured; R, reported]

Field No.	Map coordinates	Altitude (feet above sea level)	Depth of well (feet)	Water-bearing material	Water level (feet below land surface)	Date measured	Yield (gpm)	Chloride content (ppm)	Remarks
1	74.8N 1079.6E	40	82	Limestone	24	5-25-62	22R		Not being pumped when measured. Equipped with jet pump, to be replaced by turbine pump in 1962.
7	75.4N 1079.6E	35	81	Limestone, possibly sand and gravel, also.	25	5-25-62	30R	250	Being pumped when measured. Equipped with turbine pump.
11	74.2N 1078.6E	40	86	Limestone	28	5-25-62	30R	240	Do.
13	73.8N 1077.9E	50	96	do	51	5-25-62	30R	700	Do.
14	74.3N 1078.7E	40	85	Sand and gravel	20	3-14-62	50M	600	Not being pumped when measured. Equipped with turbine pump.

Pumping tests of wells

[Preliminary test by R. L. Kenan and Associates]

Field No.	Map coordinates	Date tested	Pumping rate (gpm)	Hours pumped	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)
7	75.4N 1079.6E	8-10-48	20	20	4	5
11	74.2N 1078.6E	5-26-49	40	9	13	3
13	73.3N 1077.9E	5-23-49	45	24	12	3¾

The water obtained from the Concordia field reportedly varies in quality with rainfall and with the amount of water pumped from the field. At times of heavy rainfall and minimum pumping the quality of water pumped from the Concordia fields is fair to good and the chloride content is less than 400 ppm. At times of drought and of heavy pumping the water reportedly becomes rather brackish. The chloride content of water also varies from one well to another. On May 3, 1962, a sample was taken from each of three wells in the Concordia field. Water from wells 7 and 11 had 250 ppm of chloride; that from well 13 had 550 ppm. The city supply in Christiansted on this date had 350 ppm of chloride. On May 14 water from wells 7 and 11 had 300 ppm of chloride.

The Concordia well field probably is developed to near its maximum capacity at the present time (June 1962). Probably additional water could be pumped from the field during the rainy season, but this is generally the time of least demand for water. Heavy pumping during the dry season probably will increase the salt content of the water. The increase of salt in the water probably is caused by inducement of greater inflow from deeper limestone beds when the water level in the well is lowered excessively.

Because the amount of potable water is limited, a system of monitoring the supply should be started at once. It would involve chiefly the measurement of changes in water levels and changes in chloride content of the water. Records of rainfall and of pumpage from the field also should be collected.

The depth to water in producing wells should be measured by air line, electric tape, or chalked tape at least once a month. A note accompanying each measurement should indicate whether the well was being pumped when it was measured, and which other wells were being pumped at the time. If the well is idle when measured, the note should indicate how long it has been idle. Weekly readings would be desirable for the first year of record. If air-line measurement is used, check readings with an electric tape or chalked tape should be made occasionally to make sure that the air line has not sprung a leak. One or more unused wells in the Salt River valley located near the producing wells also would be useful in maintaining a record of water-level fluctuations in the field. Tape readings could be made at monthly intervals, or a continuous record could be obtained by installing a water-level recorder on one of the unused wells. The chloride content of water from each pumped well should be determined at the same time a water-level measurement is made. Occasional samples should be analyzed in the laboratory to check the field determinations.

Records of rainfall, pumpage, water levels, and chloride content, when they have been collected long enough to cover a period including both wet and dry years and various rates of pumping, will furnish a basis for a more reliable estimate of the future yield of the well field than could be obtained in a short study no matter how intensive it might be. These remarks apply to the other well fields also.

MAHOGANY ROAD WELL FIELD

The Mahogany Road well field is about a mile north of Frederiksted (fig. 3).

Each of the three wells is pumped with a turbine pump at a rate of 30 gpm. The water is obtained chiefly from weathered volcanic-sedimentary rocks underlying the alluvium. Records of wells in the Mahogany Road field and adjacent areas are listed in table 2.

Pumping tests by R. L. Kenan and Associates on two of these wells indicated specific capacities of about 2½ and 4 gpm per foot of drawdown. A brief pumping test on the third well indicated a maximum yield of about 20 gpm when pumped by air lift. This well yielded 34 gpm when tested with a turbine pump. Pumping-test data also are summarized in table 2.

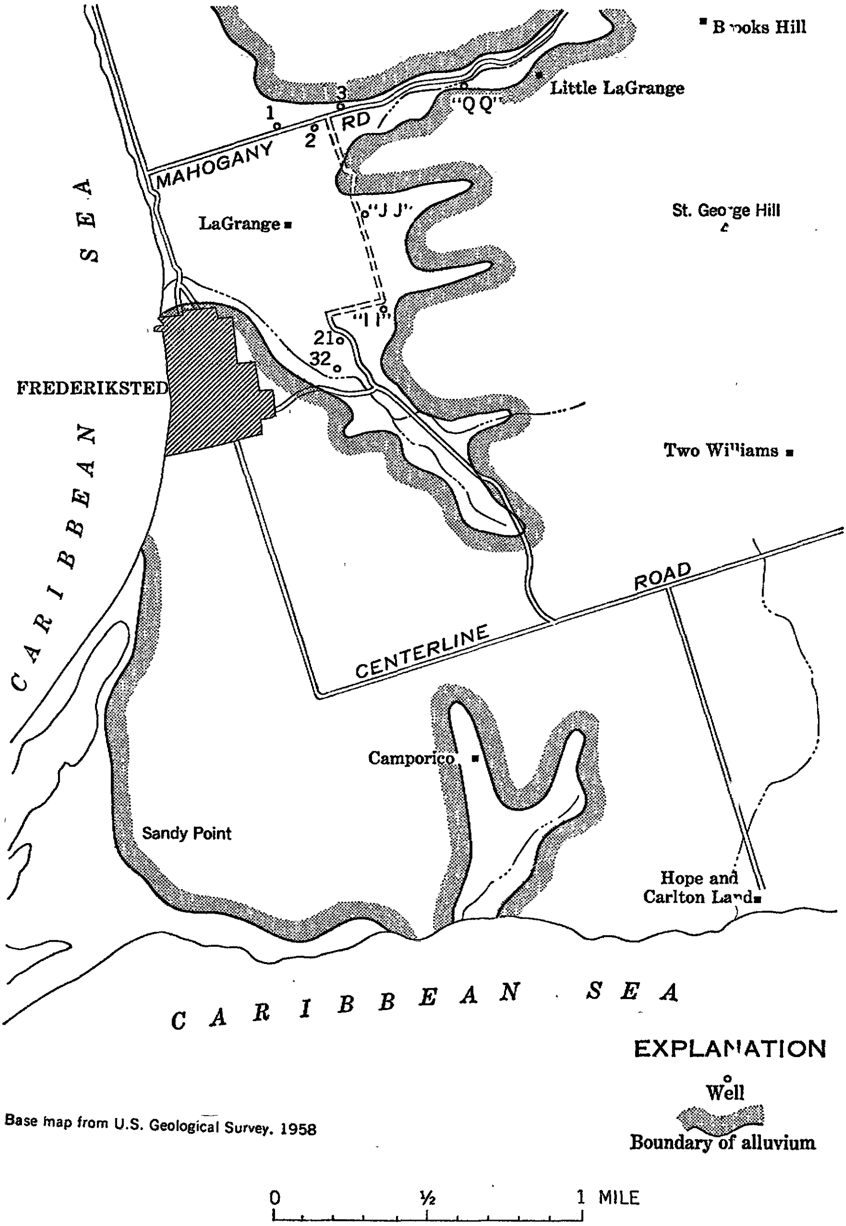

FIGURE 3.—Mahogany Road well field.

TABLE 2.—*Mahogany Road well field*

Records of wells

[Yield: M, measured; R, reported]

Field No.	Map coordinates	Altitude (feet above sea level)	Depth of well (feet)	Water-bearing material	Water level (feet below land surface)	Date measured	Yield (gpm)	Chloride content (ppm)	Remarks
1	63.1N 1041.0E	45	106	Weathered volcanic rocks	53	1947	30R		Equipped with turbine pump.
2	63.2N 1041.5E	55	86	do	53	4-9-62	30R	100	Being pumped when measured. Equipped with turbine pump.
3	63.5N 1042.0E	70	104	do	48	4-9-62	30M	100	Not being pumped when measured. Equipped with turbine pump.
21	59.5N 1042.1E	20	60	Limestone and alluvium	14	3-15-62	24M	300	Bottomed on "blue" clay at 60 feet.
32	59.0N 1042.0E	15	31	Alluvium(?)				5,300	Yielded only a trickle of salty water. Abandoned.
"II"	60.2N 1042.8E	30	60	do			5R	150	
"JJ"	61.7N 1042.4E	50	54	Alluvium and weathered rock.	38	4-30-62	3M	300	
"QQ"	64.0N 1044.0E	100	70	do	45	4-27-62	12R	150	

Pumping tests of wells

Field No.	Map coordinates	Date tested	Pumping rate (gpm)	Hours pumped	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)
1 [1]	63.1N 1041.0E	4-25-49 4-26-49	30	24	7	4
2 [2]	63.2N 1041.5E	5-23-49 6-24-49	38	24	14	2½

[1] Retest by R. L. Kenan and Associates.
[2] Final test by R. L. Kenan and Associates.

The water from the Mahogany Road well field is of excellent quality, containing only about 100 ppm of chloride. Wells near the mountains south of the well field (wells JJ, II, and 21) produce water of fair to good quality. However, well 32 was abandoned because it yielded only a trickle of very salty water. Salty water is obtained also from wells within the city limits of Frederiksted and along the coast north of the city. If the wells in the Mahogany Road field are pumped continously at a rate greater than the natural discharge to the sea, salt-water encroachment from the sea could occur. However, it appears that such encroachment is unlikely unless the present rate of pumping is greatly exceeded. If salt water is present in the rocks below the depths penetrated by the wells, its upward migration must be slow because of the low permeability of the rocks.

The Mahogany Road well field is recharged by the underflow in the valley of a westward-flowing stream which drains about 3 square miles in the wettest part of the island. Ideally, the field should be designed to intercept as much of the underflow as possible without lowering water levels to the point where salt-water encroachment might occur.

Possibly some additional development could be attempted in this field. The three existing wells, which lie along the north side of the alluvium-filled valley, penetrate volcanic-sedimentary bedrock. If a well is drilled about 200 feet south of Mahogany Road well 2 (coordinates; 63.2N, 1041.5E) it is possible that a greater thickness of alluvium and weathered rock may be penetrated and a greater yield of water obtained. Additional supplies may be obtainable in the valley upstream from the present well field. Two or three wells might have to be drilled for each new production well, because the water-bearing crevices in the rock are erratic. At the time the well field was installed in 1949, only three of nine wells were successful; these were the discovery well and the 2 original production wells.

BARREN SPOT WELL FIELD

The Barren Spot well field is about 4 miles southwest of Christiansted (fig. 4). There are seven wells in this field; as of May 1962 none had been equipped with pumps. Records of wells in the Barren Spot field are listed in table 3.

Plans are underway to install well pumps and a pumping station in the Barren Spot field and to run a pipeline from the field to Christiansted.

Each of the wells in the Barren Spot field penetrates two aquifers, alluvial material, including sand and gravel, and limestone or sandy limestone underlying the alluvium. In at least some of the wells the first water obtained was under artesian pressure and rose in the hole as much as 20 feet. There was no indication of a change in water level when the underlying limestone was reached.

Four of the wells were test pumped in April and May 1962. Results of the tests are summarized in table 3.

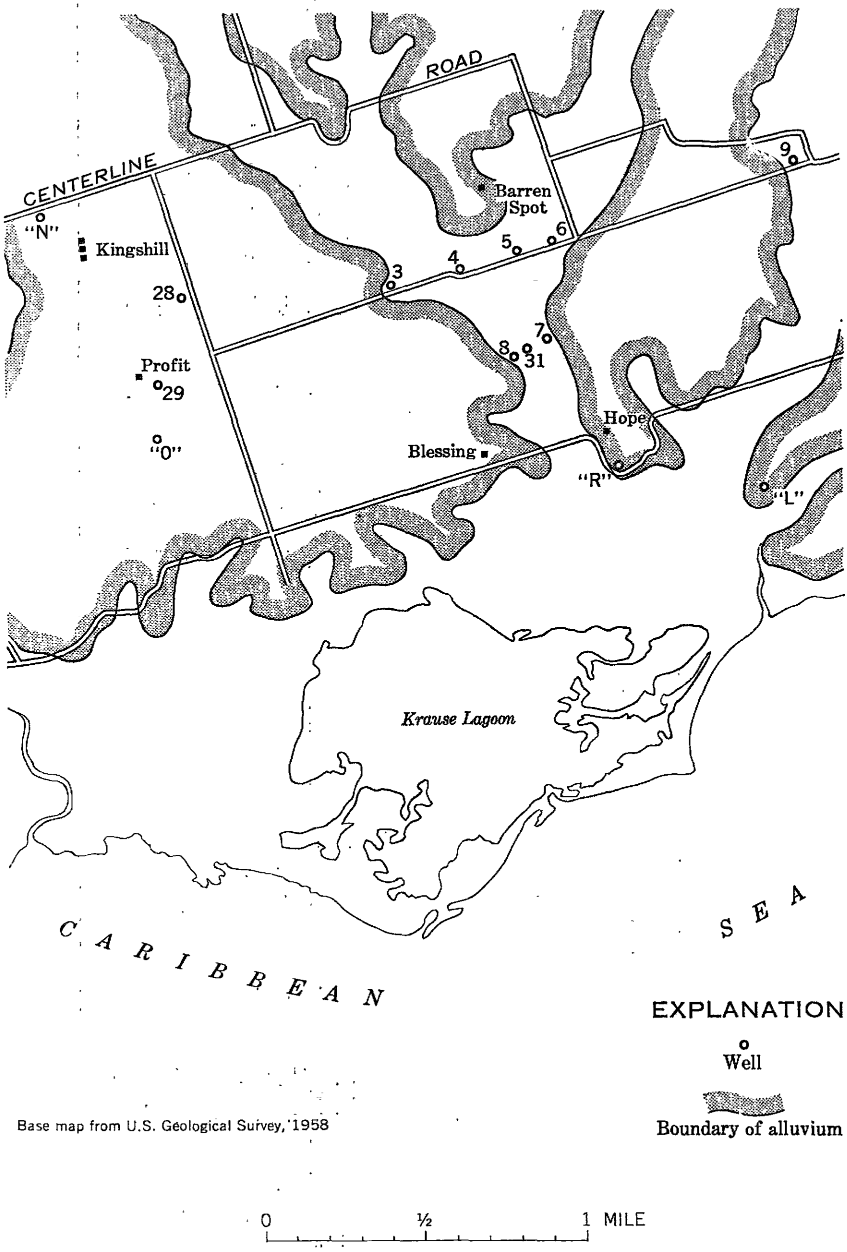

FIGURE 4.—Barren Spot well field.

TABLE 3.—*Barren Spot well field*

Records of wells

[Yield: M, measured; R, reported]

Field No.	Map coordinates	Altitude (feet above sea level)	Depth of well (feet)	Water-bearing material	Water level (feet below land surface)	Date measured	Yield (gpm)	Chloride content (ppm)	Remarks
3	62.6N 1079.4E	90	202	Limestone and alluvium	80	3-14-62	40R		Sand and gravel from 101 to 109 feet; limestone from 109 to 204 feet.
4	63.0N 1080.4E	68	114	do	60	3-14-62	100M	1,100	Sand and gravel from 70 to 75 feet; limestone from 85 to 115 feet.
5	63.3N 1081.4E	75	131	do	68	3-14-62	35R		Sand and gravel from 63 to 79 feet; limestone and marl from 19 to 131 feet.
6	63.5N 1082.1E	82	121	do	75	3-14-62	38R		Sand and gravel from 91 to 95 feet; limestone and marl from 95 to 121 feet.
7	61.9N 1081.9E	55	140	do	52	3-19-62	145M	1,000	Sand and gravel from 85 to 87 feet; limestone from 119 to 140 feet.
8	61.6N 1081.3E	52	130	do	49	3-19-62	100M	1,000	Sand and gravel from 83 to 94 feet; limestone from 120 to 130 feet.
9	84.8N 1085.9E	108	179	Limestone and alluvium	91	3-14-62	25R		Sand and gravel from 119 to 121 feet; limestone from 177 to 180 feet.
28	62.5N 1076.0E	150	180	Limestone	121	5- 3-62	10R	150	Chloride determination of bailed sample may not be representative.
29	61.1N 1075.6E	125	165	do	106	5- 9-62	10R	400	
31	61.7N 1081.6E	53	131	do	51	5-18-62	54M	850	Sand and gravel from 67 to 80 feet; limestone from 106 to 131 feet.
"L"	59.4N 1085.5E	80?	95	do	77	3-28-62	5R	900	Old dug well.
"O"	60.1N 1075.6E	100	135	do	87	3-29-62	15R	600	Had been pumping 15 minutes before water level measured.
"R"	59.7N 1083.0E	30	40	do	26	3-29-62	10R	300	
"YY"	54.2N 1075.3E	10	60	Sand	7	11-23-60	10R	1,500	

Pumping tests

Field No.	Map coor-dinates	Date tested	Pumping rate (gpm)	Hours pumped	Draw-down (feet)	Specific capacity (gpm per foot of drawdown)	Remarks
4	63.0N 1080.4E	4–13–62	100	2½	----------	----------	Test stopped because of failure of air line.
7	61.9N 1081.9F	4–26–62 4–27–62	145	24	21	7	Part of drawdown in well may be caused by entrance loss.
8	61.6N 1081.3E	4–6–62	100	5½	15	7	Do.
31	61.7N 1081.6E	5–17–62	36	3	5	7	Well was 108 feet deep when test was made.
31	61.7N 1081.6E	5–18–62	54	3	4	13	Well was 131 feet deep when test was made.

Most of the tests were too short to be subject to mathematical analysis by conventional "aquifer test" methods. Furthermore, the assumption of a homegeneous extensive aquifer made in the calculations is not valid for this area. Nevertheless, the tests provided information that should be useful in planning the development of this field.

The transmissibility of the limestone aquifer in the well field is estimated to be about 50,000 gpd per ft. In an aquifer having such a transmissibility, 50,000 gallons will move each day through each section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. The transmissibility of the limestone may be less in the upland area to the east and west of the field than in the well-field area, where the limestone underlies water-bearing alluvium. Wells 28, 29 and "O," in the uplands west of the Barren Spot well field, were reported to yield 10 to 15 gpm when bailed. These bailing tests did not provide information adequate to justify an estimate of the transmissibility of the limestone in this upland area. The transmissibility of the alluvial material in the Barren Spot field is estimated to be about 10,000 gpd per ft.

The short pumping tests were not adequate to determine the coefficients of storage. When well 7 was pumped, the drawdown in well 8, which is 600 feet distant, though small, was almost immediate. It appears that the coefficient of storage in at least one of the aquifers, especially in the limestone, is small—perhaps in the range of 0.001 to 0.0001. The coefficient of storage of the alluvium in places where the water is under artesian pressure may be in the same range. Where water in the alluvium is under water-table conditions the coefficient of storage is much greater, perhaps 0.1 to 0.3.

Measurements of water levels indicate that the hydraulic gradient of the ground water is about 3 feet per mile toward the coast. Thus, if the average transmissibility is 50,000 gpd per ft., about 150,000 gpd is moving toward the coast in each mile width of the limestone. It is possible, however, that the permeable section of the limestone is not even as much as 1 mile wide.

The significance of the small coefficient of storage is that the cone of depression expands rapidly. Even so, before there could be an appreciable lowering of the water level at the coast, saline water would tend to rise from below if wells were pumped heavily.

The chloride content of water from well 31 (coordinates: 61.7N, 1081.6E) when it was 108 feet deep was about 700 parts per million at a pumping rate of 36 gpm. When the well was deepened to 131 feet, the chloride content increased to 850 ppm at a pumping rate of 54 gpm. The chloride content of water from wells 7 (coordinates: 61.9N, 1081.9E) and 8 (coordinates: 61.6N, 1081.3E) was 1,000 ppm at a pumping rate of more than 100 gpm. It appears that water of better quality will be obtained from the Barren Spot field when the wells are pumped at a lower rate than when they are pumped at or near their maximum capacity. The chloride content of water from well "R," about half a mile south of the Barren Spot well field and about a mile north of Krause Lagoon, was only 300 ppm; but well "L," at about the same distance from the coast, yielded water containing 900 ppm of chloride. Wells 28, 29 and "O," in the uplands west of Barren Spot, yielded water containing 150, 400, and 600 ppm of chloride, respectively. The occurrence of chloride in the water from the limestone appears to be quite erratic and probably is related, among other things, to depth of the well, distance from the sea, and the rate and duration of pumping.

The Barren Spot well field is recharged by rainfall on the limestone and alluvial area to the north. No surface runoff occurs in the valley of Barren Spot even during the wet season in the average year. Consequently, it is assumed that water normally discharges from this area entirely as ground-water flow.

The amount of water that can be pumped from the Barren Spot well field depends on the amount of chloride that will be acceptable to the users. If each of the seven wells were pumped constantly at a rate of 30 gpm the field would yield about 300,000 gallons per day. At this rate of pumping it is estimated that the initial chloride content of the water would be less than 1,000 ppm, possibly as low as 800 ppm. However, it is probable that the chloride content of the water would increase as the water stored in the alluvium was used up and a relatively larger proportion of the water was drawn from the limestone.

If each of the wells is pumped at a rate of 100 gpm the field would yield about 1 million gallons of water per day. At this rate of pumping the initial chloride content of the water probably would be more than 1,000 ppm; at the end of a year of pumping the chloride content of the water might exceed 2,000 ppm.

It is unlikely that drastic changes in water levels or quality will take place overnight. In all probability a trend of lowering water levels, increasing chloride, or both will be noticeable long before the problem is critical. If such a trend were detected, pumping would have to be reduced. If the water levels, chloride content of water, pumpage from the field, and local precipitation are all plotted on a single graph, the relation of each factor to the others will be readily apparent.

The ground-water supply at Barren Spot should be monitored before and after pumping begins. Records obtained before water is pumped from the field will show the fluctuations in ground-water levels and in quality of water that occur under natural conditions. Records obtained after pumping begins will show changes in ground-water levels and in quality of water induced by withdrawing water from the field. As in the Concordia field and elsewhere, such records will be the best guides to future operations.

ADVENTURE, GOLDEN GROVE, AND MANNING WELL FIELDS

The Adventure Well field is just south of the Centerline Road about 4 miles east of Frederiksted (about 5½ miles by road) (fig. 5). There are four public-supply wells in this field. The water-bearing material, logged as yellow marl, sand, and gravel, is chiefly alluvium, although the lower marl may belong to the Kingshill Marl. Each of the wells is bottomed in "blue" clay, probably of the Jealousy Formation. Downstream from the Adventure well field are the Golden Grove well field and the Manning well field. There are four industrial wells in the Golden Grove field and five in the Manning field. Records of wells in the Adventure, Golden Grove, and Manning well fields are listed in table 4.

Pumping tests were made on each of the wells in the Adventure field. Results of the tests are summarized in table 4.

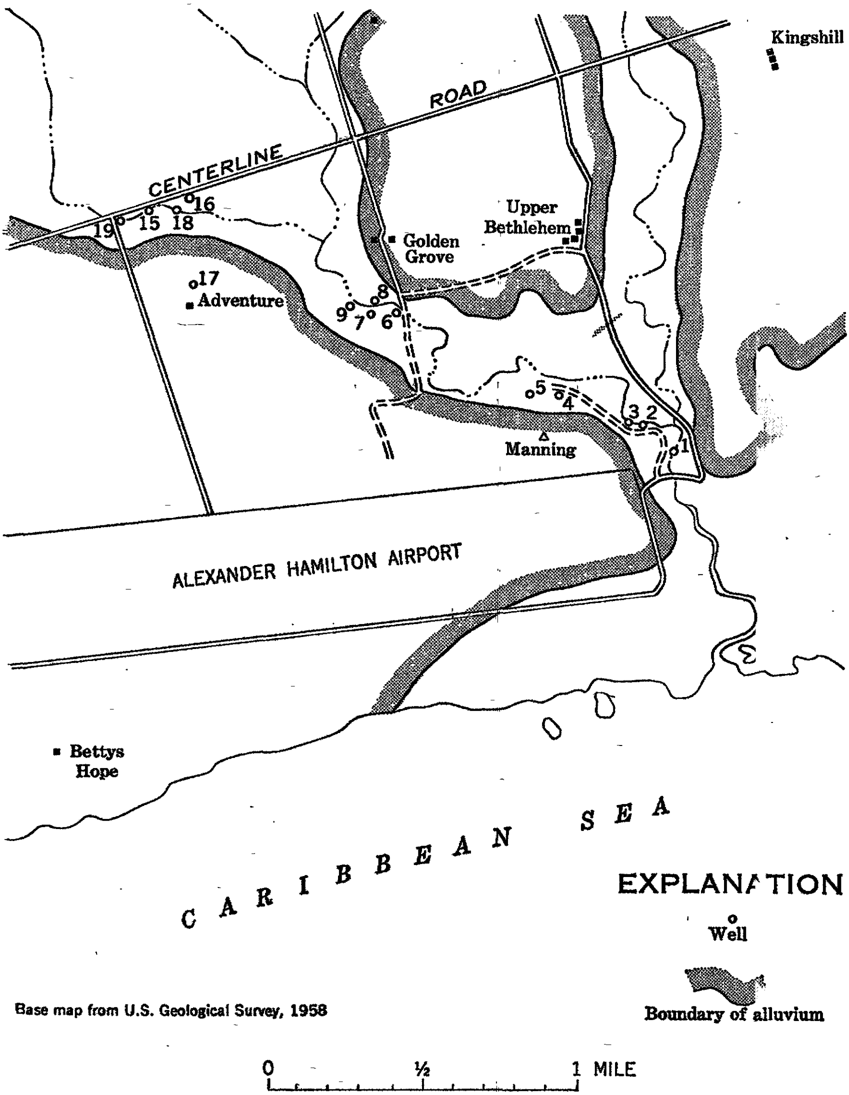

FIGURE 5.—Adventure, Golden Grove, and Manning well fields.

Table 4.—*Adventure, Golden Grove, and Manning well fields*

Records of wells

[Yield: M, measured; R, reported]

Field No.	Map coordinates	Altitude (feet above sea level)	Depth of well (feet)	Water-bearing material	Water level (feet below land surface)	Date measured	Yield (gpm)	Chloride content (ppm)	Remarks
1	56.9N 1072.7E	15		Alluvium?	29	4-29-62	40R	600	Being pumped when measured. Equipped with turbine pump.
2	57.3N 1072.2E	15		do			30R	550	Equipped with turbine pump.
3	57.4N 1072.0E	20		do			30R	300	Do.
4	57.7N 1070.9E	35		do			30R	550	Do.
5	57.7N 1070.3E	40		do			30R	500	Do.
6	59.2N 1068.1E	50		do			40R		Do.
7	59.1N 1067.7E	50		do			40R		Do.
8	59.3N 1067.7E	50		do			40R	300	Do.;
9	57.2N 1067.3E	50		Alluvium?			40R		Equipped with jet pump.
15	60.8N 1064.1E	80	106	Alluvium	8	3-15-62	150M	300	Bottomed in "blue" clay at 103 to 106 feet.
16	60.9N 1064.7E	90	107	Alluvium	15	3-15-62	40M	150	Bottomed in "blue" clay at 105 to 107 feet.
17	59.3N 1064.9E	108	154	Limestone	39	3-15-62	10R		Bottomed in "blue" clay at 149 to 154 feet.
18	60.7N 1064.5E	80	103	Alluvium	14	3-15-62	65M	200	Bottomed in "blue" clay at 101 to 103 feet
19	60.6N 1063.7E	80	127	do	10	3-15-62	65M	300	Bottomed in "blue" clay at 127 feet.

Pumping tests of wells

Field No.	Map co-ordinates	Date tested	Pumping rate (gpm)	Hours pumped	Draw-down (feet)	Specific capacity (gpm per foot of draw-down)	Remarks
15	60.8N 1064.1E	4-16-62	150	1¼	11		Test too short to determine significant specific capacity.
16	60.9N 1064.7E	4-18-62	40	2			Test stopped because surface material caved around casing.
18	60.7N 1064.5E	5-8-62	65	5	43	1½	Apparently little or no water returning to well.
19	60.6N 1063.7E	4-17-62	65	1			Test stopped because water was returning to well.

In all but one of the tests there was evidence that the water discharged from the well into the gut (streambed) was returning to the well. None of these tests was continued long enough to lower the water levels in nearby wells.

The quality of water yielded by the Adventure wells is good. Chloride ranged from 150 to 300 ppm. No change in chloride content was noted during the short pumping tests.

The aquifer apparently is recharged by infiltration of rainfall and runoff in the alluvial area at the well field itself and to the north and northwest. Probably most of the recharge comes from water running in the gut after heavy rains. During unusually heavy rains in October 1960, water reportedly was running over the Centerline Road at the Adventure field, covering the road with more than 5 feet of water. During such floods it is probable that the alluvium becomes saturated to the land surface. The short time needed for water in the gut to reach the aquifer was apparent when well 15 was test pumped on April 16 and again on April 17. The drawdown on April 16 was about 10 feet after 150 gpm had been pumped into the gut for 1 hour. On April 17 the drawdown was less than 2 feet after 2½ hours of pumping at the same rate.

The potential yield of the Adventure field could not be determined from the results of the short-term pumping tests. Probably each of the wells could be pumped at a rate of not less than 30 gpm. There appears to be little danger of encroachment of salt water from below, as each of the wells is bottomed in impermeable material. Spread of the cone of depression to the limestone bordering the alluvial material may bring in water higher in chloride content. It is possible that the cone of depression formed by pumping the wells may induce recharge of fresh water during floods that otherwise would be lost to the sea. Additional wells could be drilled along the gut between the Adventure and Golden Grove fields and also perhaps along the east branch of the gut south of Centerline Road. Salt-water encroachment from the sea could result from heavy pumping in the Manning well field and possibly in the Golden Grove field. There appears to be little danger of salt-water encroachment from the sea to the Adventure field because the static water level there is about 70 feet above sea level. The potential yield of the alluvial materials in the entire drainage area can be determined only by additional test drilling and test pumping and by keeping records of rainfall, pumpage, water levels, and chloride content for at least several years.

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