WATER-RESOURCES RECONNAISSANCE OF ST. GEORGE ISLAND, PRIBILOF ISLANDS, ALASKA

By Gary S. Anderson

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 6-76

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

Multiply Enqlish units	By	To obtain SI units
inches (in)	25.40	millimetres (mm)
feet (ft)	0.3048	metres (m)
cubic feet per second (ft3/s)	28.32	litres per second (l/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
gallons per day (gal/d)	4.381x10-8	cubic metres per second (m3/s)

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SUMMARY

A hydrologic reconnaissance of St. George Island, Pribilof Islands, Alaska, was made in May 1974 to determine the feasibility of locating a source of water containing less sodium chloride than the present supply. The existing wells are apparently either too deep relative to sea level or too close to the ocean; they may be pumping from a transition zone between the freshwater and saltwater bodies. Other than a few lakes on the island, surface-water availability is limited. However, the presence of several freshwater springs suggests that ground water of good quality does exist on the island. The island is relatively narrow, the rate of recharge is low, and the rocks are permeable; it is therefore concluded that the freshwater lens is thin. Fresh ground water should be obtainable near the center of the island. However, production wells should be designed so as to skim freshwater from near the top of the lens.

INTRODUCTION

The village of St. George is on the north shore of St. George Island, one of several islands within the group of Pribilof Islands (figs. 1 and 2) in the Bering Sea. Maritime weather conditions prevail at the islands, with predominantly cloudy, foggy weather. At St. George Island, total precipitation for the year is about 30 in (inches) or 762 mm (millimetres), and mean annual air temperature is about 36°F or 2°C (Celsius).

A hydrologic reconnaissance of St. George Island was made on May 24-27, 1974, by the U.S. Geological Survey at the request of the National Marine Fisheries Pribilof Islands Program. Subsequent to the trip, records on file with the Geological Survey were reviewed. The purpose of the study and field reconnaissance was to evaluate the existing village water supply and to determine the feasibility of developing a source of water that contains fewer dissolved solids, mainly sodium and chloride, than the present system.

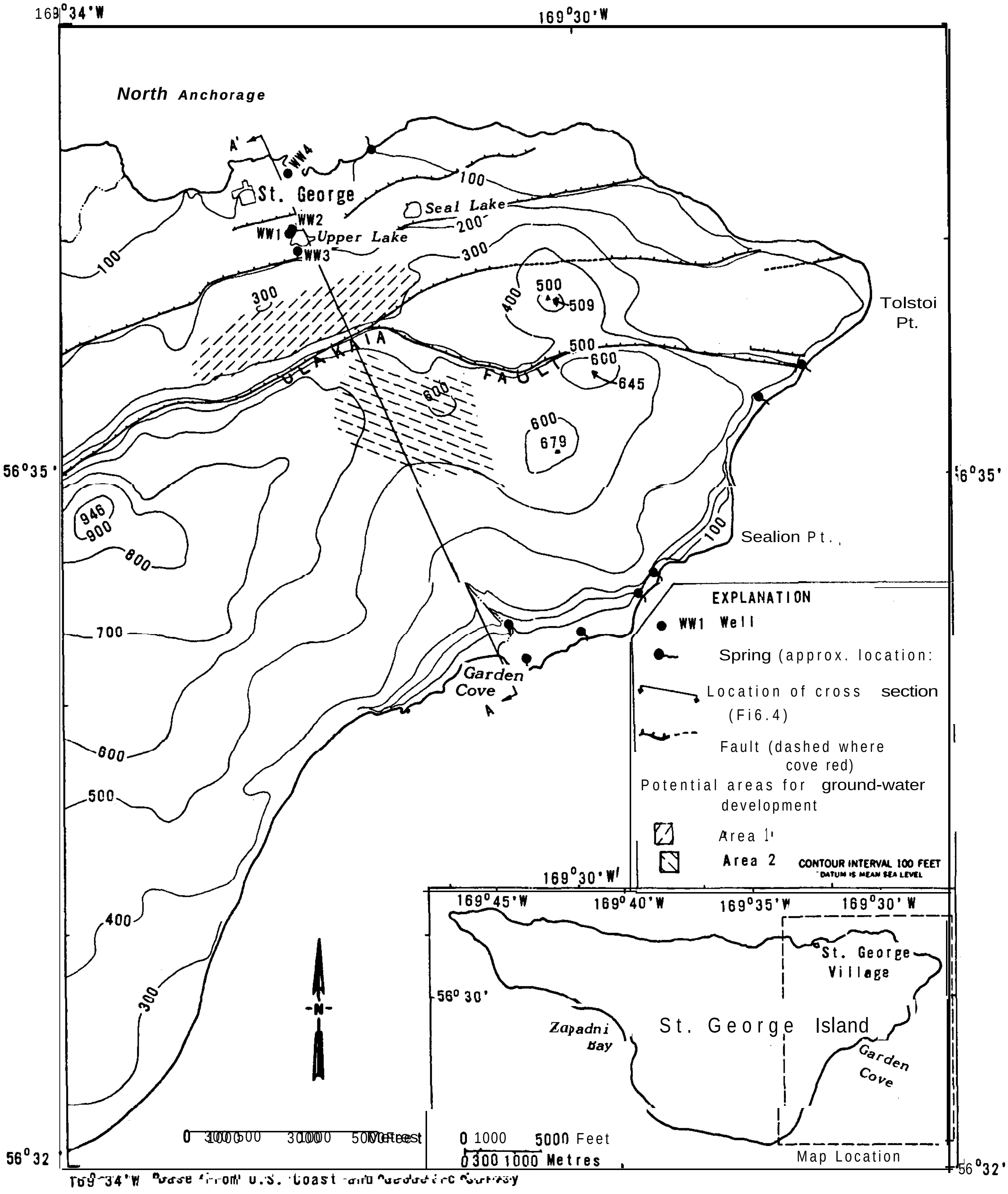


Figure 2.--Geohydrology of the eastern portion of St. George Island.

PRESENT WATER SUPPLY AND USE

The current domestic water supply on St. George Island is obtained from two wells. The wells are reported by village maintenance personnel to have individual capacities of 55 and 20 gal/min (gallons per minute) or 3.5 and 1.3 l/s (litres per second). Water is pumped from one or both wells into a concrete storage tank. Water in excess of the village's 25,000 gal/d (gallons per day) or 0.001 m^3/s (metres cubed per second) requirement is discharged from the storage tank through an overflow into Upper Lake (fig. 2). During the field reconnaissance in May 1974, the tank overflow ranged from none to an estimated 5 gal/min (0.3 l/s) when the smaller capacity well was pumping, and a measured flow of 35 gal/min (2.2 l/s) when the larger capacity well was pumping. The village people generally object to the quality of the well water because of the salty taste, so the U.S. Public Health Service hospital operates a distillation plant which provides refined drinking water for the village.

SOURCES OF WATER

In addition to ground water, which occurs at several places on the island, a few small lakes near the village could be used for a water supply. However, Upper Lake has been contaminated by the discharge of excess, somewhat saline well water and now has concentrations of sodium and chloride which cause an objectionable taste (table 2). Other lakes near the village are reported to be fresh, but the water would require disinfection before being used for drinking; the lakes, further, may provide a limited water supply in the winter because of freezing and lack of recharge.

Other than the few lakes, surface water is limited on the island. Garden Cove Spring is reported to flow year-round and is of potable quality. On May 23, 1974, the discharge from the Garden Cove drainage basin, including the spring, was measured at 1.6 ft^3/s (cubic feet per second) (45 l/s), or 718 gal/min. However, this measurement was made during a period of snowmelt and the winter flow of the spring would be much less. The only other major stream was observed at Zapadni Bay, but its flow was estimated to be less than 0.1 ft^3/s (2.8 l/s).

GROUND-WATER CONDITIONS

The geology of St. George Island has been described by Barth (1956) and is shown on unpublished field mapping done in 1965 by D. M. Hopkins and Th. Einarsson. Barth's work and the more recent mapping show that the rocks commonly exposed on St. George Island are lava flows, basalt sills, and minor amounts of pyroclastic material and glacial sediments. On parts of the island older peridotite basement rock crops out near sea level and is intruded by dikes. A series of east-west-trending faults have vertically displaced the rocks.

Young volcanic rocks are commonly very permeable, and this appears to be the case on St. George Island. The primary permeability of these rocks is usually low; however, secondary permeability is high because of layering of the flows, interbeds of gravel or scoria, and cooling fractures within the rocks. The peridotite basement rocks are impermeable and probably restrict the flow of ground water. It is not known if the major east-west-trending faults are conduits or barriers for ground-water movement.

The topography of St. George Island appears to be only slightly modified since the volcanic structures were built up. Volcanic cones, flows, and fault scarps appear very fresh, and there is no significant development of surface drainage. Much of the land surface has a relatively thick cover of unconsolidated sediments, which is conducive to the infiltration of surface water. However, the areas of low relief have vigorous tundra growth overlying peat which restricts both surface runoff and subsurface infiltration. Since much of the island has bare soil exposed at the surface and evapotranspiration losses probably are small in the areas of tundra growth and peat, it is inferred that a high percentage of precipitation does infiltrate to the subsurface rocks.

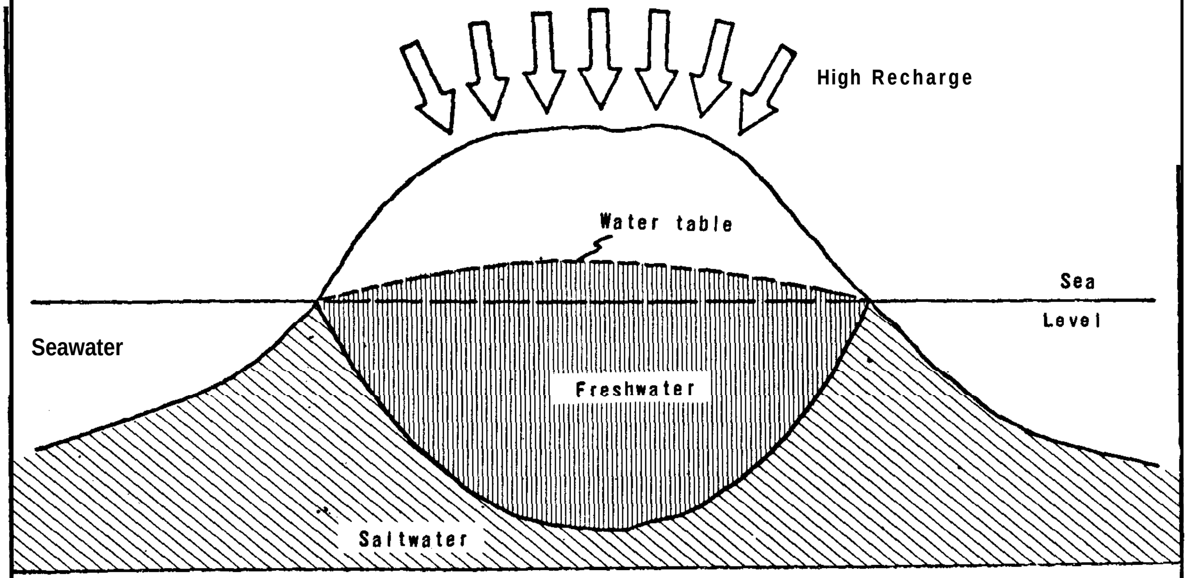
The occurrence of ground water and hydraulic properties of the rocks can be inferred from (1) visual inspection of rock exposures, (2) geomorphic characteristics of the land surface, (3) occurrence and distribution of springs, (4) records of wells and test borings (table 1), (5) response of ground-water levels to pumping and tidal fluctuation, and (6) the chemical characteristics of ground water and springs.

In general, on an oceanic island of uniform geology a freshwater lens, shown schematically in figure 3, is formed by the radial movement of freshwater toward the coast. The surface profile and thickness of the freshwater lens is determined by the rate of freshwater recharge, the size of the island, and the permeability of the rocks. A large island made up of rocks of low permeability and with a high rate of recharge will have a high head of freshwater above sea level, thus a thick freshwater lens. Conversely, a small island with highly permeable rocks and a low rate of recharge will have a low head of freshwater above sea level and a thin freshwater ?ens. In either case, if the geology is complicated by rocks of contrasting permeability or by geologic structures such as faults, dikes, or sills., the flow of freshwater to the shore may be impeded or ground water may be perched above the regional hydraulic surface.

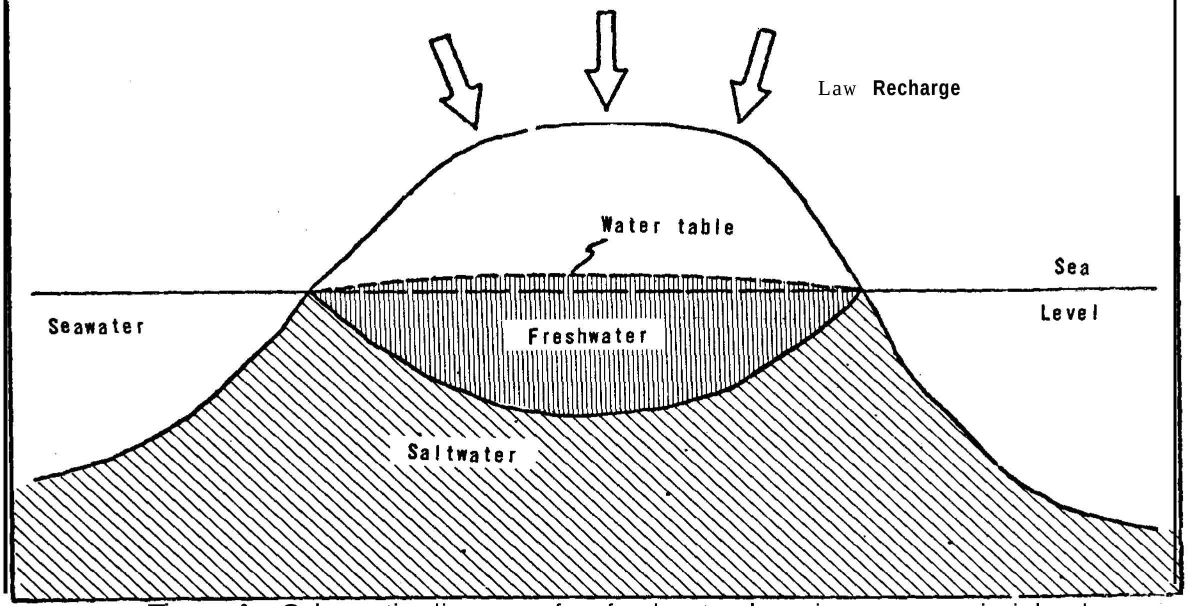
The occurrence of potable ground water on St. George Island is inferred from known geologic and hydrologic conditions and by analogy to other oceanic volcanic islands. Figure 4 is a schematic cross section of the island from St. George Village to Garden Cove. Records from production and test wells near the village have shown that the water table there is near sea level and that the wells, which are

Table 1.--*Logs* of wells

Material	Thickness (feet)	Depth (feet)
St. George Island Water Well No. 1 Driller: B.E. Strotman, 1954		
Soil and broken lava.	4	4
Lava, broken.	20	24
Lava, hard.	16	40
Lava, broken.	8	48
Lava, hard.	22	70
Lava, broken, and some clay	20	90
Lava, hard.	6	96
No log; losing drilling water	41	137
Lava, broken, and loose rock; losing drilling water	11	148
Lava, broken; holding drilling water.	44	192
Lava, hard.	6	198
Lava, broken; water-bearing	4	202
St. George Island Water Well No. 2 Driller: B.E. Strotman, 1954		
Soil and broken lava.	3	3
Lava, broken.	20	23
Lava, solid	22	45
Lava, hard.	10	55
No log	28	83
Lava, soft, or volcanic ash	16	99
Lava, hard.	6	105
Lava, soft, or volcanic ash	5	110
No log	13	123
Lava, solid	13	136
Lava, broken.	7	143
Lava, gray, hard.	22	165
Lava, brown, solid.	28	193
Volcanic ash.	3	196
Lava, brown, solid.	7	203
Lava, broken; water-bearing	3	206
Lava, gray, solid, hard	10	216
Lava, broken; water-bearing	9	225

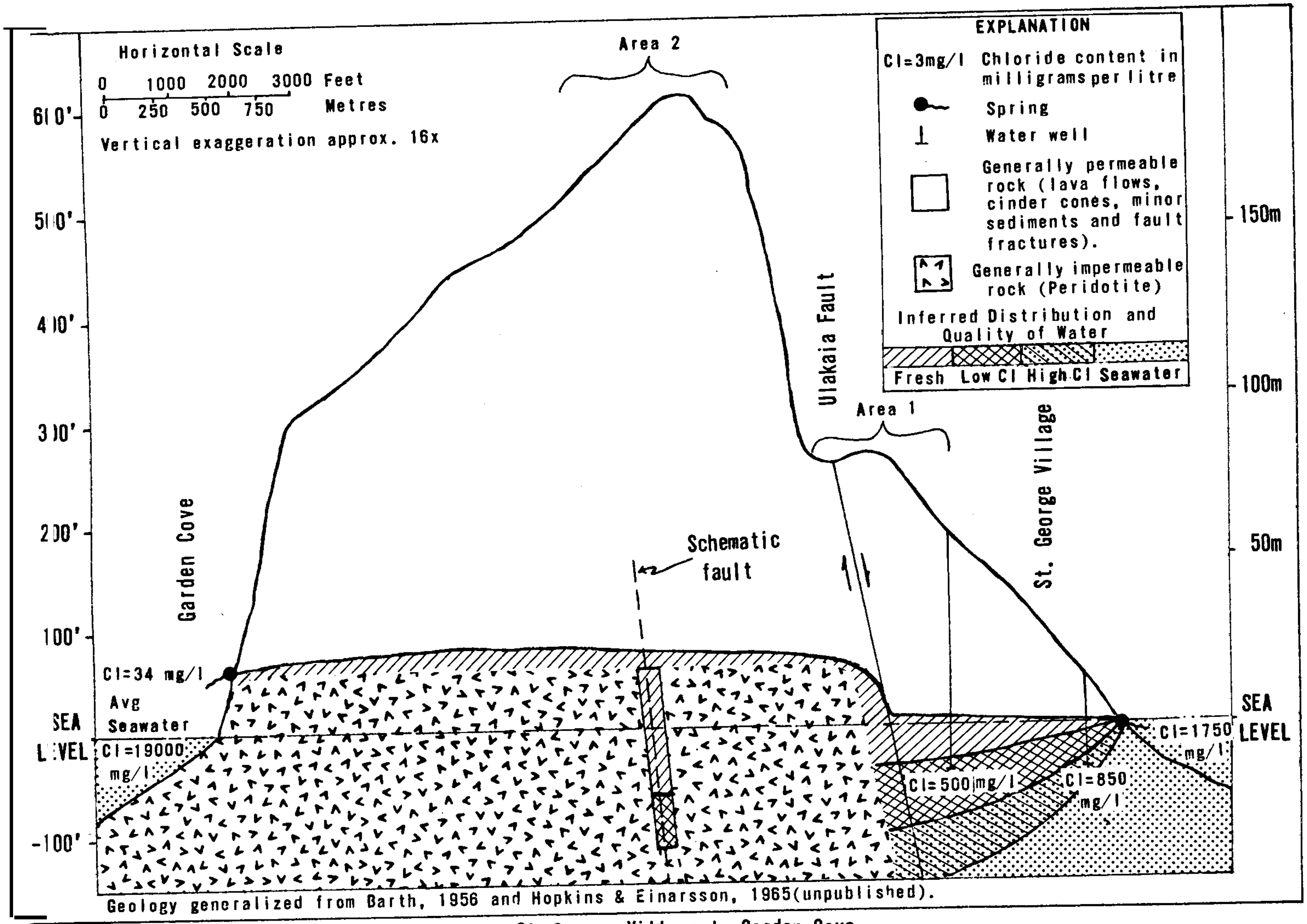


Freshwater lens on an oceanic Island composed of rocks of low permeability and with a high rate of natural recharge.



Freshwater lens on an oceanic island composed of rocks of high permeabi 1 ity and with a low rate of natural recharge.

Figure 3.--Schematic diagram of a freshwater lens in an oceanic island.



Geology generalized from Barth, 1956 and Hopkins & Einarsson, 1965(unpublished).

Figure 4.--Schematic geologic section, St. George Village to Garden Cove.
(Line of section shown on figure 2)

completed at depths from 20 to 40 ft (feet) or 6 to 12 m (metres) below sea level, are producing a mixture of freshwater and seawater. Field inspection of the geology and observations of water-level fluctuations in the production wells caused by pumping and by tidal action indicate that the rocks are very permeable. It is concluded that the freshwater lens is thin because the island is relatively narrow, the rate of recharge is low, and the rocks are permeable.

A series of east-west-trending faults on St. George Island have elevated the peridotite basement rocks above sea level so that freshwater is perched on top of these impermeable rocks. Numerous springs observed along the shoreline from Garden Cove to Tolstoi Point issue from the contact between the peridotite and overlying basalt flows or are associated with vertical fault zones. Most of these springs were estimated to be discharging less than 20 gal/min (1.3 l/s), and only a few associated with the fault zones were discharging as much as ZOO gal/min (13 l/s). The permeable rocks on the south side of the island probably do not contain great quantities of water, but what is available is concentrated on top of the impermeable basement rock or within minor fracture zones associated with faults in the basement rock. This freshwater is geologically and hydraulically separated from seawater so there probably is no mixed zone similar to that which occurs on the north side of the island.

QUALITY OF WATER

Except for samples from Upper Lake, the surface water on St. George Island is of suitable chemical quality for most usage (table 2). Upper Lake has relatively high concentrations of sodium and chloride; however, this contamination is believed to be caused by the discharge of well water into the lake.

Water from springs on the island is also of generally potable quality. Two samples from a spring east of the village, at the base of the sea cliff (table 2), had concentrations of sodium and chloride in excess of Environmental Protection Agency (1973) recommended limits; however, it is believed the amounts of sodium and chloride may be due to seawater which intrudes the rock fractures during high tide. Garden Cove Spring is fresh, and seven springs from Garden Cove to Tolstoi Point had field-measured specific conductivities that ranged from 100 to 200 micromhos at 25'C. The chemical quality of these springs should be representative of the quality of ground water where it is not mixed with seawater.

All of the ground-water samples from deep production and test wells have objectionable quantities of sodium and chloride (table 2). The wells are apparently either too close to the ocean or are too deep relative to sea level and the thickness of the freshwater lens and are pumping from the transition zone between the freshwater and saltwater bodies. Because of the high permeability of the fractured lava and the low withdrawal rate of the wells, current pumping probably is not causing saltwater to encroach on the well field. The saltwater front may be moved slightly landward from its natural position; however, if it had reached the well field, the salinity of the water would increase with time and repetitive samples from the water-distribution system (table 2) should reflect this change.

ALTERNATIVES FOR DEVELOPMENT

Three potential water sources are available for use by the village of St. George: lakes, streams, and ground water. Seal and Upper Lakes could be developed; however, it will require time for the saline water in Upper Lake to be naturally flushed out. Both Seal and Upper Lakes may offer limited supplies in the winter. If storage facilities were. constructed, the stream at Garden Cove appears to have sufficient perennial flow to be a dependable source of water, but the cost of developing this source may be prohibitive. Ground-water development probably is the most economical and dependable of the three possible sources.

Ground water of acceptable chemical quality probably cannot be developed any closer to the village than the present well field. It is conceivable that additional wells drilled near the existing well field and which would penetrate only a short distance into the water table might provide water of potable quality. However, since the existing wells have been discharging brackish water to Upper Lake for more than 12 years, and because Upper Lake is, in turn, recharging the aquifer with the brackish water, it is possible that all ground water in the vicinity of the well field is now contaminated.

Fresh ground water should be obtainable by drilling wells nearer the center of the island. However, production wells should be designed to skim the freshwater from near the surface of the water table with a minimum of drawdown. Two areas in which new wells may be successful are indicated in figure 2. In area 1, the geology is inferred to be similar to that at the present well sites; however, at this location the freshwater lens should be slightly thicker than at the well sites. In area 2, the altitude of the top of the basement rocks is expected to be near or above sea level, and freshwater may be perched on them. Also, freshwater may be available from fracture zones near faults within the basement rocks. The water in area 2 may be of better quality than in area 1 because the relatively impervious basement rocks would prevent the mixing of freshwater and seawater.

SUGGESTED ADDITIONAL STUDIES

The ground-water evaluation presented in this report is based on studies of surficial geology and incomplete information on the existing

Table 2.--*Selected chemical analyses.*

Location Latitude	Location Longitude	Unique Alaska number	Name	Sample depth (feet)	Date	Silica (SiO_2) mg/l	Iron (Fe) µg/l	Manganese (Mn) µg/l	Calcium (Ca)
Ground water samples collected at well									
56'36'03"	169'32'12"	26001	St. George WW 2[1]	225	05/24/74	22	40	0	21
56'36'03"	169'32'12"	26001	St. George WW 2 1	225	07/31/55	22	110	10	15
56°36'02"	169'32'14"	26000	St. George WW 1	202	07/31/55	21	60	0	17
56'36'02"	169'32'14"	26000	St. George WW 1	202	08/15/92				
56'36'15"	169°32'06"	26002	St. George WW 4	77	08/18/62				
56'36'12"	169°32'40"		Dug well at hospital		07/12/72	24	700	30	6.6
Samples (from distribution system) which are a composite of wells 1 and 2									
			Tap water at cottage D		D5/25/74	2	60		22
			Composite sample of wel **No. 1 and 2 -** sample location not known		07/08/58	2	0	1	17
			"		1961	21	20	4	20
			"		04/16/69				
			"		07/18/70	1	5900	0	48
			"		*09/ /70*	1	200	20	51
			"		04/28/72	1	2500	0	19
Springs									
56'34'20"	169°30'30"		Garden Cove		08/16/62				
56'36'22"	169'32'15"		Spring east of village		08/15/62				
			Spring east of village		08/15/62				

Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride[3] (Cl)	Fluoride (F)	Nitrate as N (NO_3)	Dissolved solids Calculated	Hardness as $CaCO_3$	Specific conductance µ mhos at 25°C	pH	Temperature (°C)	Color	Trace metals (µg/l)
mg/l (milligrams per liter)															
36	240	11	45	0	58	450	0.0	--	864	200	1680	7.5	4.0	2	B=80 Cd=1 Cu=17 Pb=5 Zn=90
24	238	14	51	0	60	390	0.0	0.0	788	136	1480	6.7	3.5		
33	298	18	51	0	72	500	0.0	0.0	984	178	1850	6.8			
	300					520					1840	7.1			
	500					850					2960	7.1			
4.3	25	1.9	34		6.5	35	0.1	2.9	123	34	197	7.4		90	
38	270	12	43	0	65	490	0.0		943	210	1860				B=87 Cd=2 Cu=7 Pb=4 Zn=360
35	294	14	51		71	520	0.0	0.7	997	186	1880	6.6		0	
35	286	16	52	0	68	520	.2	.9	993	194	1880	6.9		0	
	290					475				187	1660				
15	296	11	46	0	65	532	0	2.6		182	1770	7.6		5	
14	300	13	42	0	71	508		2.6	1000	186	1790	6.8		5	
32	280	10	46		62	486	.2	3.9	932	179	1800	7.6		0	
	21					34					169	7.1	3.5		
	991					1780					5830	6.9			
	650					1200					4080	7.0			

Table 2.--Continued

Location		Unique Alaska number	Name	Sample depth (feet)	Date	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)
Latitude	Longitude					mg/l	µg/l		
Surface Water									
56°36'10"	169'31'15"		Seal Lake		08/22/62				
56'34'10"	169'39'30"		Stream at Zapadni Bay		08/20/62				
56'34'20"	169'30'30''		Stream at Garden Cove		07/12/72	24	50	20	1.6
56°36'00"	169'32'10''		Upper Lake 2		07/08/58	1.7	0	10	a.3
56'36'00"	169'32'10''		Upper Lake'		08/15/62				
56'36'00"	169'32'10''		Upper Lake '		07/12/72	10	330	50	7.0
			Natural precipitation		08/13-33/62				

1 also referred to as number 3 in old records

'Lake contaminated by ground water discharge from well

"'On the basis of taste preferences, not because of toxic considerations, it is recommended that chloride in public water supply sources not exceed 250 mg/l if sources of lower levels are available". EPA, 1972, p.61

Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate as N (NO_3)	Dissolved solids Calculated	Hardness as $CaCO_3$	Specific conductance µ mhos at 25°C	pH	Temperature (°C)	Color	Trace metals (µg/l)
mg/l (milligrams per liter)															
	14					25					106	5.6	11.0		
	16					25					103	6.2	11.0		
2.2	15	1.3	50	0	4.3	26	0	0.4	79	13	113	7.0		10	
20	180	8.5	21		43	315	0.1	0.2	587	102	1150	5.8		10	
	200					390					1340	6.6			
14	120	6.5	16	0	27	206	0.1	1.2	400	75	783	6.6		25	
	16					29					131	6.5			

production wells. Further study is warranted to better assess the potential for developing fresh ground water on the island. The objective of these studies would be to define the ground-water hydraulics and subsurface geology.

The altitude of the water table with reference to mean sea level should be accurately determined in existing wells. Then, by projecting the known water-level profile from the shoreline through the well field and toward the center of the island, it may be possible to estimate the freshwater head near the center of the island. This estimate could be improved if the hydraulic properties of the aquifer were better known. Crude estimates of the aquifer hydraulics could be made by simultaneous measurement of water-level changes of the ocean and in the wells. It is,also important to determine if a freshwater lens is present and, if so, its thickness in the existing production wells. This could be determined by borehole geophysical techniques.

Determination of geologic conditions and exploration for potable ground water is best accomplished by a test-drilling program. However, test drilling is a costly and time-consuming operation. Often the efficiency of a test-drilling program can be improved if a geophysical survey of subsurface conditions is made prior to drilling. Under certain conditions geophysical surveys can determine the structure and water-bearing characteristics of the rocks, the depth to water, and the quality of water. Geophysical surveying of an oceanic island such as St. George would be especially advantageous if geologic structures which would impede the flow of freshwater toward the ocean can be located. Such structures may exist near the center of the island where the peridotite basement rock has been raised above sea level.

SUGGESTED PROCEDURE FOR TEST DRILLING AND WELL COMPLETION

Test drilling will be required to positively locate potable water. Considering the cost of mobilizing a drill rig on St. George Island, it is suggested that it would be best to use a rig with full capability for the construction of water wells. Before drilling commences, the surface altitude at each drilling site should be accurately determined. Preferably, the wells should be designed with a large diameter and terminated near sea level. However, it may not be practical to have well diameters greater than 12 in (305 mm), and it may be necessary to drill below sea level to allow for the needed drawdown at the desired production rate.

The probable allowable depth of penetration below sea level can be estimated from the known density relationship of freshwater and saltwater. If a true freshwater lens situation exists, there theoretically is about 40 ft (12 m) of freshwater below mean sea level for each foot of freshwater head above. However, with high permeability rocks and a tidal range of several feet, one usually finds a thick mixing zone far inland. This usually means that even though fresh potable water may exist near the top of the lens, brackish non-potable water may occur near the base. Here, one could probably safely plan for conventional wells open to the basalt at least 10 ft (3 m) below sea level for each foot of head above sea level without getting into salinity problems. During drilling, careful sampling of the water will be required to determine the location of potable water below sea level. Salinity, or relative salt content, can be determined in the borehole or from selected-depth samples with an electrical conductivity meter. If drilling is done near the center of the island, drill cuttings should be carefully collected and analyzed to determine where the peridotite basement rock is penetrated. It probably would not be profitable to drill very deeply into the basement rock because these rocks are impermeable and water sources would thus be limited to the occasional fracture zones.

Having located a suitable water source, the well should be finished and developed to yield the maximum discharge with the minimum drawdown. The completed well should be test pumped to determine optimum pump depth-setting and discharge rate. In the process of skimming freshwater from near the top of the lens, the pump should not be set deeper than necessary to allow for drawdown while pumping. Because of the apparent high permeability of the rocks, the rate of pumping that would satisfy present and future demand should not be a serious factor in causing a change in quality of the water supply.

REFERENCES

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