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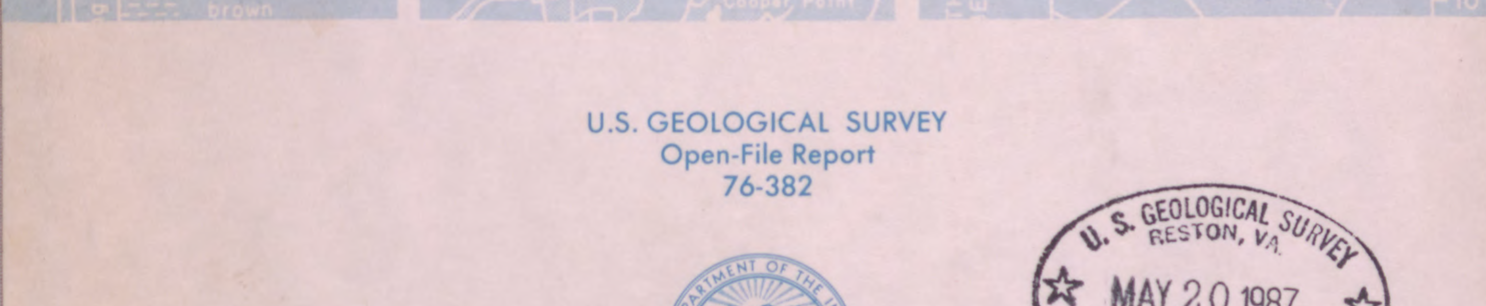
RECONNAISSANCE OF GROUND-WATER RESOURCES OF THE SQUAXIN ISLAND INDIAN RESERVATION, WASHINGTON



U.S. GEOLOGICAL SURVEY
Open-File Report
76-382

Prepared in Cooperation With The
Squaxin Island Indian Tribal Council

UNITED STATES
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

RECONNAISSANCE OF GROUND-WATER RESOURCES OF THE SQUAXIN ISLAND INDIAN RESERVATION, WASHINGTON

By W. E. Lum II and Kenneth L. Walters

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Tacoma, Washington
1976

For further information on this investigation and on other water-resources studies in Washington carried out by the U.S. Geological Survey, contact the U.S. Geological Survey, Water Resources Division, 1305 Tacoma Avenue South, Tacoma, Wash. 98402

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The following factors are provided for conversion of English values used in this report to metric values:

Multiply	By	To obtain
Inches	25.4	millimetres (mm)
	2.54	centimetres (cm)
	0.0254	metres (m)
Feet (ft)	0.3048	metres (m)
Miles (mi)	1.609	kilometres (km)
Square miles (mi^2)	2.590	square kilometres (km^2)
Acres	4047.	square metres (m^2)
Acre-feet (acre-ft)	1233.	cubic metres (m^3)
Gallons per minute (gal/min)	0.06309	litres per second (l/s)

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ABSTRACT

A supply of fresh ground water for the Squaxin Island Indian Reservation exists in saturated deposits underlying the 3.09-square-mile island, whereas surface-water supplies are practically nonexistent. Four test wells tapped a water-bearing zone of sand and gravel and had yields ranging from 27 to 170 gallons per minute, with drawdowns of about 5 feet to about 65 feet. Except for high concentrations of iron and manganese (which can be treated and reduced for domestic use), the water quality is good. Conditions for drain-field waste disposal (such as from septic tanks) are probably good in at least the northern two-thirds of the island. The potential for seawater encroachment into the water-bearing zones underlying the island is unknown but may be great in places. The danger of inducing encroachment can be minimized by maintaining pumping levels above sea level, using a network of several wells pumped intermittently into a storage facility, and spacing these wells to spread out the effects of pumping. Monitoring of the water quality in all wells would help indicate early signs of increasing chloride content that warn of impending seawater encroachment.

In the northern half of the island, where ground-water conditions are the most favorable, wells 100 to 200 feet deep may yield 25 to 100 gallons per minute with minimum chances of seawater encroachment. The southern half of the island has a smaller apparent potential for ground-water development and an increased possibility of seawater encroachment.

INTRODUCTION

Purpose and Scope of the Study

In 1971 the Squaxin Island Indian Tribal Council adopted a set of goals for the tribe intended to provide a self-sustaining and stable Indian community on its reservation. This set of goals include development of the following:

1. Fisheries and aquiculture resources of the island for the maximum benefit of the tribe.

2. A cultural center for Indian education and recreation.

3. A private and separate area in which the Squaxin Island tribal members could live in a relaxed atmosphere.

4. A recreation tourist industry that would be in keeping with the natural character of the reservation.

Because some of the goals require an adequate water supply, the U.S. Geological Survey, in cooperation with the Squaxin Island Indian Tribal Council, began this study in 1974 to evaluate the water resources of Squaxin Island. As there are no significant perennial springs or streams on the island this study concerns itself mainly with ground water, specifically:

1. Occurrence of ground water beneath the island and expected yields from wells.

2. Depths from which the ground water must be pumped.

3. The chemical quality of the ground water.

4. The actual or potential pollution problems from seawater encroachment or other sources.

To define the hydrology of the reservation and respond to the above desires for information, a general reconnaissance of the entire island was carried out, along with a program of data collection. The data-collection phase consisted mainly of drilling and testing four wells between January and March 1975.

Description of the Island

The Squaxin Island Indian Reservation boundary encompasses all of Squaxin Island which is in the southwestern part of the Puget Sound lowland about 8 miles north of Olympia, Wash. (fig. 1). Squaxin Island is about 4 miles long, averages about 0.8 mile wide, and, including tidelands, covers about 3.09 mi^2 (1,980 acres). The maximum altitude on the island is about 180 feet above mean sea level, and the moderately undulating surface of the island is covered mostly with second-growth cedar and fir. Precipitation over the island averaged about 52 inches per year during 1930-57 (U.S. Weather Bureau, 1965). According to the [U.S.] National Oceanic and Atmospheric Administration (1972), about 80 percent of the rainfall at nearby Shelton, Wash., occurs during October-March.

The only economic developments on the reservation have been a few small farms--which are now abandoned--infrequent logging operations, commercial oyster growing which has been practiced on some of the tidelands for a number of years, and a tribal aquiculture area recently developed offshore. A boat dock and picnic area at Squaxin Island State Park near the south end of the island attracts numerous visitors. The only roads are overgrown logging trails. There are no permanent residents on the island, and most tribal members live in nearby areas. Docking facilities are limited to two sites at present (1975) and do not provide for landing of construction materials and equipment for development of the island.

Previous Investigations

A geologic reconnaissance of Squaxin Island is discussed in a report on the geology and hydrology of southeastern Mason County by Molenaar and Noble (1970); that report provided a means of correlating the results of this study with the regional geology of the area. Well logs in that report were helpful in relating conditions on Squaxin Island to the regional conditions of ground-water occurrence.

The geology and hydrology in adjacent Thurston County are discussed in reports by Wallace and Molenaar (1961) and Noble and Wallace (1966). These reports provided well logs in northern Thurston County and background information that was of value to this study.

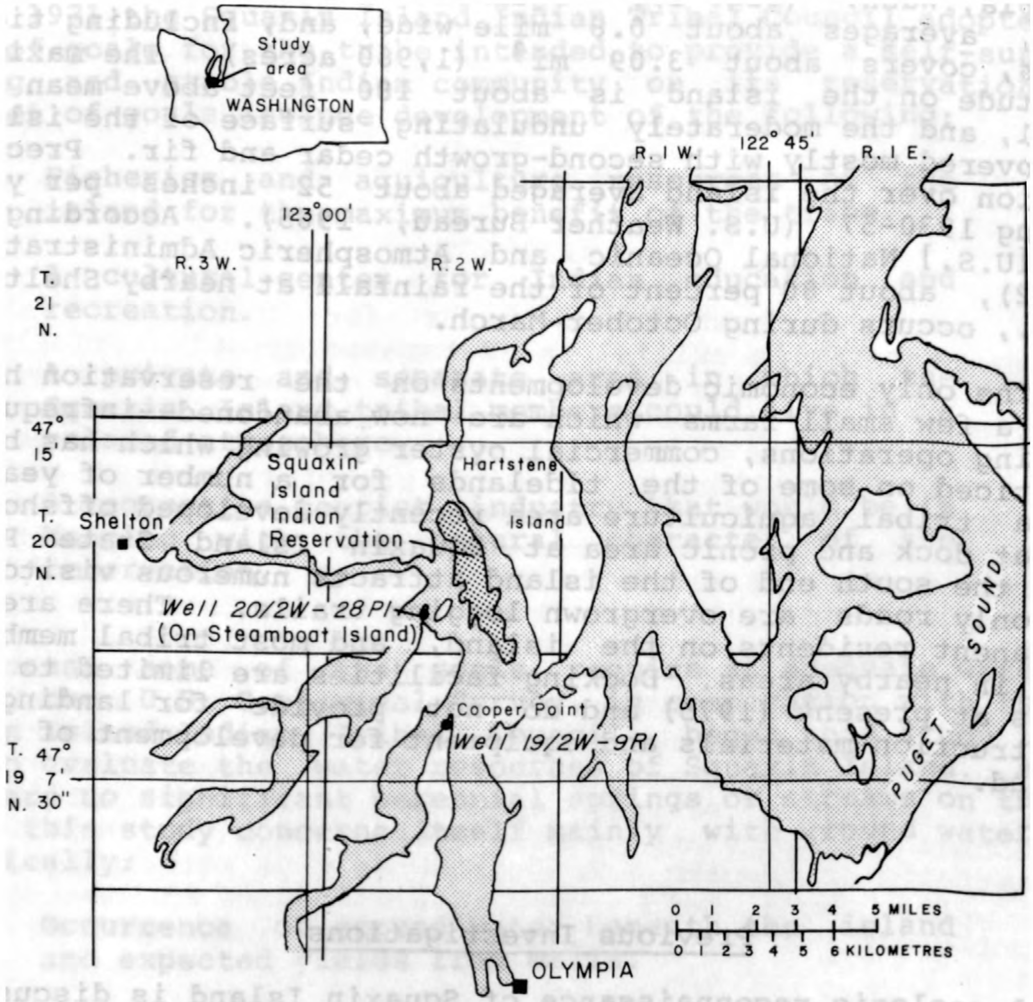


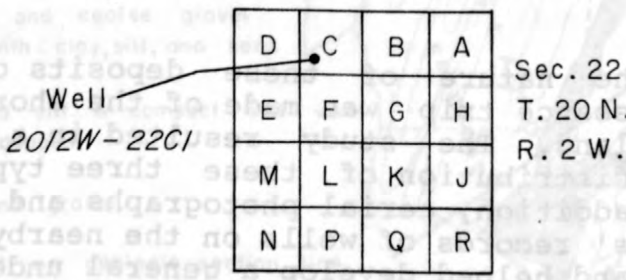
FIGURE 1.--Location of Squaxin Island Indian Reservation in southern Puget Sound area, Washington, and two wells studied outside the reservation.

Acknowledgments

The authors thank the personnel of the 1118th Transportation Company of the Washington National Guard for their support in the logistics of transporting the drilling and pumping equipment for the test wells completed during the project. Special acknowledgment of careful transportation planning is due Lt. R. K. Oglesbee and Sgt. E. J. Shinn. Without their help a large part of the program would not have been possible.

Well-Numbering System

In this report wells are designated by symbols that indicate their location according to the official rectangular public-land survey. For example, in the symbol 20/2W-22C1, the part preceding the hyphen indicates successively the township and range (T.20 N., R.2 W.) north and west of the Willamette base line and meridian. The first number following the hyphen indicates the section (sec.22), and the letter (C) indicates the 40-acre subdivision of the section, as shown in the accompanying diagram.



The last number is the serial number of the well in the particular 40-acre tract. Thus, well 20/2W-22C1 is in the NE¼NW¼ sec.22, T.20 N., R.2 W., and is the first well in the tract to be listed.

All the test wells drilled during this project are within T.20 N., R.2 W. To simplify the discussion in the text the T. and R. numbers are omitted and the wells are referred to by section and 40-acre subdivision of the section, such as 22C1, 22G1, 26F1, and 35D1.

GEOLOGY AND GROUND-WATER EXPLORATION

General Geology of the Area

The entire Puget Sound lowland was covered several times by glacial ice sheets that originated in Canada, the last glacial advance occurring as recently as about 14,000 years ago. The glaciers deposited large amounts of materials over the southern Puget Sound lowland--including Squaxin Island--near the southern limit of these glacial advances. In some places the deposits are more than 2,000 feet thick (Walters and Kimmel, 1968). Three general types of deposits are associated with glaciers:

Sand and gravel - mostly deposited beyond the margins of the glaciers by melt-water streams flowing from the ice.

Till - A compact, unsorted mixture of rock fragments ranging in size from clay to boulders, and deposited directly by the ice as it moves over the land surface. Till is often referred to as "hardpan" by drillers.

Clay and silt - deposited in local depressions filled by lakes and ponds.

To determine the nature of these deposits on Squaxin Island, a reconnaissance trip was made of the shoreline and interior of the island. The study resulted in a map (fig. 2) of the general distribution of these three typical geologic units. In addition, aerial photographs and correlations with drillers' records of wells on the nearby mainland and Hartstene Island helped develop a general understanding of the surface and subsurface geology of Squaxin Island.

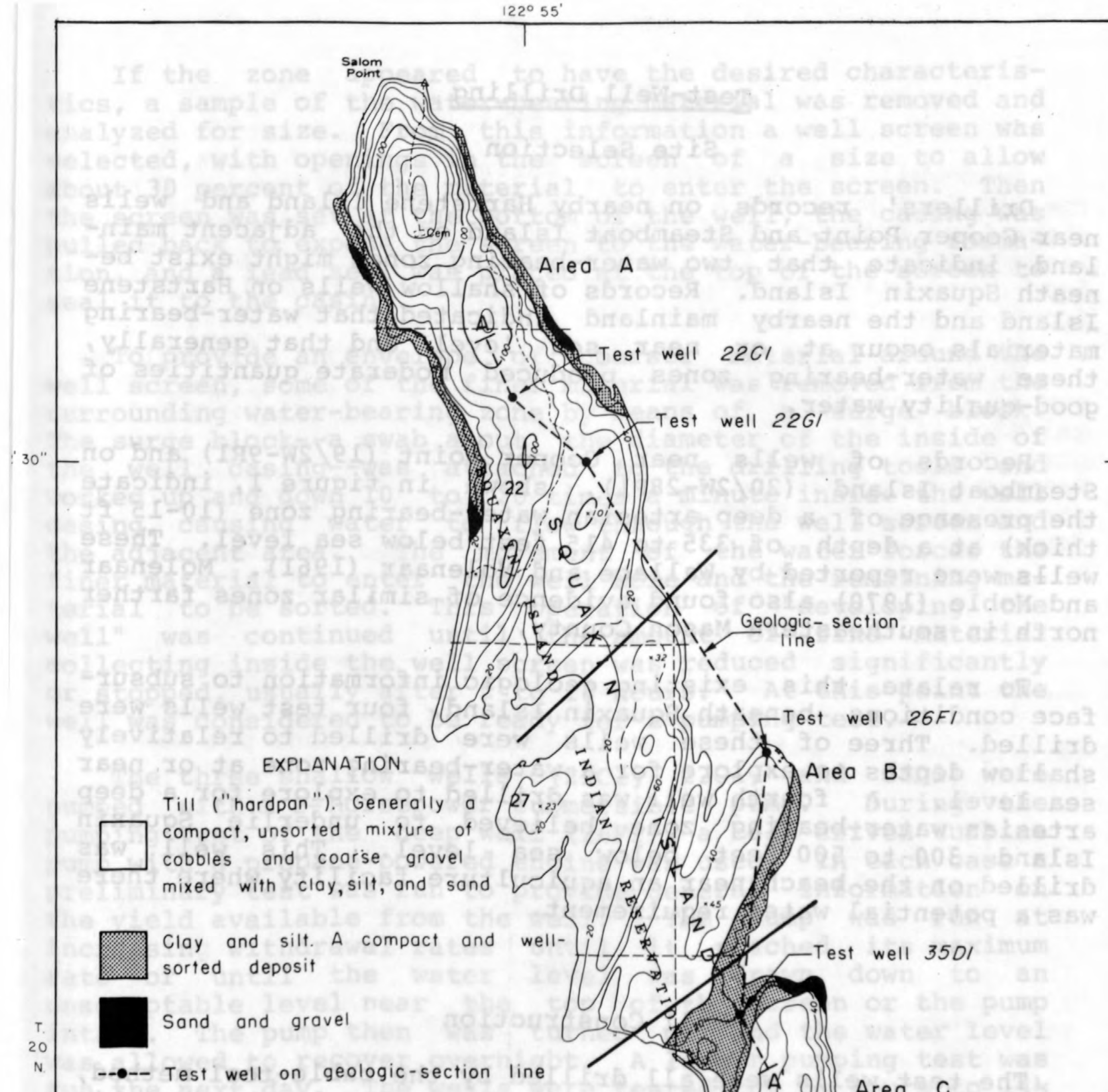


FIGURE 2.--Generalized geology of Squaxin Island and location of the geologic section shown in figure 7 and areas A, B, and C (discussed in text).

Test-Well Drilling

Site Selection

Drillers' records on nearby Hartstene Island and wells near Cooper Point and Steamboat Island on the adjacent mainland indicate that two water-bearing zones might exist beneath Squaxin Island. Records of shallow wells on Hartstene Island and the nearby mainland indicated that water-bearing materials occur at or near sea level and that generally, these water-bearing zones produced moderate quantities of good-quality water.

Records of wells near Cooper Point (19/2W-9R1) and on Steamboat Island (20/2W-28P1), shown in figure 1, indicate the presence of a deep artesian water-bearing zone (10-15 ft thick) at a depth of 335 to 415 feet below sea level. These wells were reported by Wallace and Molenaar (1961). Molenaar and Noble (1970) also found evidence of similar zones farther north in southeastern Mason County.

To relate this existing geologic information to subsurface conditions beneath Squaxin Island, four test wells were drilled. Three of these wells were drilled to relatively shallow depths to explore for a water-bearing zone at or near sea level. A fourth well was drilled to explore for a deep artesian water-bearing zone believed to underlie Squaxin Island 300 to 500 feet below sea level. This well was drilled on the beach near an aquiculture facility where there was a potential water requirement.

Well Construction

The test wells were all drilled by the cable-tool method, by Harbor Pump and Drilling Co. of Gig Harbor, Wash. In this method of drilling, a tool suspended on a cable was used to drill the borehole and drive the casing down inside the borehole in alternating steps. The cuttings from the well were removed periodically with a bailer to allow more drilling and a visual inspection of the material being penetrated. When a relatively thick section of water-bearing material was penetrated, a short (10 minutes to 1 hour) bailing test (withdrawing water from the well with the bailer) was usually made to gain some information on the possible yield of the water-bearing zone.

If the zone appeared to have the desired characteristics, a sample of the water-bearing material was removed and analyzed for size. From this information a well screen was selected, with openings in the screen of a size to allow about 30 percent of the material to enter the screen. Then the screen was set at the bottom of the well, the casing was pulled back to expose the screen to the water-bearing formation, and a lead seal was placed at the top of the screen to seal it to the casing.

To provide an envelope of coarser material around the well screen, some of the finer material was removed from the surrounding water-bearing zone by means of a surge block. The surge block--a swab about the diameter of the inside of the well casing--was attached to the drilling tools and worked up and down 10 to 20 times a minute inside the well casing, causing water to flow through the well screen and the adjacent area. The movement of the water forces the finer material to enter the well bore and the remaining material to be sorted. This operation of "developing the well" was continued until the amount of fine material collecting inside the well screen was reduced significantly or stopped, usually after 2 to 10 hours. At this point the well was considered to be ready for a pumping test.

The three shallow wells (22C1, 22G1, and 35D1) were pumped with a 2-horsepower submersible pump. During the pumping test of the deep well (26F1), a belt-driven turbine pump with a propane-powered engine was used. In each case a preliminary test was run to provide general information on the yield available from the well. The pump was run at increasing withdrawal rates until it reached its maximum rate or until the water level was drawn down to an unacceptable level near the top of the screen or the pump intake. The pump then was turned off and the water level was allowed to recover overnight. A longer pumping test was run the next day. The wells were tested for 5½ hours to 14½ hours, depending on the times required for their drawdowns to begin to stabilize. Samples of the pumped water were collected and the water levels were measured before, during, and after the pumping tests. All these data are presented partly in graphic form in figures 3,4,5, and 6 and are listed in tables 2 and 3.

Test Well 22C1

Test well 22C1 was drilled during January 21-28, 1975. The 110-foot well has a 6-inch casing extending from 1 foot above land surface (altitude about 82 ft) to 104½ feet below land surface (fig.3). The well is finished with a stainless-steel wire-wrapped screen with a 0.045-inch slot size from 104 to 110 feet below land surface.

During a pumping test on January 29, 1975, the well was pumped 12 hours and 40 minutes at an average rate of 52 gal/min. From a static water level of 66 feet below land surface, the water was drawn down about 25 feet, to about 9 feet below sea level. From this the specific capacity[1] of the well was determined to be 2.1 gal/min per foot of drawdown.

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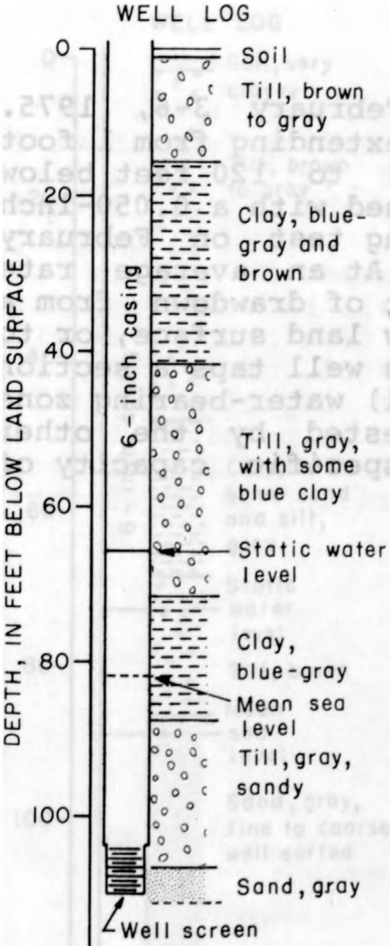
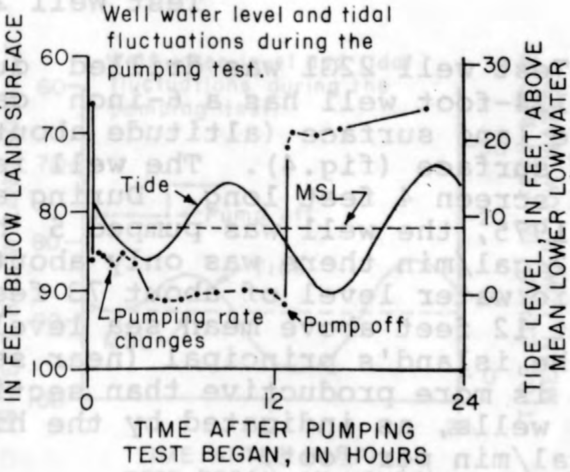
[1]The discharge expressed as rate of well yield per unit of drawdown of water level, generally as gallons per minute per foot of drawdown.





Chemical Analysis of Well Water

Constituents:	Concentration (mg/l)	Recommended acceptable concentration (mg/l)
Iron	3.8	[a] 0.3
Manganese	0.25	[a] 0.05
Calcium	15	(b)
Magnesium	12	(b)
Chloride	4.4	[a] 250
Fluoride	0.1	[a] 2.0
Nitrite + nitrate as N	0.0	[a] [d] 10
Dissolved solids	136	no recommended limit[a] ([c] 500)
Total hardness	87 (moderately hard)	(b)

[a] [U.S.] Environmental Protection Agency, 1973.

[b] No limits of concentration for calcium, magnesium, and total hardness are established--high concentrations of calcium and magnesium contribute to hardness of the water.

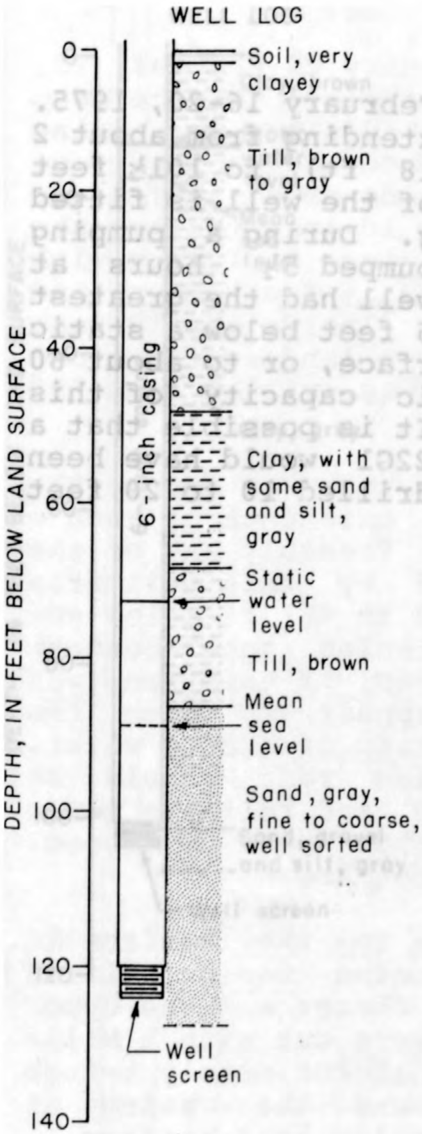
[c] U.S. Public Health Service, 1962.

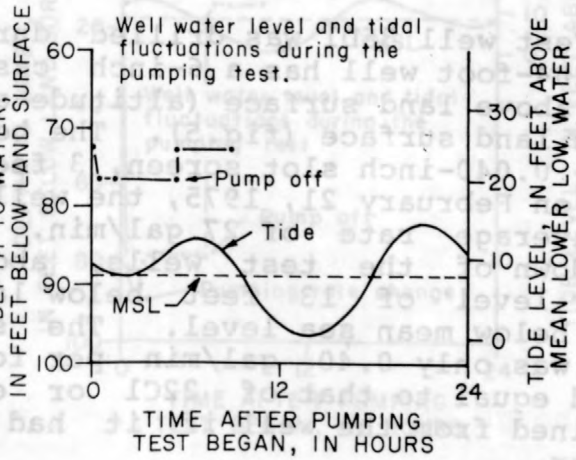
[d] Nitrite should not exceed 1 mg/l.

FIGURE 3.--Geohydrologic data from test well 22C1.

Test Well 22G1

Test well 22G1 was drilled during February 3-6, 1975. The 124-foot well has a 6-inch casing extending from 1 foot above land surface (altitude about 89 ft) to 120 feet below land surface (fig.4). The well is finished with a 0.050-inch slot screen 4 feet long. During a pumping test on February 10, 1975, the well was pumped 5 hours. At an average rate of 52 gal/min there was only about 4 feet of drawdown from a static water level of about 73 feet below land surface, or to about 12 feet above mean sea level. This well taps a section of the island's principal (near sea-level) water-bearing zone that is more productive than sections tested by the other test wells, as indicated by the higher specific capacity of 13 gal/min per foot.





Chemical Analysis of Well Water

Constituents:	Concentration (mg/l)	Recommended acceptable concentration (mg/l)
Iron	1.5	[a]0.3
Manganese	0.9	[a]0.05
Calcium	16	(b)
Magnesium	10	(b)
Chloride	3.6	[a]250
Fluoride	0.1	[a]2.0
Nitrite + nitrate as N	0.0	a [d]10
Dissolved solids	140	no recommended limit [a] ([c]500)
Total hardness	81 (moderately hard)	(b)

[a][U.S.] Environmental Protection Agency, 1973.

[b]No limits of concentration for calcium, magnesium, and total hardness are established--high concentrations of calcium and magnesium contribute to hardness of the water.

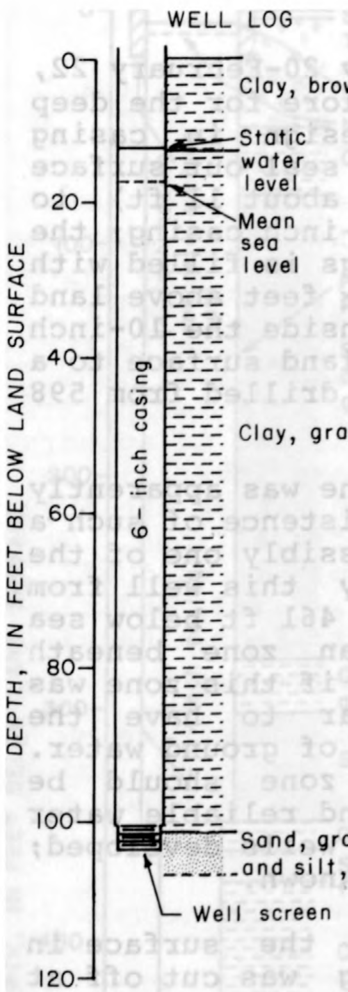
[c]U.S. Public Health Service, 1962.

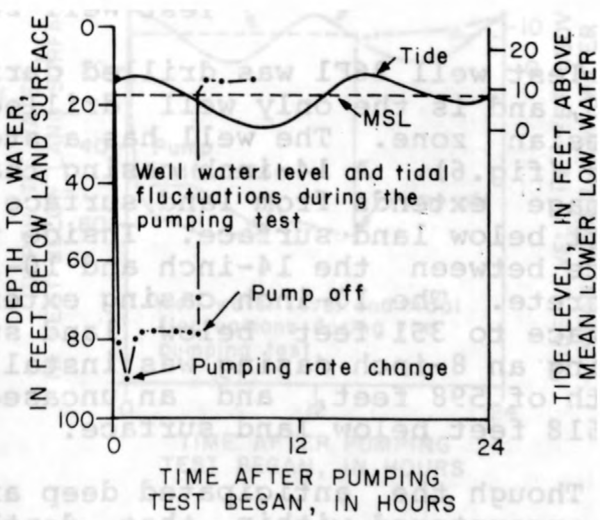
[d]Nitrite should not exceed 1 mg/l.

FIGURE 4.--Geohydrologic data from test well 22G1.

Test Well 35D1

Test well 35D1 was drilled during February 16-20, 1975. The 104-foot well has a 6-inch casing extending from about 2 feet above land surface (altitude about 18 ft) to 101½ feet below land surface (fig.5). The bottom of the well is fitted with 0.040-inch slot screen, 3 feet long. During a pumping test on February 21, 1975, the well was pumped 5½ hours at an average rate of 27 gal/min. This well had the greatest drawdown of the test wells, about 65 feet below a static water level of 13 feet below land surface, or to about 60 feet below mean sea level. The specific capacity of this well was only 0.40 gal/min per foot. It is possible that a yield equal to that of 22C1 or even 22G1 would have been obtained from the well if it had been drilled 10 to 20 feet deeper.





Chemical Analysis of Well Water

Constituents:	Concentration (mg/l)	Recommended acceptable concentration (mg/l)
Iron	0.06	[a]0.3
Manganese	0.07	[a]0.05
Calcium	26	(b)
Magnesium	9	(b)
Chloride	4.2	[a]250
Fluoride	0.1	[a]2.0
Nitrite + nitrate as N	0.0	[a] [d]10
Dissolved solids	172	no recommended limit[a] ([c]500)
Total hardness	100 (moderately hard)	(b)

[a] [U.S.] Environmental Protection Agency, 1973.

[b] No limits of concentration for calcium, magnesium, and total hardness are established--high concentrations of calcium and magnesium contribute to hardness of the water.

[c] U.S. Public Health Service, 1962.

[d] Nitrite should not exceed 1 mg/l.

FIGURE 5.--Geohydrologic data from test well 35D1.

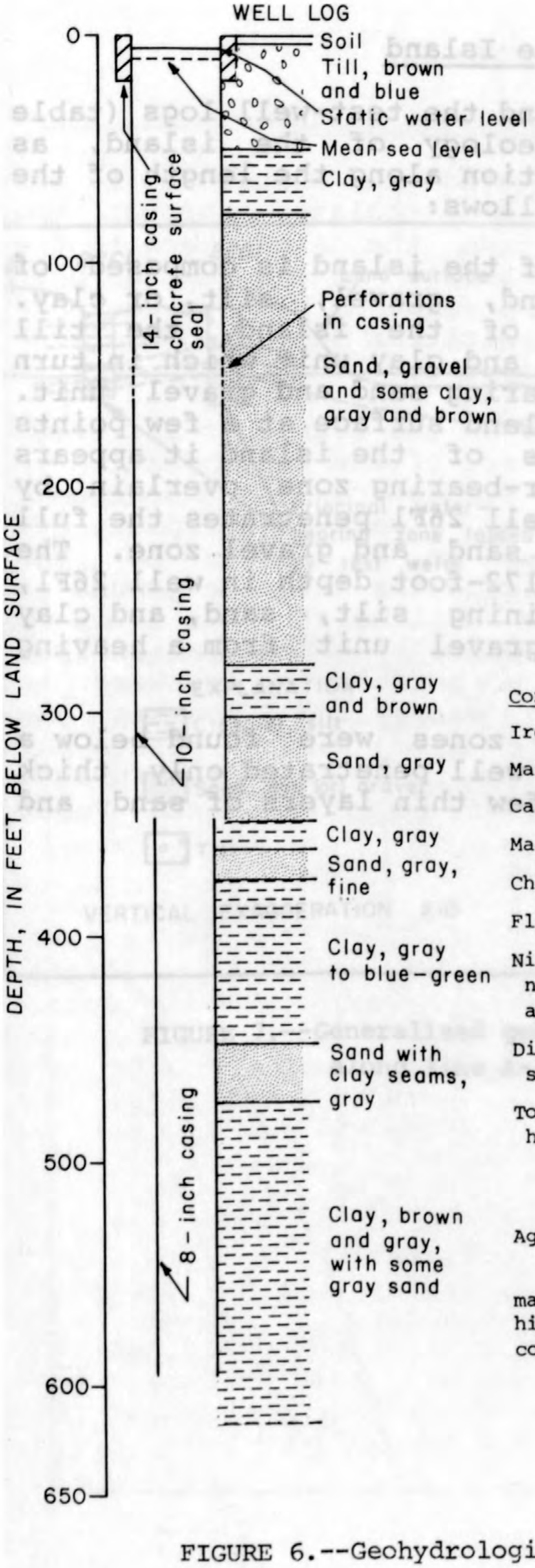
Test Well 26F1

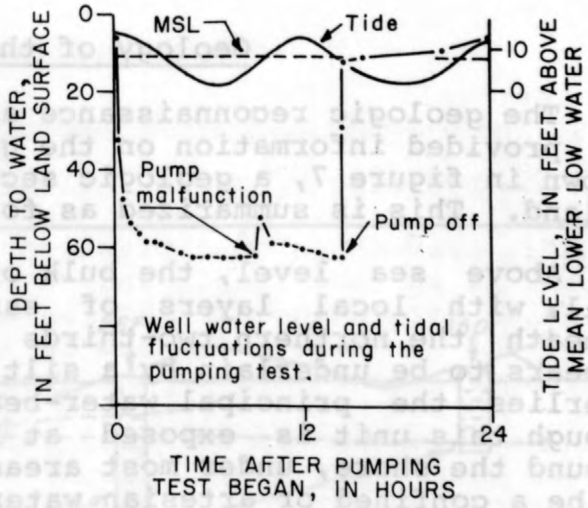
Test well 26F1 was drilled during January 20-February 22, 1975, and is the only well drilled to explore for the deep artesian zone. The well has a step-down design in casing size (fig.6). A 14-inch casing that acts to seal out surface seepage extends from land surface (altitude about 11 ft) to 18 ft below land surface. Inside this is 10-inch casing; the space between the 14-inch and 10-inch casings is filled with concrete. The 10-inch casing extends from 1½ feet above land surface to 351 feet below land surface. Inside the 10-inch casing an 8-inch casing was installed, from land surface to a depth of 598 feet, and an uncased hole was drilled from 598 to 618 feet below land surface.

Though the anticipated deep artesian zone was apparently not encountered within that depth the existence of such a zone under the island was not disproven. Possibly one of the several sand and gravel zones penetrated by this well from 301 to 472 feet below land surface (290 to 461 ft below sea level) may correlate with the deep artesian zone beneath Cooper Point and Steamboat Island. However, if this zone was penetrated by this test well it did not appear to have the capacity to yield any significant quantity of ground water. Further exploration for a deep artesian zone should be considered for a possibly more abundant and reliable water supply than that obtained from the shallow wells developed; but the depth at which one may occur is not known.

To develop a water-bearing zone close to the surface in this deep exploratory well, the 8-inch casing was cut off at the 350-foot depth with an explosive charge and the upper part was removed from the well. Slots were cut with a Mills knife in the 10-inch casing. Six slots approximately ¼-inch by 1½-inches were uniformly spaced around the casing at 6-inch intervals from 141½ to 158½ feet below land surface.

During a pumping test on February 28, 1975, the well was pumped 14 hours 25 minutes at an average rate of 170 gal/min. From the static water level of about 8 feet below land surface, the water level was drawn down 55 feet, or to about 52 feet below sea level. The specific capacity of this well was about 3.1 gal/min per foot. Because of some restriction of flow through perforations in the casing, the drawdown may have been somewhat greater than it would have been if the well had been fitted with a screen.





Chemical Analysis of Well Water

Constituents:	Concentration (mg/l)	Recommended acceptable concentration (mg/l)
Iron	0.3	[a]0.3
Manganese	0.07	[a]0.05
Calcium	14	(b)
Magnesium	5.2	(b)
Chloride	2.3	[a]250
Fluoride	0.1	[a]2.0
Nitrite + nitrate as N	0.01	[a] [d]10
Dissolved solids	92	no recommended limit[a] ([c]500)
Total hardness	56 (soft)	(b)

[a] [U.S.] Environmental Protection Agency, 1973.

[b] No limits of concentration for calcium, magnesium, and total hardness are established--high concentrations of calcium and magnesium contribute to hardness of the water.

[c] U.S. Public Health Service, 1962.

[d] Nitrite should not exceed 1 mg/l.

FIGURE 6.--Geohydrologic data from test well 26F1.

Geology of the Island

The geologic reconnaissance and the test-well logs (table 1) provided information on the geology of the island, as shown in figure 7, a geologic section along the length of the island. This is summarized as follows:

Above sea level, the bulk of the island is composed of till, with local layers of sand, gravel, silt, or clay. Beneath the northern two-thirds of the island, the till appears to be underlain by a silt and clay unit which in turn overlies the principal water-bearing sand and gravel unit. Though this unit is exposed at land surface at a few points around the shore, under most areas of the island it appears to be a confined or artesian water-bearing zone overlain by silt and clay or by till. Only well 26F1 penetrates the full thickness of this water-bearing sand and gravel zone. The base of the unit is at about the 172-foot depth in well 26F1, where a 25-foot thick unit containing silt, sand, and clay separates the overlying sand and gravel unit from a heaving sand below.

No significant water-bearing zones were found below a depth of 350 feet, and the deep well penetrated only thick sections of clay along with a few thin layers of sand and (or) gravel.

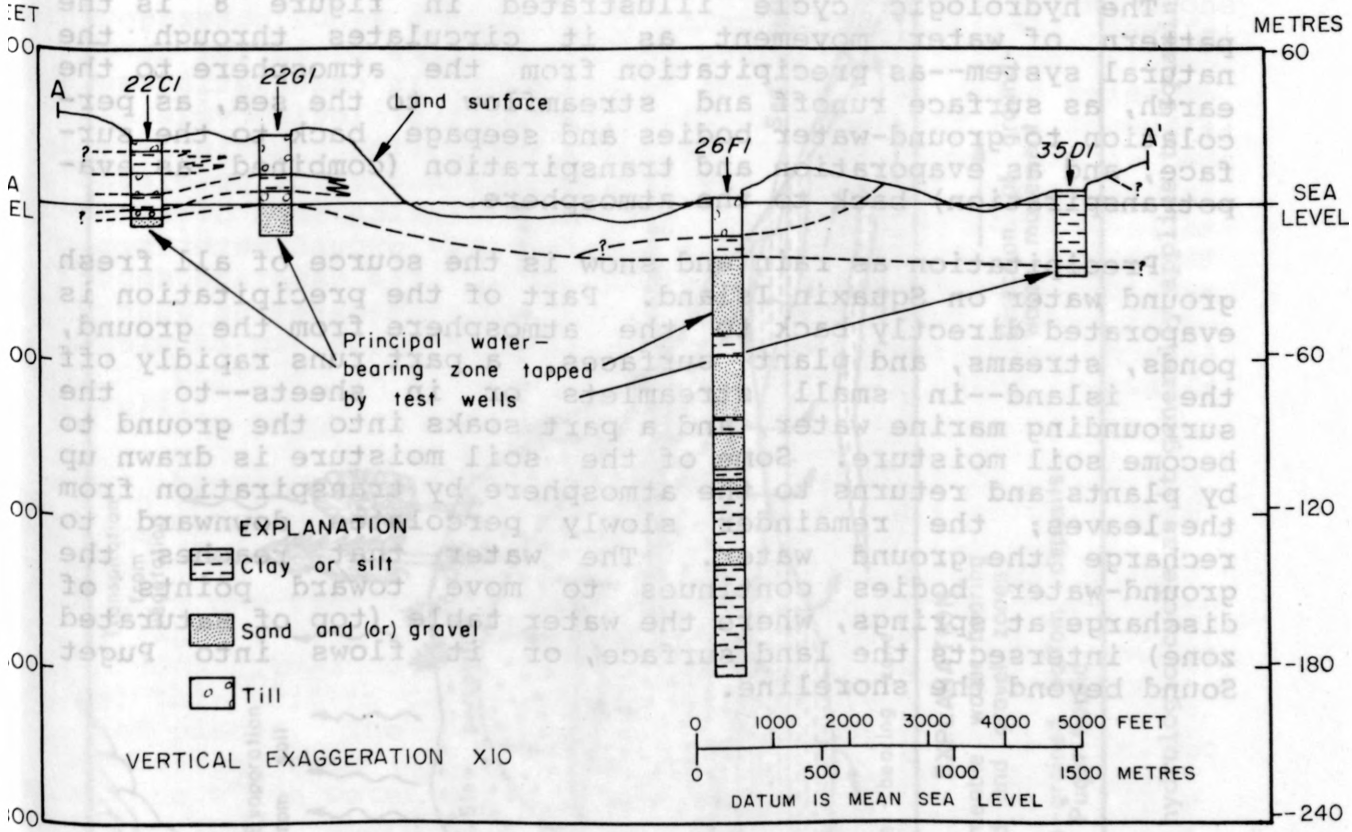


FIGURE 7.--Generalized geologic section between test wells, along line A-A' shown in figure 2.

The Hydrologic Cycle on the Island

The hydrologic cycle illustrated in figure 8 is the pattern of water movement as it circulates through the natural system--as precipitation from the atmosphere to the earth, as surface runoff and streamflow to the sea, as percolation to ground-water bodies and seepage back to the surface, and as evaporation and transpiration (combined as evapotranspiration) back to the atmosphere.

Precipitation as rain and snow is the source of all fresh ground water on Squaxin Island. Part of the precipitation is evaporated directly back to the atmosphere from the ground, ponds, streams, and plant surfaces, a part runs rapidly off the island--in small streamlets or in sheets--to the surrounding marine water, and a part soaks into the ground to become soil moisture. Some of the soil moisture is drawn up by plants and returns to the atmosphere by transpiration from the leaves; the remainder slowly percolates downward to recharge the ground water. The water that reaches the ground-water bodies continues to move toward points of discharge at springs, where the water table (top of saturated zone) intersects the land surface, or it flows into Puget Sound beyond the shoreline.

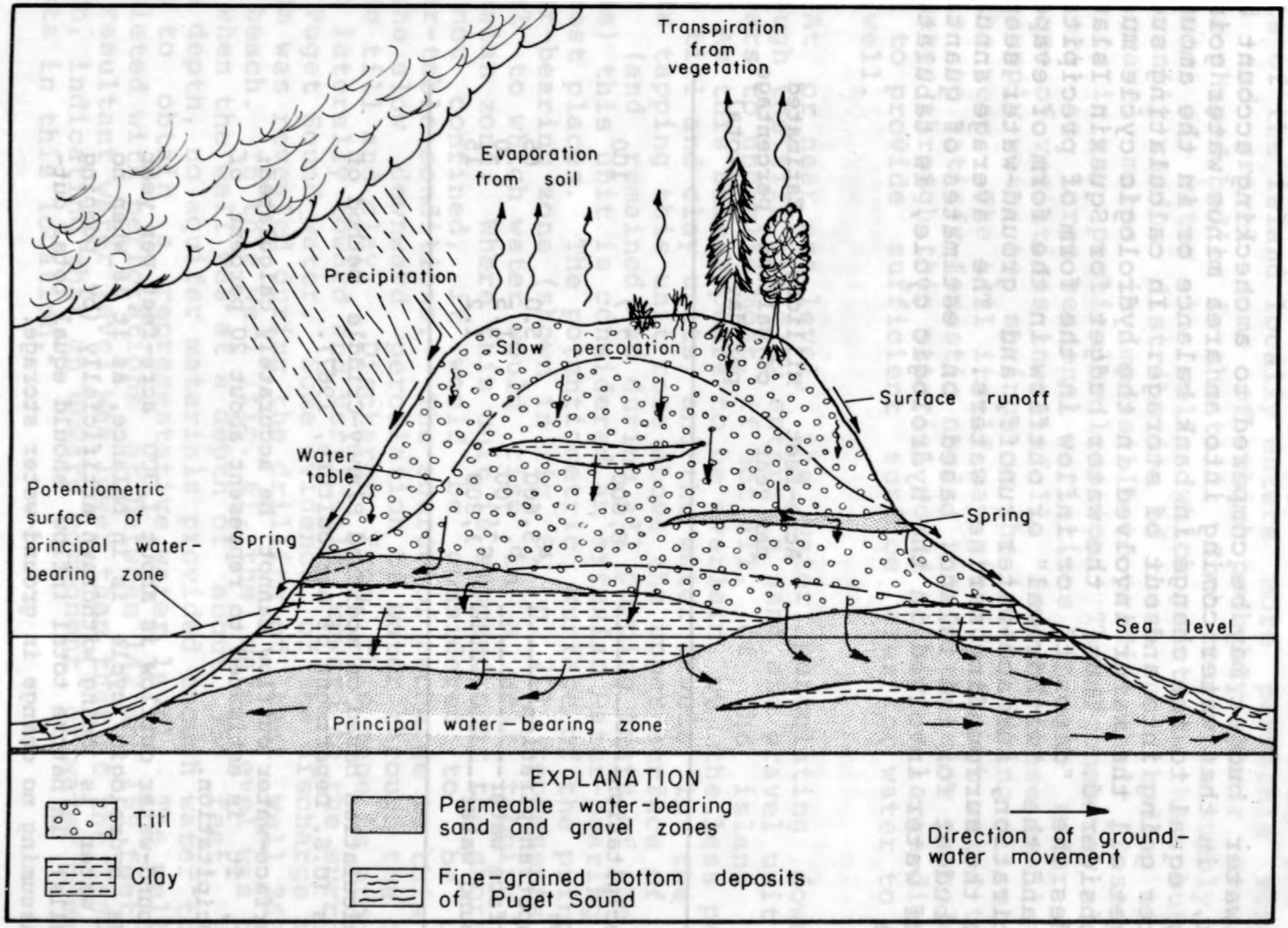


FIGURE 8.--Diagrammatic sketch of the hydrologic cycle as it generally applies to Squaxin Island.

The Water Budget

A water budget may be compared to a checking account at a bank, in that water coming into an area minus water going out is equal to the change in bank balance or in the amount of water going into and out of storage. In calculating such a budget all the water involved in the hydrologic cycle must be considered. Thus, the water budget for Squaxin Island includes the "deposit" or inflow in the form of precipitation, and the "withdrawal" or outflow in the form of evapotranspiration, surface-water runoff, and ground-water seepage to the surrounding marine waters. The average annual water budget for the island, based on estimates of quantities of water involved in the hydrologic cycle, is tabulated below:

	Acre-feet per year	Millions of gallons per day	Estimated percentage of total
Inflow:			
Precipitation------------	8,600	7.7	100
Outflow:			
Evapotranspiration-------	[a] 5,600	5.0	65
Surface water------------	[b] 1,700	1.5	20
Ground water-------------	[c] 1,300	1.2	15

[a] Calculation based on modified Blaney-Criddle method of analysis (U.S. Department of Agriculture, 1967).

[b] Surface-water outflow cannot be accurately calculated; however, it is estimated to represent about 20 percent of the precipitation.

[c] Ground-water outflow is about 1,300 acre-feet per year when the hydrologic cycle is in balance, as it is when no ground water is being withdrawn artificially (by pumping from wells); in nature total inflow should equal total outflow, assuming no change in ground-water storage.

Ground-Water Occurrence and Movement

Water moving downward through the thick till and clay units of the island locally enters more permeable zones of sand and gravel some of which probably occur as small lense-shaped bodies in the till. Such zones can supply small amounts of water to wells which penetrate them, but the apparently random distribution of these small bodies of sand and gravel makes it impossible to predict their presence or absence in any particular location. These zones may also be subject to large seasonal variations in the water table because of variations in rainfall. Some of these small units may supply water to springs on the island during all or part of the year. The till itself may provide enough water to dug wells to satisfy domestic needs, though the slow percolation of water through this material would require a large-diameter well to provide sufficient surface area for water to enter the well.

At or near sea level, the water percolating downward through the till and clay enters a sand and gravel unit that appears to underlie most, if not all, of the island (fig. 7). As this unit appears to be overlain by the less permeable till and clay units, and the water levels in the test wells tapping this unit rose above the upper surface of this unit (and remained so during all pumping tests of the test wells) this unit is considered an artesian water-bearing zone in most places. The potentiometric surface of the principal water-bearing zone (shown in fig. 8, p. 21) represents the level to which water would rise in a well tapping this artesian zone. Where this unit is exposed near the shore and is not confined, it would be considered to be under water-table conditions. The source of recharge to this zone is the slow downward percolation of water through the overlying till and clay. Discharge from this zone is probably both laterally toward and vertically upward to the surrounding Puget Sound water. Some evidence of the discharge mechanism was revealed during the drilling of test well 26F1 on the beach. In this well (fig. 6), the water level was highest when the well was at a depth of about 350 feet. Below this depth, no aquifer materials provided enough water to the well to obtain a representative water level. The well was completed with perforations at between 142 and 159 feet, and the resultant water level was lower than that at the 350-foot depth, indicating that an upward component of water movement exists in this location.

The shallower wells, drilled nearer the north-south axis of the island, did not penetrate deeply into the principal water-bearing zone; consequently no changes in water level with increasing depth could be noted.

The ground-water occurrence on the island may be summarized as follows:

1. Over most, if not all of the island, the best source of water appears to be a sand and gravel unit which lies at or near sea level, and which receives its water from precipitation percolating through the overlying till and clay that make up the bulk of Squaxin Island.

2. In places, small water supplies may be obtained from dug wells in the till or from wells penetrating small permeable zones contained within the body of the till and clay units.

Water Quality

Of the many chemical constituents found in the water samples collected from the test wells, only a few are of major concern to the user. Fluoride, nitrate, and nitrite are among those which have maximum concentration limits suggested by the EPA ([U.S.] Environmental Protection Agency, 1973). For fluoride the acceptable maximum limit is 2.0 mg/l (milligrams per litre) at average temperatures prevailing in this area; larger concentrations can cause permanent discoloration of developing juvenile teeth. The highest concentration found in water from any of the test wells was 0.1 mg/l, or about 5 percent of the recommended limit. The method of analysis for nitrite plus nitrate combines the two which are reported as elemental nitrogen (NO_2+NO_3 as N). The concentration of this combination should not exceed 10 mg/l, and the concentration of nitrite (NO_2) alone should not exceed 1 mg/l, according to the EPA (1973); above this limit serious health problems may arise. Water from only one of the test wells (26F1) had any nitrite plus nitrate; the water had 0.01 mg/l, one-tenth of 1 percent of the limit. Other common dissolved minerals cause no serious health hazards in the concentrations found.

The amount of dissolved solids in water has no maximum recommended limit, but as a general rule concentrations less than 500 mg/l cause no problems (U.S. Public Health Service, 1962). Some of the problems associated with higher concentrations may include deposition in or corrosion of pipes, unpleasant taste, and a laxative effect. The highest dissolved-solids concentration found was 172 mg/l.

Water with high concentrations of calcium, chloride, iron, magnesium, and manganese, and a high total-hardness value is unpleasant to use but is not harmful to people. Water with high chloride concentrations is noticeable by its taste and causes corrosion of faucets and pipes. The recommended maximum concentration of chloride is 250 mg/l (EPA, 1973). None of the water had concentrations greater than 2 percent of this limit at the time of sampling.

Manganese and iron appear to be the most troublesome of the constituents of the well waters. Water with manganese concentrations greater than 0.05 mg/l has an unpleasant taste, stains plumbing fixtures, and may damage distribution systems with deposits of manganese oxide. All the wells yielded water containing concentrations of manganese greater than the recommended limits, and two wells, 22C1 and 22G1, had very high concentrations. Iron concentrations greater than 0.3 mg/l cause the water to have an unpleasant taste; also clothes washed in this water will spot, and rust will accumulate in distribution systems. Water from three wells had iron concentrations equal to or greater than the recommended limit.

The most common chemicals contributing to the hardness of water are calcium and magnesium; hardness increases with the amount of these two constituents dissolved in water. Hard water causes scaly deposits in hot-water heaters and greatly increases the amount of soap needed to create lather. Waters from all the wells had low concentrations of calcium and magnesium and were soft to moderately hard.

Important water-quality data are included in figures 3-6 and all data are given in table 3.

Potential Contamination Problems

Biological Contamination

If large-scale development of Squaxin Island is undertaken, biological contamination of the shallow ground water could occur from improper treatment and disposal of wastes from homes, septic tanks, outhouses, and industries. Although a comprehensive study of the suitability of soil types for waste disposal through septic-tank drain fields was not made during this study, most areas generally appear to be acceptable for such development.

Soil type has a major effect on the workability of drain fields from septic tanks. Septic tanks with adequate drain fields should function properly in areas of the island underlain by weathered till with a well-developed soil zone. However, the use of drain fields may be impractical near the southern end of the island where clay is at or near the surface. The clay would probably slow the downward percolation of the waste liquids and could cause them to flow laterally toward the beaches or to pond in depressions. Any waste liquid that reaches beach areas or ponds without sufficient filtering by the soil would pose a serious health hazard. A detailed percolation test, such as described by the U.S. Public Health Service (1967), should be performed at each site under consideration. Furthermore, according to the Washington Department of Social and Health Services (1974, p. 8), wells should be kept upslope and a minimum of 100 feet from any outhouse or drain field.

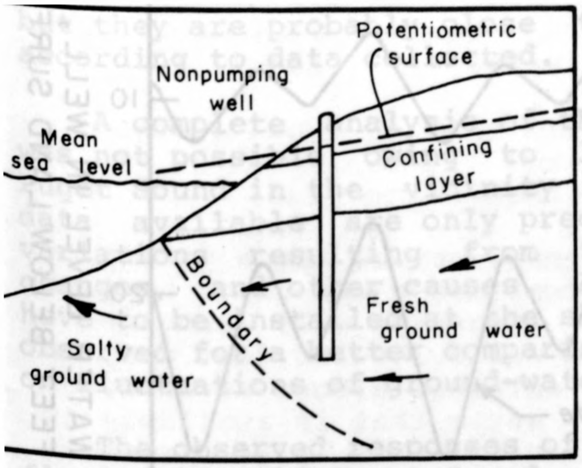
In the event of industrial development, the waste water may require special treatment, and any large amount of sewage from a concentration of houses may also require treatment before its disposal.

Seawater Encroachment

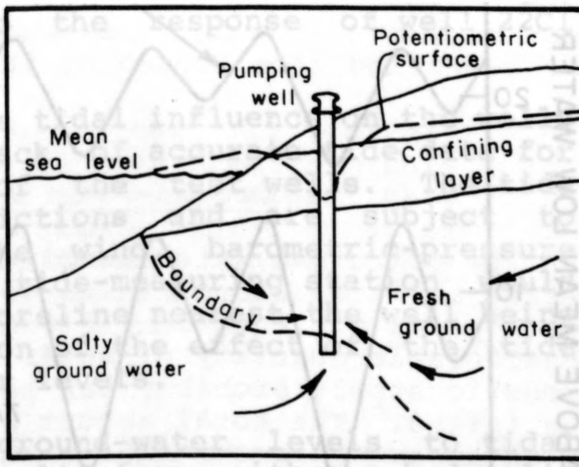
When a well near a marine shoreline is pumped, especially if the well is open to a water-bearing zone below sea level, seawater encroachment should be considered a possibility.

Over the years an equilibrium has been established between the freshwater flowing from the island and the denser (heavier) salty water that may underlie the freshwater in the water-bearing zone. This equilibrium is characterized by a boundary between the fresh ground water and the salty ground water as shown diagrammatically in part A of figure 9. This boundary, also referred to as a zone of diffusion, is where the fresh ground water is continually mixing with the salty ground water while flowing through the water-bearing zone. This boundary is stable under natural conditions, moving only slightly as the tide rises or falls, and with the seasonal changes caused by variations in rainfall. The ground water moves in the directions indicated by the arrows. However, when a well tapping this zone is pumped, the equilibrium is disturbed and the ground-water flow pattern begins to change. As water is pumped out of the water-bearing zone faster than water can flow in to replace it (part B, fig. 9), a cone of depression forms in the potentiometric surface around the well, resulting in the boundary moving upward toward the well intake. A long period of pumping can cause this freshwater-seawater boundary to move closer toward the well. In some cases, as shown in part B of figure 9, large-scale pumping may cause the well to draw in salty water. This is possible under either water-table or artesian conditions.

Tidal fluctuations in Puget Sound affect the water levels in all the test wells, as much as 7.5 feet during a 7-hour period in well 26F1. These constant water-level fluctuations were recognized as a complicating factor in any water-level measurements made during pumping tests of the wells. Therefore, to determine the extent of tidal influence, continuous recorders were installed in two of the wells (22C1 and 26F1). Figure 10 shows the results of 4 days of record from the water-level recorder in well 26F1 and the corresponding tidal fluctuations.



A. Well tapping a confined water-bearing zone under non-pumping conditions.



B. Same well under conditions of intensive pumping, with salty ground water being drawn into well.

FIGURE 9.--Schematic diagrams showing typical conditions before and during seawater encroachment due to intense pumping of a well. Arrows indicate direction of ground-water flow.

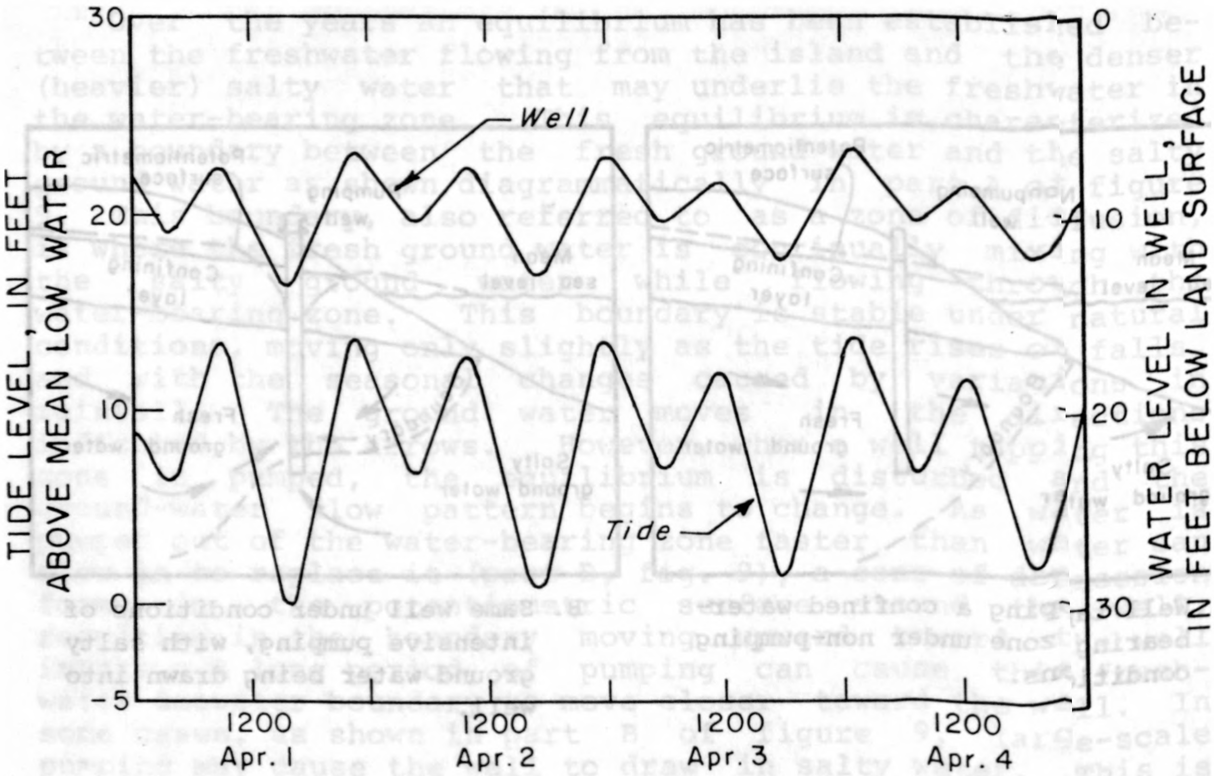


FIGURE 10.--Comparison of water-level fluctuations in test well 26F1 and tidal fluctuations, during 4 days beginning at midnight on April 1, 1975.

The test wells varied in their responses to the tidal changes. In well 26F1, the response was immediate but reduced to the extent that, for every 4-foot change in tide stage, there was a 2-foot change in the well water level. Water-level changes in well 22C1 lagged behind the tidal changes by an average of 50 minutes (ranging from a 20- to 80-minute delay). For a tidal stage change of 4 feet the well responded with only 1 foot of change. Water levels in the other two test wells were not measured long enough to derive a response time and a ratio of water-level change, but they are probably close to the response of well 22C1 according to data collected.

A complete analysis of the tidal influence on the wells was not possible owing to lack of accurate tide data for Puget Sound in the vicinity of the test wells. The tide data available are only predictions and are subject to variations resulting from the wind, barometric-pressure changes, and other causes. A tide-measuring station would have to be installed at the shoreline nearest the well being observed for a better comparison of the effect of the tide on fluctuations of ground-water levels.

The observed responses of ground-water levels to tidal fluctuations in Puget Sound result from either a hydraulic connection between the seawater and the water-bearing zone, or tidal loading on top of the less permeable layers above the water-bearing zone (which may be isolated from the sea-water). Under a direct hydraulic connection between the water-bearing zone and the seawater, less pressure is exerted on these water-bearing zones as the tide falls, and the water levels in the wells also decline. If this is the case the water-bearing zone is directly connected with the seawater, and seawater encroachment may be rather sudden; a well could produce salty water following a short period of continuous, heavy pumping. However, the water-bearing zones may actually be isolated from seawater by an overlying clay and (or) till layer in addition to the fine-grained bottom sediments of Puget Sound. These may act as a barrier to seawater, keeping it out of the water-bearing zone. If this is the case, water-level changes would be caused by pressure loading transmitted through the overlying clays or till to the water-bearing zones, and the possibility of seawater encroachment would be greatly reduced.

There is no practical way to determine the degree of connection between the water-bearing zone and the seawater, and thus whether or not seawater encroachment will occur. If any of the test wells is pumped for long periods at rates which cause the water level to be drawn down below sea level, seawater encroachment may occur. As a general rule the chloride content of the well water will increase, warning of impending seawater encroachment before it becomes noticeable to the taste. A simple chemical test of the well water could provide useful information and possibly a warning of ongoing seawater encroachment into the water-bearing zone tapped by the well.

Ground-Water Availability

The principal water-bearing zone, which has a potentiometric surface about 5 to 15 feet above sea level beneath most parts of Squaxin Island, probably will provide a considerable quantity of water to wells 100-200 feet deep; a domestic supply probably can be obtained almost anywhere on the island. The total amount of water that is available to be withdrawn on a continuing basis is about 1,300 acre-feet per year. This is the quantity of water that is estimated to pass annually through the ground-water system beneath the island and is equal to the annual recharge to, and outflow from, the ground-water reservoir assuming no change in the amount of water in storage.

The rate of recharge to the water-bearing zones underlying the island depends on the permeability of the soil and subsurface rock materials. For example, in area C (fig.2) which is underlain by a greater thickness of clay, there is a resulting more rapid runoff of rainfall and slower infiltration into the ground, causing less water to percolate to the water-bearing zone.

Of the total ground-water recharge it is assumed that the water-bearing zone below area A (fig. 2) receives about 75 percent (980 acre-ft per year), area B receives about 20 percent (260 acre-ft per year), and area C receives about 5 percent (65 acre-ft per year). However, because of the inefficiency of wells and practical considerations on the number of wells that could be drilled to tap the ground-water reservoir, it is assumed that only about 35 percent of the total available recharge could reasonably be recovered. In view of the foregoing considerations the quantities of ground water that can be pumped from the three areas is estimated to be as follows:

Area A: About 340 acre-feet per year (210 gal/min continuously) could be recovered from a well field properly placed on the higher ground along the north-south axis of the island. This is potentially the most productive area of the island for wells 100 to 200 feet deep.

Area B: About 90 acre-feet per year (55 gal/min continuously) could be recovered from wells placed in the central part of the area.

Area C: About 22 acre-feet per year (13 gal/min continuously) could be recovered from this least productive of the three areas; this quantity is adequate for domestic supplies, but would require intermittent pumping along with storage facilities.

Potential yields of wells in all these areas would be considerably higher than the maximum continuous yields stated above. It is possible that well 35D1 would have been more productive if it had been drilled slightly deeper or in a different location. In area A each well could yield from 50 to 200 gal/min, but pumping at higher rates would probably result in excessive drawdown of the water level. If the water level is drawn down below sea level for more than a few hours, the danger of seawater encroachment increases rapidly. Therefore, to reduce the encroachment problem, wells should be pumped at a low rate or be pumped intermittently at a moderate rate, allowing time for the water level to recover above sea level; this applies in all areas of the island.

To obtain, at a reasonable pumping level, a greater yield than could be produced from a single well drawing water near sea level, several smaller-yield wells could be developed. By pumping each well continuously at a somewhat reduced rate, or by intermittent pumping into a reservoir and allowing water levels to recover between pumping periods, the local stress on the water-bearing zone would be reduced and possible problems with seawater encroachment would be reduced.

In order for such a network of wells to be of maximum efficiency, individual wells should be spaced far enough apart so that the drawdown from a pumping well does not appreciably affect the water level in neighboring wells. Although the test wells drilled for this study are too widely spaced to provide data on the minimum desirable distance between wells, a well spacing of 800-1,000 feet is considered adequate for a network of producing wells. Water-level data from wells so spaced could help determine if closer spacing is practical.

Seasonal fluctuations in water levels, in contrast to those resulting from tidal fluctuations, result mainly from seasonal variations in the amount of rainfall, which is the only source of water for recharge of the principal water-bearing zone underlying Squaxin Island. The period October-March, when 80 percent of the rainfall occurs, is the time of maximum recharge of the ground-water body. The water-table level rises during this period and generally is highest in March or April and begins dropping shortly thereafter, with the lowest water levels usually occurring during September or October. The seasonal fluctuations of the shallow water table may be as much as 10 feet in the central part of the island, and very shallow wells may go dry in late summer. None of the test wells are open to the shallow ground-water zones, so no seasonal fluctuation could be measured. Water levels in the test wells were measured during June-September 1975, each time under nearly identical tide conditions to eliminate fluctuations caused by tide changes. The results are listed below.

Well no.	Depth to water below land surface (ft)				
	June 6	June 27	July 25	Aug. 20	Sept. 5
22C1	69.00	69.07	69.17	69.35	69.30
22G1	73.76	73.65	73.70	73.81	73.58
26F1	12.13	12.20	12.29	12.40	12.61
35D1	14.50	14.46	14.49	14.62	14.66

Deep wells drilled on the island in the future pobably will encounter sequences and types of glacial material similar to those found in well 26F1, down to the depth eplored in that well. Any further planning for exploration or the deep artesian zone not encountered by any of the tes wells but believed to be at depth below the island, should allow for drilling to depths as great as 1,000 feet belw sea level. If this water-bearing zone is found it may proide a substantial quantity of water with much less chance f seawater encroachment.

CONCLUSIONS AND RECOMMENDATIONS

Squaxin Island is underlain by a moderately productive water-bearing zone of sand and gravel. Water in this zone is, in most places, under some artesian pressure, but in most parts of the island wells that tap it probably would not have water levels that would rise above the land surface to create a flowing artesian well. A deep artesian zone may exist below the island, but its depth is greater than was anticipated when this study was planned. The cost of deeper exploratory drilling for this zone may not be justified.

Well 22G1 is the most productive, and 35D1 the least productive, of the three shallow test wells. The higher areas in the northern half of the island (area A) are the most productive for shallow wells. The principal water-bearing zone there may produce as much as 340 acre-feet per year (210 gal/min continuously). In the central part of the island (area B) wells tapping the principal water-bearing zone may produce about 90 acre-feet per year or about 55 gal/min continuously. In the southern part of the island (area C) wells may produce only about 22 acre-feet per year or 13 gal/min continuously. All test wells produced adequate amounts of water for individual domestic needs and it appears that wells of similar depth at most places on the island would produce water similar in quantity and quality.

The potential for seawater encroachment exists at all locations on the island, although there is no practical method of determining the quantity of pumping or the time required to cause encroachment to occur--or if it will occur. However, if encroachment does occur, monthly records of quantities pumped, pumping water levels, lengths of pumping periods, and total quantity of water pumped would help guide further development. All wells should be monitored on a frequent and continuing basis for any signs of seawater encroachment. Because an increasing chloride concentration would indicate the beginning of seawater encroachment into a well, periodic chemical analyses for chloride concentration would give warning of approaching encroachment. Water samples should be collected and tested perhaps daily from any single well that pumps more than 75,000 gal/day, and weekly from a well pumping more than 25,000 gal/day. Samples collected monthly from any well used only for single-dwelling domestic supply would probably be adequate to detect any change.

If salty water is eventually pumped from any of the wells, other wells should be checked closely for signs of impending encroachment. Under these conditions the amount of pumping may have to be reduced to avoid further encroachment. Construction of additional properly spaced wells to distribute the effects of pumping could also lessen chances of encroachment.

To obtain a large supply of ground water a well field consisting of several wells should be developed. The most favorable places for these additional wells would be in area A, the northern half of the island, and as far from the shoreline as possible. This well field could consist of wells 100 to 200 feet deep and spaced according to the drawdown characteristics of the water-bearing zones. Adequate storage facilities should be provided and wells should be pumped on an intermittent basis to reduce the chances of seawater encroachment. If wells are pumped continuously, pumping levels should be maintained above sea level; intermittent pumping levels below sea level may be permitted if adequate time is allowed for recovery of the water levels between periods of pumping.

Except for troublesome concentrations of iron and manganese, all ground water sampled is of good quality. Water with high concentrations of iron and manganese, which is probably present everywhere beneath the island, can be treated and made suitable for domestic use. Water for a fish hatchery may not require treatment.

In most areas of the island, except parts of area C where clay is at the surface, septic tanks probably will work well. Each site should be individually tested and should be as far as practical from wells and beaches.

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TABLE 1.-Materials penetrated by test wells

Material	Thick-ness (feet)	Depth (feet)
Well 22C1		
Soil	1	1
Till, brown, and some decaying vegetation	9	10
Till, gray-brown with small amount of decaying vegetation	4	14
Till, gray, with fine gravel	2	16
Clay, blue-gray with small amount of sand	12	28
Clay, gray-brown, with some sand	14	42
Sand and silt, gray	8	50
Till, gray, and blue clay, with fine gravel	6	56
Till, gray, and blue clay, with pea gravel	4	60
Till, gray, gravelly, and blue clay, water-bearing	7	67
Till, gray, gravelly, water-bearing	5	72
Clay, blue-gray, with some pebbles	16	88
Till, gray, sandy, with medium gravel, water-bearing	10	98
Till, gray, sandy, with fine gravel, less clay, water-bearing	9	107
Sand, gray, with some gray clay, water-bearing	4	111
Well 22G1		
Soil, very clayey	3	3
Till, brown, with medium gravel	17	20
Till, brown-gray, with medium gravel	10	30
Till, gray, and coarse gravel	6	36
Till, gray, with medium gravel	12	48
Sand and silt, gray	4	52
Clay, gray, with some decaying vegetation	16	68
Till, brown	3	71
Gravel, coarse, water-bearing	2	73
Till, brown	13	86
Sand, gray, fine, well-sorted, water-bearing	12	98
Sand, gray, coarse, water-bearing	29	127
Well 35D1		
Clay, brown with some vegetation	12	12
Clay, gray	88	100
Sand and gravel, gray, water-bearing	4	104
Sand and silt, gray, water-bearing	3	107

TABLE 1.-Materials penetrated by test wells-continued

Material	Thick-ness (feet)	Depth (feet)
Well 26F1		
Soil	4½	4½
Till, brown, sandy, with some decaying vegetation	9½	14
Till, blue-gray	38	52
Clay, gray, greasy feel	27	79
Sand and gravel, gray, coarse, water-bearing	8	87
Sand and gravel, gray, fine, water-bearing	3	90
Sand and gravel, brown, water-bearing	4	94
Sand and gravel, brown, fair sorting, water-bearing	47	141
Clay, with sand, gray, not water-bearing	2	143
Sand and gravel, brown, fair sorting, water-bearing	29	172
Sand and silt, gray, with thin layers of green clay, some wood fragments	25	197
Sand, gray, heaving, well-sorted, some water	84	281
Clay, gray	12	293
Clay, brown, with some decaying vegetation	5	298
Clay, brown-green, with some sand seams	3	301
Sand and silt, brown	6	307
Sand, gray, fine	36	343
Sand, gray, with gray clay seams	7	350
Clay, gray, with peat seams	9	359
Sand, gray, fine	16	375
Clay with fine sand, gray	9	384
Clay, gray with some wood fragments	13	397
Clay, blue-green to gray brown, alternating	51	448
Sand, gray, well-sorted	2	450
Clay with sand, gray	5	455
Sand grading to sand and gravel, gray	6	461
Clay, gray	1	462
Sand, gray, fine	10	472
Clay, brown, with some vegetation	22	494
Clay, brown, gray, and green layers	13	507
Clay, gray	41	548
Silt, gray	22	570
Clay, gray	10	580
Clay, gray, with some wood fragments	22	602
Clay, gray to green, with gray sand	16	618

TABLE 2.--Data from pumping of test wells

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temperature (°C)	Remarks
		Well 22C1			
1/29/75					Tidal fluctuations in well
8:40 a.m.	--	65.56	--	--	
8:49	--	65.66	--	--	
9:04	--	65.76	--	--	
9:11	--	65.81	--	--	
9:14	--	65.86	--	--	
9:22	0	65.96	--	--	Pump on
	½	82.11	about 45	--	
9:23	1	83.53	--	--	
	2	84.23	--	--	
	3	84.25	--	--	
	4	84.19	48	--	
	5	84.17	--	--	
	6	83.86	--	--	
	7	83.41	--	--	
	8	83.12	--	--	
	9	83.34	46	--	
	10	83.30	--	--	
	13	85.75	--	9.9	
	16	--	52	--	
	17	85.01	--	--	
	21	84.99	--	--	Chloride negligible[1]
	26	84.23	--	9.9	
	27	--	50	--	
	32	84.91	--	--	
	34	--	50	10.0	
	34½	--	50	--	
	37	--	50	--	
	38	--	--	9.9	
	40	85.55	49	--	
	50	--	46	--	
	54	84.99	48	--	
	60	85.30	47	--	
	80	86.51	49	--	
	92	--	50	--	
	93	86.66	--	9.9	
	100	86.77	49	--	
	110	--	47	--	
	130	84.97	--	--	
11:38 a.m.	136	--	47	--	
12:05 p.m.	163	--	60	--	
	164	87.65	48	--	
	166	87.19	--	--	
	171	86.38	46	--	
	182	--	--	--	Chloride negligible
	183	86.11	47	--	
	215	89.98	53	--	
	220	91.46	56	--	Chloride negligible
	224	90.22	50	10.0	
	234	90.93	--	--	
	241	90.34	53	--	
	288	--	52	--	
2:15 p.m.	293	--	--	10.0	

[1]Field analysis for chloride content.

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land suface)	Pumping rate (gal/min)	Temper- ature (°C)	Remarks
		Well 22C1--continued			
1/29/75--Con.					
2:22 p.m.	300	90.46	--	--	
	315	--	54	--	
	330	90.61	51	--	
	350	90.36	--	--	
	400	90.11	51	--	
	473	89.78	--	--	
	500	89.71	54	--	
	600	89.70	54	--	
	700	90.66	54	9.9	
	750	91.23	52	--	
	756	91.23	--	--	Average 52 gal/min.
10:00	758	--	--	--	Pump off
10:01	+1	71.51	--	--	Recovery
	2	69.91	--	--	
	3	69.72	--	--	
	4	69.68	--	--	
	5	69.65	--	--	
	6	69.61	--	--	
	7	69.58	--	--	
	8	69.55	--	--	
	9	69.52	--	--	
	10	69.51	--	--	
	21	69.38	--	--	
	30	69.38	--	--	
	40	69.37	--	--	
	50	69.40	--	--	
	60	69.42	--	--	
	70	69.48	--	--	
	80	69.53	--	--	
	93	69.59	--	--	
	100	69.62	--	--	
12:00 p.m.	120	69.74	--	--	
1/30/75					
0:30 a.m.	150	69.90	--	--	
	200	70.10	--	--	
	250	70.07	--	--	
	300	69.71	--	--	
	350	69.09	--	--	
	400	68.28	--	--	
	450	67.46	--	--	
	500	66.74	--	--	
7:00 a.m.	540	66.22	--	--	

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temperature (°C)	Remarks
		Well 22G1			
2/10/75					
9:35 a.m.	--	72.62	--	--	
9:44	--	72.62	--	--	
9:47	0	--	--	--	Pump on
	½	76.18	about 50	--	
	1	76.24	--	--	
	1½	76.26	--	--	
	2	76.26	60	--	
	3	76.30	--	--	
	4	76.23	--	--	
	5	76.24	57	--	
	7	76.41	--	--	
	9	76.36	--	--	
	9¼	76.28	--	--	
	10	76.30	--	--	
	15	76.03	--	--	
	20	76.43	--	--	
	30	76.51	--	--	
	40	76.58	54	--	
	50	76.56	--	--	Chloride negligible
	56	--	52	--	
	60	76.55	--	--	
	70	76.60	--	--	
	78	76.58	--	--	
	79	76.58	--	--	
	90	76.62	--	--	
11:27 a.m.	100	76.62	--	--	
12:07 p.m.	140	76.68	52	--	
	160	76.68	--	--	
	193	76.72	--	10.0	
	220	76.76	--	--	
	268	76.76	--	--	
	300	76.78	52	--	
	315	76.79	--	--	
	323	76.80	--	--	
	324	76.79	--	--	
3:15	328	--	--	--	Pump off
3:16	+1	73.15	--	--	Recovery
	2	73.07	--	--	
	3	73.00	--	--	
	4	72.98	--	--	
	5	72.95	--	--	
	6	72.94	--	--	
	7	72.92	--	--	
	8	72.91	--	--	
	9	72.90	--	--	
	10	72.90	--	--	
	15	72.88	--	--	
	20	72.87	--	--	
	25	72.87	--	--	
	30	72.86	--	--	
	40	72.85	--	--	
	55	72.85	--	--	
	65	72.83	--	--	
4:25 p.m.	70	72.82	--	--	

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temper-ature (°C)	Remarks
		Well 22G1--continued			
2/10/75--Con.					
4:35 p.m.	80	72.81	--	--	
	90	72.82	--	--	
	100	72.82	--	--	
	110	72.82	--	--	
	120	72.79	--	--	
	165	72.76	--	--	
	200	72.77	--	--	
7:00 p.m.	+225	72.78	--	--	
		Well 35D1			
2/21/75					
9:47 a.m.	--	13.16	--	--	
9:48	--	13.16	--	--	
9:56	--	13.14	--	--	
10:01	0	13.16	--	--	Pump on
10:02	1	44.80	about 40	--	
	1½	55.40	40	--	
	2	64.43	40	--	
	3½	79.33	40	--	
	4½	86.70	40	--	
	5½	87.37	30	--	
	6½	85.18	--	--	
	8	82.65	--	--	
	9	81.78	30	--	
	10	81.34	--	--	
	12	80.90	28	--	
	15	83.00	--	10.8	
	20	88.17	30	--	
	24	--	30	--	
	25	88.70	--	--	
	30	87.17	--	--	
	38	--	30	--	
	40	86.94	--	--	
	50	87.63	--	--	
	60	90.58	31	--	
	70	90.80	--	--	Chloride negligible
	77	--	27	--	
	80	79.90	--	--	
11:42 a.m.	100	79.25	--	--	
12:02 p.m.	120	78.12	26	--	
	141	77.63	27	--	
	165	77.75	26	--	
	180	77.85	--	--	
	220	78.02	--	--	
	250	77.80	26	--	
	300	78.18	--	--	
3:20 p.m.	319	--	26	--	

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temperature (°C)	Remarks
		Well 35D1--continued			
2/21/75-- Con.					
3:30 p.m.	329	78.48	--	--	Pump off
	+ ½	69.23	0	--	Recovery
3:31	1	61.42	--	--	
	1½	54.80	--	--	
	2	50.42	--	--	
	2½	44.02	--	--	
	3	39.83	--	--	
	3½	36.05	--	--	
	4	32.80	--	--	
	5½	25.61	--	--	
	6	23.82	--	--	
	7	21.22	--	--	
	8	19.80	--	--	
	9	17.72	--	--	
	10	16.70	--	--	
	12	15.45	--	--	
	15	14.61	--	--	
	20	14.16	--	--	
	25	14.07	--	--	
	30	14.00	--	--	
	40	13.96	--	--	
	50	13.96	--	--	
	60	13.96	--	--	
	70	13.99	--	--	
	80	13.99	--	--	
	90	14.03	--	--	
	100	14.07	--	--	
	125	14.14	--	--	
	158	14.28	--	--	
6:50 p.m.	+200	14.42	0	--	
		Well 26F1			
2/28/75					
8:10 a.m.	--	4.60	--	--	
8:22	0	--	--	--	Pump on
	1	--	about 150	--	
	2	30.43	--	--	
	3	30.70	--	--	
	4	30.54	--	--	
	5	30.80	--	--	
	6	31.13	about 160	--	
	7	34.35	--	--	
	9	35.77	--	--	
	10	37.38	--	--	
	11	37.80	--	--	
	12	38.07	--	--	
	14	38.50	--	--	
	15	38.81	--	--	
8:41 a.m.	17	42.65	--	--	

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temperature (°C)	Remarks
		Well 26F1--continued			
2/28/75--Con.					
8:42 a.m.	18	43.15	--	--	
	20	43.10	--	--	
	24	44.25	162	--	
	25	44.18	--	--	
	27	--	164	--	
	30	45.70	--	--	
	35	47.05	--	--	
	39	--	170	--	
	40	48.00	--	--	
	45	--	170	--	
	50	51.11	--	--	
	60	51.88	170	--	
	71	53.15	--	--	
	80	53.43	170	--	
	90	54.38	--	--	
	100	55.16	170	--	
	120	56.43	170	--	
	142	--	168	--	
	150	56.05	168	--	
	173	--	--	10.8	
	180	57.64	--	--	
11:59 a.m.	215	58.45	170	--	
12:34 p.m.	250	59.81	170	--	
	300	60.41	170	--	
	335	60.25	--	--	
	360	60.23	167	--	
	390	60.20	167	--	
	420	59.85	167	--	
	429	--	183	--	
	431	59.95	--	--	
	433	60.25	--	--	
	434	60.37	--	--	
	435	60.57	--	--	
	436	60.78	--	--	
	437	60.86	--	--	
	439	59.94	--	--	
	440	--	167	--	
	442	59.29	--	--	
	450	59.98	172	--	
	458	59.80	170	--	
	475	60.52	175	--	
	501	59.42	173	--	
	520	59.64	173	--	
	558	50.22	145	--	
	560	50.10	145	--	
	568	55.80	164	--	
	593	55.31	164	--	
	600	57.77	175	--	
	610	57.90	175	--	
	620	57.68	173	--	
	660	57.15	172	--	
	670	57.24	172	--	
7:52 p.m.	690	57.17	172	--	

TABLE 2.--Data from pumping of test wells--Continued

Date and time	Pumping or recovery time (minutes)	Depth to water (ft below land surface)	Pumping rate (gal/min)	Temperature (°C)	Remarks
		Well 26F1--continued			
2/28/75--Con.					
8:12 p.m.	710	58.07	175	--	
	720	58.50	176	--	
	750	58.81	175	--	
	780	59.39	175	--	
	810	59.84	175	--	
	825	60.55	176	--	
	847	61.02	176	10.8	
	860	60.63	176	--	
10:47	865	59.71	176	--	Pump off
10:48	+1	26.85	0	--	Recovery
	1½	19.50	--	--	
	2	17.57	--	--	
	2½	16.05	--	--	
	3	14.47	--	--	
	3½	13.45	--	--	
	4	12.72	--	--	
	4½	12.22	--	--	
	5	11.91	--	--	
	5½	11.61	--	--	
	6	11.48	--	--	
	7	11.17	--	--	
	8	10.95	--	--	
	9	10.76	--	--	
	10	10.67	--	--	
	11	10.55	--	--	
	12	10.49	--	--	
	13	10.42	--	--	
	15	10.32	--	--	
	17	10.22	--	--	
	20	10.13	--	--	
	22	10.06	--	--	
	26	10.00	--	--	
	30	9.98	--	--	
	35	9.95	--	--	
	45	9.97	--	--	
	50	10.01	--	--	
	55	10.05	--	--	
	60	10.07	--	--	
11:57 p.m.	70	10.15	--	--	
3/1/75					
0:07 a.m.	80	10.25	--	--	
	100	10.40	--	--	
	110	10.49	--	--	
	120	10.60	--	--	
	140	10.76	--	--	
	170	10.97	--	--	
	200	11.03	--	--	
	260	10.75	--	--	
	320	9.42	--	--	
	380	7.50	--	--	
	440	5.77	--	--	
	503	4.62	--	--	
8:05 a.m.	+558	4.18	--	--	

TABLE 3.--Water-quality data from test wells

Pump or flow period prior to sampling (minutes)	Instantaneous flow rate (gal/min)	Temperature (°C)	Dissolved silica (SiO_2) (mg/l)	Dissolved iron (Fe) (µg/l)	Dissolved manganese (Mn) (µg/l)	Dissolved calcium (Ca) (mg/l)	Dissolved magnesium (Mg) (mg/l)	Dissolved sodium (Na) (mg/l)	Dissolved potassium (K) (mg/l)	Bicarbonate (HCO_3) (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	Dissolved sulfate (SO_4) (mg/l)
Test well 22C1. Sampled Jan. 29, 1975. Altitude of land surface 82 ft. Depth to top of sample interval 104½ ft.												
23	52	9.9	--	--	--	--	--	--	--	--	--	--
34	50	9.9	--	3,800	--	--	--	--	--	--	--	--
288	52	10.0	54	3,800	250	15	12	7.4	2.0	116	95	2.1
700	54	9.9	--	4,000	--	--	--	--	--	--	--	--
Test well 22G1. Sampled Feb. 10, 1975. Altitude of land surface 89 ft. Depth to top of sample interval 120 ft.												
48	52	10.0	--	210	--	--	--	--	--	--	--	--
213	52	10.0	52	1,500	900	16	10	6.3	1.1	116	95	1.3
Test well 26F1. Sampled Feb. 28, 1975. Altitude of land surface 11 ft. Depth to top of sample interval 141½ ft.												
42	165	10.8	--	--	--	--	--	--	--	--	--	--
253	160	10.8	32	300	70	14	5.2	5.1	1.8	65	53	2.0
398	160	10.8	--	--	--	--	--	--	--	--	--	--
638	172	10.8	--	--	--	--	--	--	--	--	--	--
743	175	10.8	--	90	60	--	--	--	--	--	--	--
840	175	10.8	--	40	60	--	--	--	--	--	--	--
Test well 35D1. Sampled Feb. 21, 1975. Altitude of land surface 18 ft. Depth to top of sample interval 101½ ft.												
29	30	10.8	--	1,000	70	--	--	--	--	--	--	--
311	26	10.8	32	60	70	26	9.0	20	3.4	153	126	1.9

Dis-solved chlo-ride (Cl) (mg/l)	Dis-solved fluo-ride (F) (mg/l)	Dis-solved nitrite plus nitrate (N) (mg/l)	Dis-solved solids (resi-due at 180°C) (mg/l)	Dis-solved solids (sum of constit-uents) (mg/l)	Dis-solved solids (tons per acre-ft)	Hard-ness (Ca,Mg) (mg/l)	Non-car-bonate hard-ness (mg/l)	Percent sodium	Sodium adsorp-tion ratio	Spe-cific con-duct-ance (micro-mhos)	Color (Plat-inum-cobalt units)
4.3	--	--	--	--	--	--	--	--	--	185	--
--	--	--	--	--	--	--	--	--	--	--	--
4.4	0.1	0.00	136	158	0.19	87	0	15	0.3	187	90
4.7	--	--	--	--	--	--	--	--	--	189	--
3.4	--	--	--	--	--	--	--	--	--	189	--
3.6	.1	.00	140	150	.19	81	0	14	.3	195	40
2.4	--	--	--	--	--	--	--	--	--	--	--
2.3	.1	.01	92	95	.13	56	3	16	.3	114	3
2.2	--	--	--	--	--	--	--	--	--	--	--
2.3	--	--	--	--	--	--	--	--	--	--	--
2.3	--	--	--	--	--	--	--	--	--	--	--
2.0	--	--	--	--	--	--	--	--	--	--	--
.9	--	--	--	--	--	--	--	--	--	--	--
4.2	.1	.00	172	172	.23	100	0	29	.9	249	3