AQUIFER CHARACTERISTICS AND SEAWATER INTRUSION OF MACHAYE HARBOR AREA AND NORTHERN LOPEZ ISLAND SAN JUAN COUNTY, WASHINGTON

by Susan Perkins

September 1986

Open-File Technical Report 86-03

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MEMORANDUM

September 15, 1986

TO: Krystyna Kowalik

FROM: Susan Perkins

SUBJECT: Aquifer Characteristics and the Extent of Seawater Intrusion in the Mackaye Harbor area, Lopez Island, San Juan County

Previous Department of Ecology studies of the Mackaye Harbor aquifer were done to evaluate groundwater applications (Wildrick, 1980, 1981). These studies included short and long duration pump tests, measurement of tidal influence on the wells, and estimation of recharge and aquifer yield. The scope of the studies was limited to the immediate area of the wells in question.

This study was initiated due to continued concern about water availability and the possibility of seawater intrusion. The purposes of this investigation were to: 1) determine the extent and characteristics of aquifers in the greater Mackaye Harbor area; and 2) assess the extent of seawater intrusion by measuring chloride levels in the groundwater.

METHODS

Fifty-nine well logs were used to interpret subsurface geology of the area (see Appendix). Of these, 20 are in the immediate Mackaye Harbor area covered by Wildrick's studies. Location, water level, and chloride data for 15 of the wells were obtained from USGS records (Whiteman, 1983; also unpublished data, 1986).

Data for the rest of the wells used in this study were collected in July and August of 1986. Most of the wells are in domestic use, and in some cases measured water levels may reflect drawdown due to recent use. Water samples were analyzed for conductivity and for chloride (ion chromatography method). Most well elevations were estimated from the topographic map. Well elevations measured by surveying or altimetry are indicated in the Appendix.

GEOLOGY AND AQUIFER CHARACTERISTICS

Figure 1 shows well locations and general geology of the study area.

Bedrock

Bedrock is exposed on the peninsula south of Barlow Bay (section 24); south of Aleck Bay Road (sections 19 and 20); and north of Mackaye Harbor (section 13). To the east, wells in the vicinity of Cole Road hit bedrock below 30 to 100 feet of unconsolidated deposits (wells which penetrate bedrock are shown as dark circles on Figure 1).

The bedrock of Southern Lopez Island is part of the Lopez Complex, a chaotic mixture of elongate fault-bound slices of sedimentary, volcanic and metamorphic rocks (Brandon, 1983; Cowan and Whetten, 1977). The rocks are of Jurassic to Mid-Cretaceous age. A pervasive foliation dips steeply northeast and trends northwest, parallel to the structural trend of the fault slices. Bedding is sub-parallel to the foliation.

The sedimentary rocks are sandstones, shales, conglomerates, and cherts. Most are thin-bedded, graded beds known as flysch, deposited by turbidity currents (Whetten, 1975). The volcanic rocks are primarily pillow basalts, with minor tuffs, diabase, and breccias. The metamorphic rocks are highly deformed greenstones. They are coarse-grained igneous rocks of greenschist facies metamorphism (Whetten, 1975).

The wells drilled in bedrock yield far less water than those in unconsolidated sediments. They are also much deeper, often more than 100 feet below sea level (Figure 2). The source of groundwater is fractures in the rock, as the rock itself is quite impermeable (Whetten, 1975).

Unconsolidated Deposits

Wells in the unconsolidated deposits were classified on the basis of stratigraphy, chloride levels, and presence of artesian pressure. The three major categories are:

1. Mackaye Harbor artesian wells
2. Mackaye Harbor water table wells
3. Mud Bay artesian wells

Figure 3 shows the location of artesian (confined) and water table (unconfined) wells.

Figure 2.
Estimated elevation from which well draws water (bottom of screen, or bottom of casing if no screen present). In feet below Mean Sea Level.

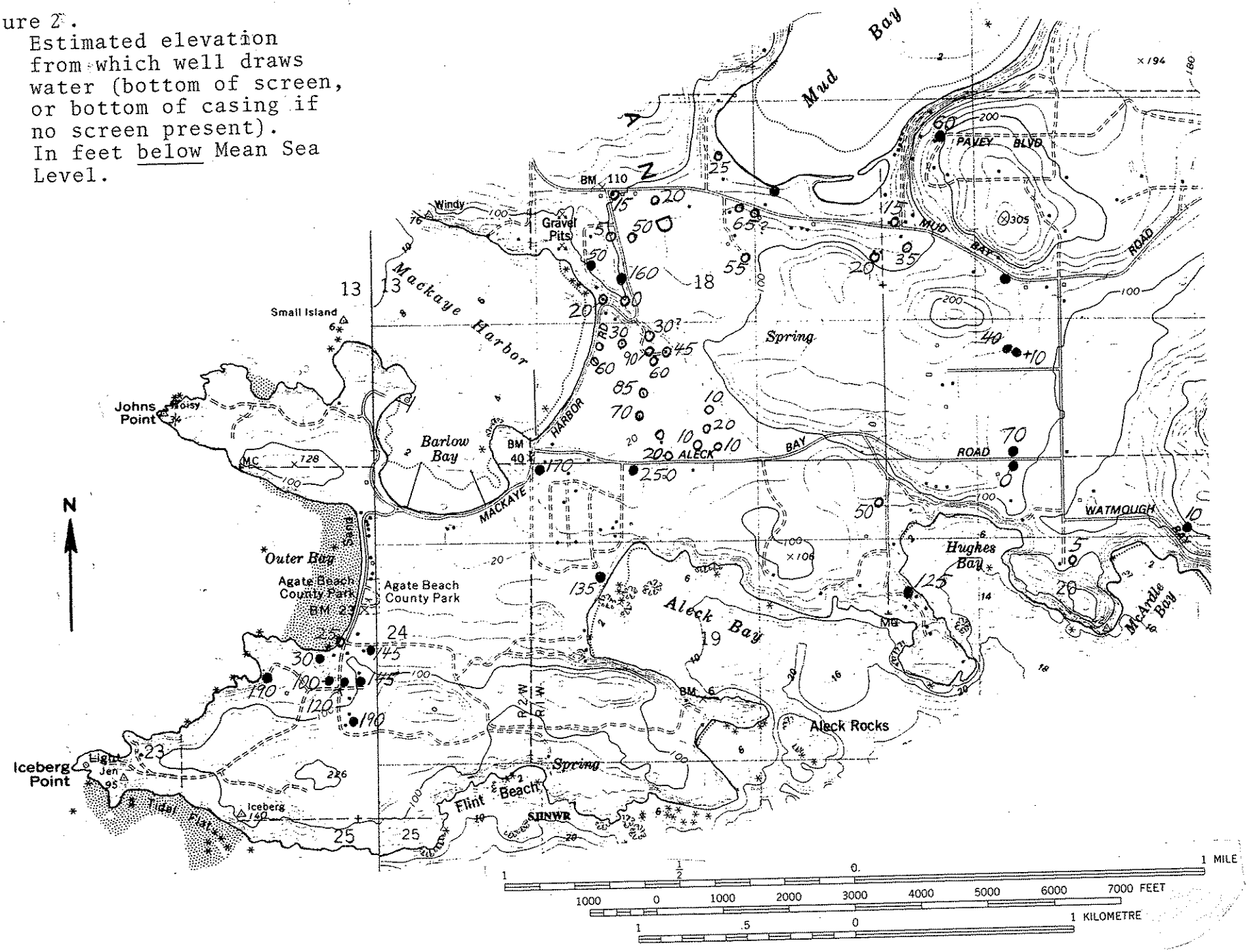


Figure 3.

Water level elevations
(feet above Mean Sea Level)

(10) estimated elevation

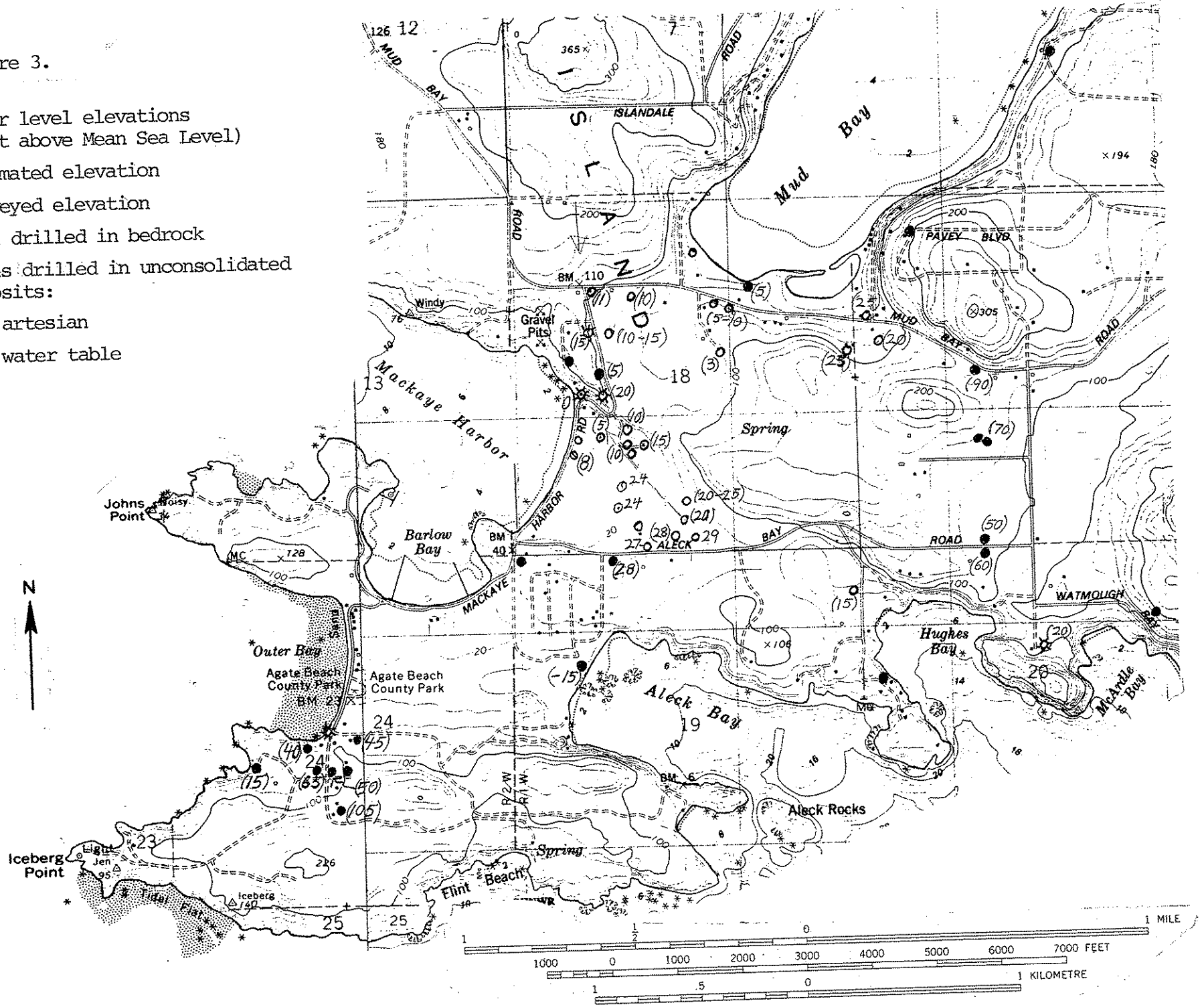
23 surveyed elevation

● well drilled in bedrock

wells drilled in unconsolidated deposits:

○ artesian

☼ water table



1. Mackaye Harbor artesian wells.

In addition to the artesian wells of the Mackaye Harbor watershed (described by Wildrick), this category includes wells on the isthmus between Mud Bay and Mackaye Harbor (18E4, F1, F2). Most of the sampled wells have chloride levels of 100-120 mg/L (see Figure 6).

In these wells, a gravelly sand aquifer is overlain by a clay-rich confining layer (Figure 4). Well logs indicate that the clay ranges from 25 to 100 feet in thickness; in places it contains sand or gravel interbeds. Sandy clay or cemented sand and gravel underlie the clay in many wells. The confining strata are probably clay-rich glacial till, overlain in places by fine-grained alluvium.

The bottom of the confining layer mimics the slope of the surface topography. From about 10 feet above sea level at the Mackaye Harbor well (18Q1), it drops to about 50 feet below sea level near the shore (Figure 4). This results in considerable artesian pressure in some of the wells.

The textural composition of the aquifer varies from gravel to sand, rarely sandy silt. The thickness of the aquifer is unknown, as most wells penetrate it less than ten feet. It may be only 20 to 30 feet thick, as a few well logs show hardpan or clay beneath 20 to 30 feet of the sand (18P2, P3, P6).

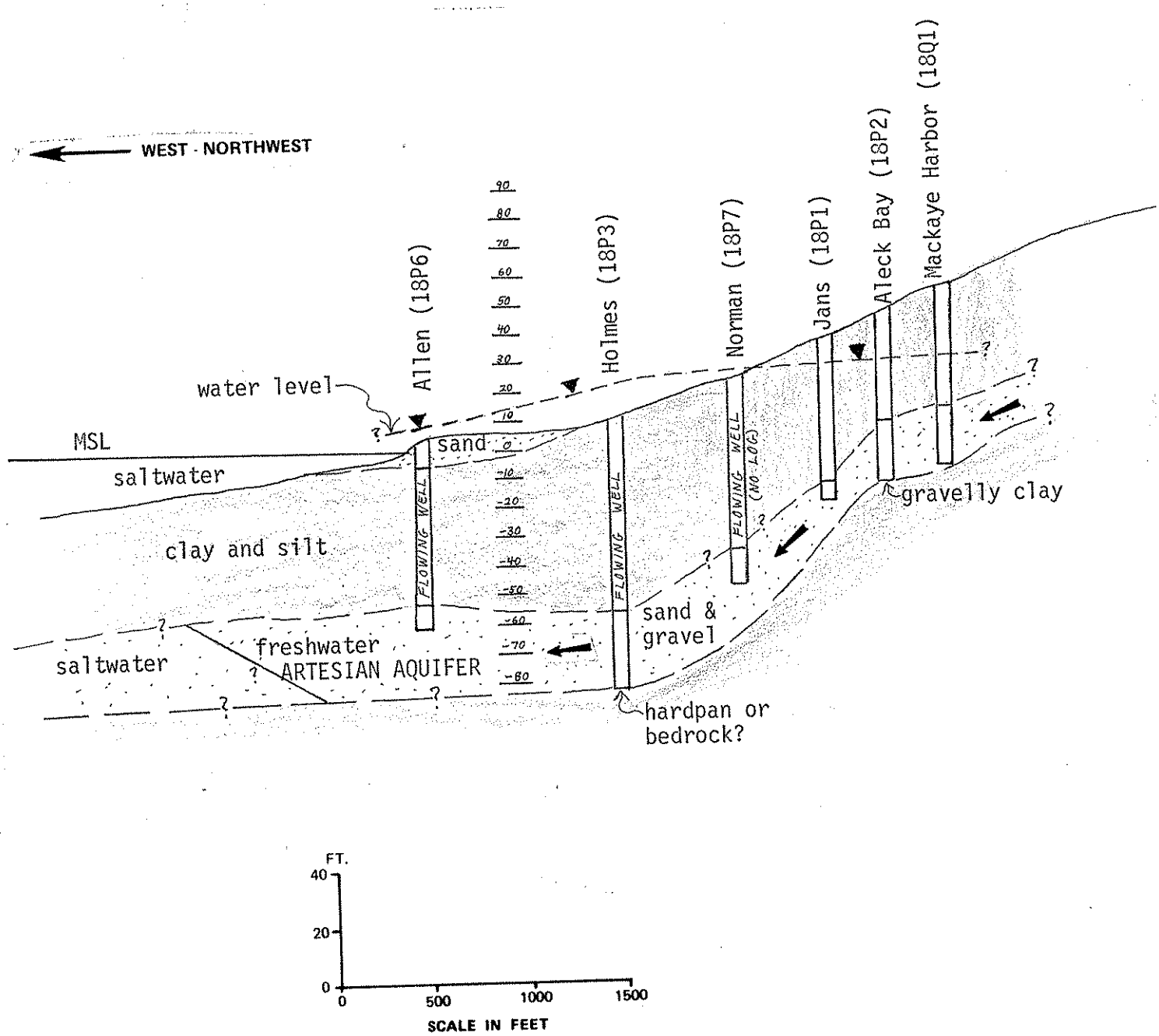
The aquifer's texture and position beneath the till suggest that it is glacial advance outwash. If this is the case, the upper surface was probably eroded by streams and ice from the advancing glacier (Whetten, 1975). As a result, the aquifer may vary considerably in thickness.

Water levels in the Mackaye Harbor watershed decrease to the northwest (Figure 3). Groundwater flow probably parallels the orientation of the watershed. Measurements of wells near the shore show that water levels drop more rapidly than postulated by Wildrick (1981). The piezometric surface is less than 10 feet above sea level at the shore (see Figure 4). Based on water level data and well logs, I also differ from Wildrick in interpreting the Post and Vietske wells (18L2, L4) as artesian.

Figure 4.

Geologic Cross - Section
Mackaye Harbor Area
Lopez Island

(modified from Wildrick, 1981, based on data from logs for Allen and Aleck Bay wells)



Water levels in the wells between Mud Bay and Mackaye Harbor are about 10 feet above sea level. Groundwater probably flows into the area from the north; it could flow either into Mud Bay or Mackaye Harbor.

2. Mackaye Harbor water table wells

This category includes 3 wells on the ridge near the gravel pit (18E1, L1, and M2). It also includes most of the shallow wells cited by Wildrick in his 1981 report, for which there are no logs. Chloride levels are in the same range as for the artesian wells (see Figure 6).

The water level in 18M2, the well closest to the shore, is just above sea level. Water levels in 18L1 and M2 are 15-20 feet above sea level, which is at least as high as in nearby artesian wells. This suggests that these two water table wells may share the same aquifer as the artesian wells. There is no artesian pressure because the piezometric surface is lower than the clay layer. The similar chloride levels support this hypothesis.

3. Mud Bay artesian wells

Wells 17E1, 17E2, and 18H1 tap a sand and gravel aquifer which is overlain by up to 60 feet of mudstone. Clay and till overlie the mudstone. Water levels in these wells are about 20 feet above sea level. The chloride levels are very low, ranging from 50 to 60 mg/L (Figure 6). The stratigraphy and low chloride levels are evidence that this artesian aquifer is not related to the Mackaye Harbor aquifer.

The other wells in the Mud Bay area (18G1-G3) have relatively high chloride levels. The stratigraphy of these wells is variable, and they probably tap aquifers of very limited extent.

Extent of the Mackaye Harbor Artesian Aquifer

Wildrick (1981) used the boundaries of the Mackaye Harbor watershed as the approximate extent of the recharge area for the aquifer. One goal of this study was to define the aquifer boundaries more precisely.

Unfortunately, there are no wells in southeast Section 18 to provide information. Further east, in the Cole Road vicinity, bedrock is present at an elevation of about 100 feet, and the aquifer no longer exists.

Groundwater from the high elevation central area could flow to Mackaye harbor, Hughes Bay and/or Mud Bay. The 0.4 square mile Mackaye Harbor watershed represents the minimum recharge area for the aquifer. Figure 5 shows the estimated maximum area from which groundwater could flow toward Mackaye Harbor.

The water-bearing strata of the aquifer apparently extend into the northwest part of Section 18, and probably as far north as the bedrock at Islandale Road. This area may provide some recharge to the lower part of the Mackaye Harbor aquifer. However, it seems more likely that groundwater from this area flows toward Mud Bay.

SEAWATER INTRUSION

Chloride levels were measured in 28 wells as part of this study. Combined with USGS data from 1978-1986, chloride measurements are available for 40 wells in the study area (two-thirds of the inventoried wells). Results are tabulated in the Appendix, and shown in Figure 6.

The chloride content of well water is commonly used as an index of seawater intrusion. Based on extensive sampling of wells in 1981, a USGS study (Whiteman, et al, 1983) suggested the following criteria for groundwater in the San Juan Islands:

Chloride Concentration (mg/L)	Condition
less than 100	background level
100-160	Leading edge of seawater/freshwater interface (zone of diffusion)
greater than 160	seawater contamination

The Washington Department of Ecology currently has no criteria for determination of seawater intrusion.

Figure 5.

Estimated recharge area of the Mackaye Harbor aquifer.

watershed boundary

direction of surface water flow

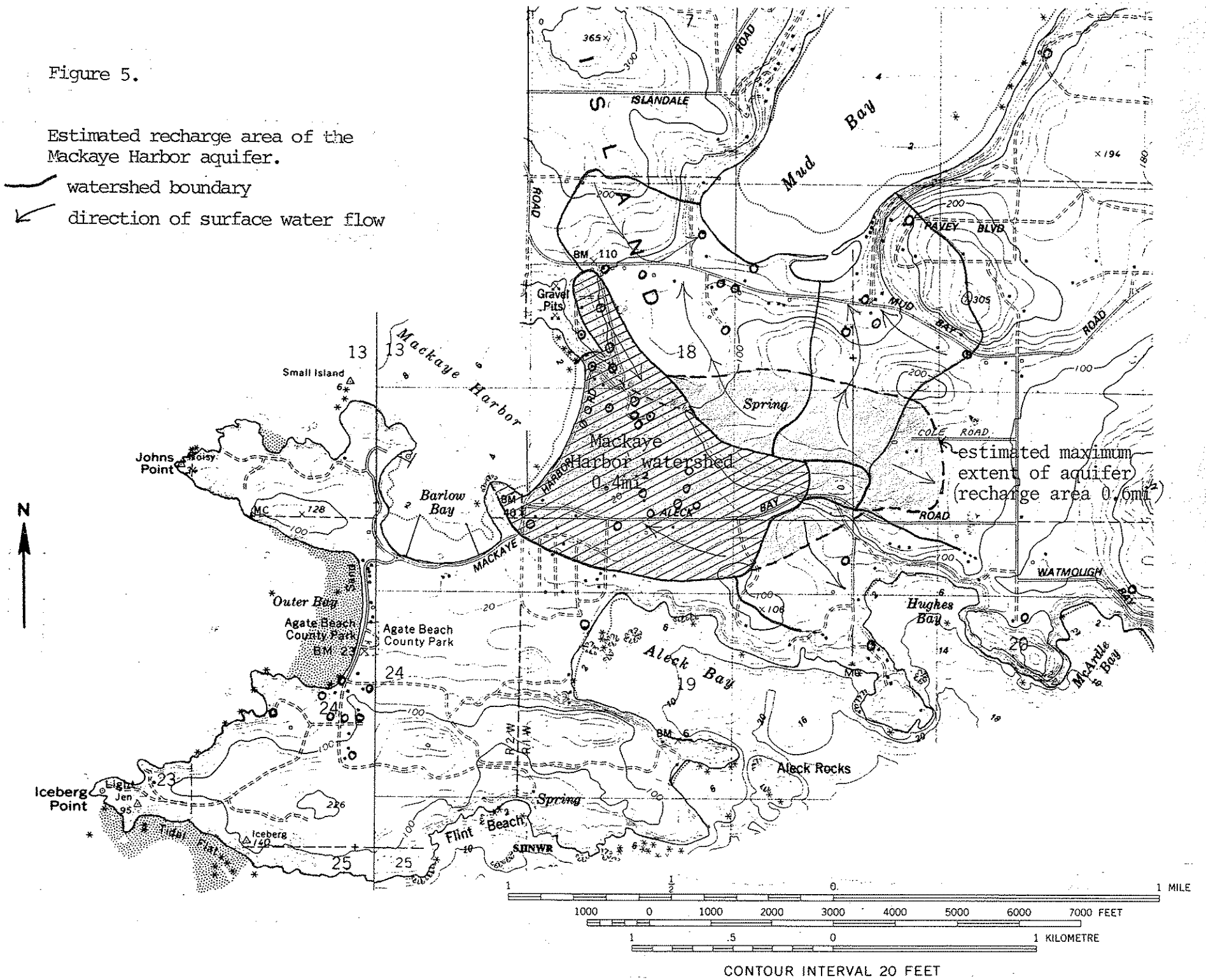
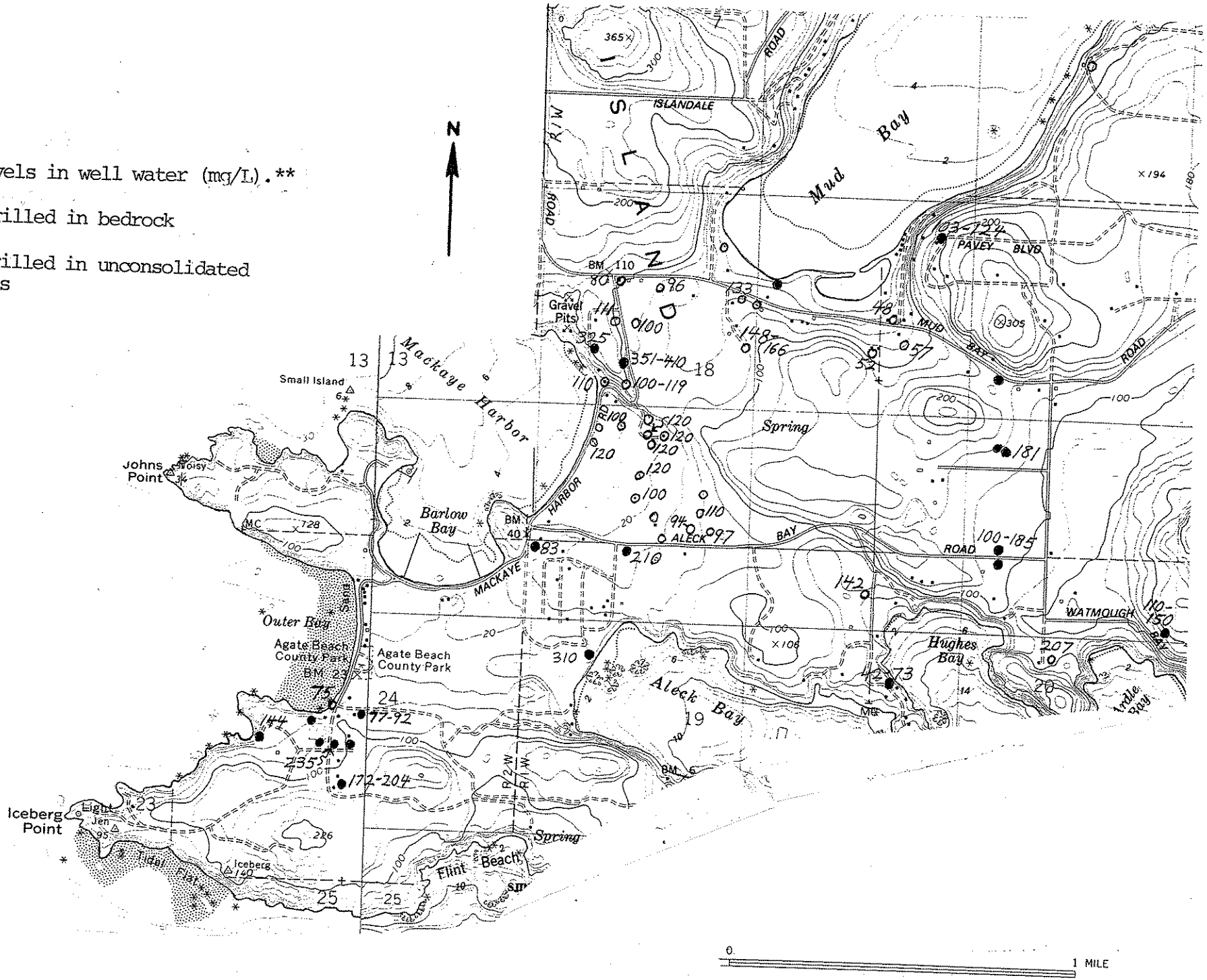


Figure 6.

Chloride levels in well water (mg/L).**

- ● well drilled in bedrock
- o well drilled in unconsolidated deposits



** For wells measured more than once, the range of chloride levels is shown only if levels varied by more than 10mg/L. If less than 10mg/L difference, the mean of the chloride levels is shown.

Chloride levels exceed 100 mg/L in the majority of the wells in the study area. Many wells drilled in bedrock exceed the 160 mg/L level.

Wells in unconsolidated sediments fall into two main groups: 1) The Mackaye Harbor area wells, with chloride levels in the 100-120 mg/L range. Chloride levels do not appear to be related to well depth, distance from shore, or the presence of artesian pressure. 2) The Mud Bay wells, with chloride levels below 60 mg/L.

Bedrock wells

Chloride levels in bedrock wells are much more variable, ranging from 42 to 410 mg/L. Most of the very high chloride levels are from bedrock wells. Three wells had a chloride level above 250 mg/L, the EPA standard for drinking water. (Above this level, the average person can detect a salty taste.)

Lithology and well depth have no apparent effect on chloride levels. The variability in chloride levels may be a function of which fracture system a well penetrates. The wells with the highest chloride levels probably tap fractures with a direct connection to seawater.

Water levels in the bedrock wells are all above sea level, with the exception of 34/1W-19E1 (Figure 3). This well has one of the highest chloride levels (310 mg/L). At the time of sampling, the water level was 17 feet below sea level. pumpage induced drawdown may be contributing to seawater intrusion in this well.

Long-term Changes

In 1981, USGS sampled numerous San Juan County wells in April and again in September. The greatest fluctuations occurred in wells with high chloride levels. Wells with low chloride levels showed little seasonal change (Whiteman, 1983). In the south Lopez area, seasonal changes up to 80 mg/L were observed in bedrock wells, and up to 18 mg/L in non-bedrock wells.

No conclusive data exist on long-term changes in chloride levels. Only nine wells in the study area have been sampled for more than one year (Table 1). Of these, two are in the Mackaye Harbor area (18P2 and 18P4). With the possible exception of 34/1W-20E1, year to year changes are less than the seasonal variability, so no long-term changes in chloride level are discernible.

TABLE 1
Chloride (mg/L)

Well location	8/78	11/79	9/80	4/81	9/81	7/82	4/86	7/86
34/1W-17E1	52			59	61			
34/1W-17P1				100	179	145		180
34/1W-18E2	410			351	404			
34/1W-18G1				148	166			148
34/1W-18H1				46	51		52	
34/1W-18P2		93-98						89
34/1W-18P3			120	120				120
34/1W-20A1	110			150	113			
34/1W-20E1	42			73	71			

Discussion

Chloride levels in the Mackaye Harbor aquifer are higher than the normal background level for the San Juan Islands. If this represents the leading edge of the seawater/freshwater interface, one might expect the highest chloride levels to be near the shoreline. Instead, chloride levels are fairly uniform throughout the aquifer.

The high chloride levels do suggest a connection with seawater. This may occur offshore, where the aquifer discharges to the sea, or onshore through fractures in the bedrock. In either case, fractures in the unconsolidated sediments may promote rapid diffusion throughout the aquifer, resulting in uniform chloride levels.

High chloride levels could also result from ancient seawater intrusion, or from sediments deposited during a period of high sea level (Eddy, 1975; Whiteman, 1983).

It is not clear whether high chloride levels in the study area occur naturally, or whether they result from excessive pumping of groundwater. In either case, seawater could be drawn inland if groundwater withdrawals exceed recharge over a long period. The recharge area of the Mackaye Harbor aquifer may be as small as 0.4 square miles, so recharge estimates should be calculated accordingly.

Recommendations

To determine if seawater intrusion is taking place, sampling for chlorides should be conducted on at least a quarterly

basis. Using this data, a range of variability could be established for each well. This then could be used to determine the significance of any measured chloride increases.

At less frequent intervals, chemical analyses of major cations and anions should be done on representative wells. Well water dominated by sodium and chloride ions would provide a second line of evidence for seawater intrusion.

SP:sc

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USGS Well #	Log Name	Log Source	Location known?	WATER SAMPLES: Source	Date	Cl⁻ (mg/L)	Conduct. µmhos	water level (feet below LSD)	well LSD elevation S=surveyed A=altimete	De
34/1W										
17B1	Snug Harbor Assn.	DOE Bulletin No. 46 (1975)	✓	driller	4/75					
17C1	Michael	DOE files	NO					174	185	2(
17D1	Mayo	"	✓	driller	3/74					24
				USGS	4/81	103	812	20	190	25
				"	9/81	124	741	64.1		
17E1	Fagerholm	DOE files	✓	driller	8/76			43.6		
				USGS	8/78	52	755	59	80	115
				"	4/81	59	785			
17E2	Squeiros	DOE files		"	9/81	61	696			
→17F1/F2			✓	driller	8/82					
17G1	Miller	"		DOE	7/86	48	707	32		
17H1	Williams	USGS records	NO		same as Williams ?			32.0	55	70
			✓	USGS	4/81	155	921			290
-17F1	Greenthal	DOE Bulletin No. 46			9/81	171	844		165	290
17L1	Gastil	DOE files	NO							
			✓	driller	10/66					60
17L2	Abbott	"		DOE	7/86	180	1370	66	138	130
17F2	Bond (now Rebate)	"	✓	driller	11/76					
7P1	Hughes Bay Water Users Assn (well deepened in 1966)	"	✓	"	10/77			73	140	190
			✓	"	4/65			60	150	100
				USGS	4/81	100	730	60	101 A	120
					9/81	179	977		(105 tops)	170
				Water Assn.	7/82	145	1030			
8B1	Andrews	DOE Bull. 46		DOE	7/86	180	1150			
E1	Boroughs (now Pomeroy)	DOE files	✓					50		
			✓	driller	1/68				~20	45
E2	Dexter	"		DOE	8/86	111	863	78	~95	98
			✓	driller	8/76			81		
				USGS	8/78	410	1820	94	100	260
				"	4/81	351	1560			
F3	Gerring	DOE files		"	9/81	404	1675			
				driller	6/79					
4	Johnson, Peter	"	✓	DOE	8/86	325	1670	111	≈115	167
			✓	driller	2/82			115.4		
1	Droubay	"		DOE	7/86	80	874	89		
			✓	driller	7/75			93.5 (well recently used)	100 A	127
	Norman	"		DOE	8/86	96	978	60	72 A	95
			✓	driller	5/85			61		
				DOE	7/86	100	869	65	(76?A) tops looks like 85	126

USGS well #	Name	Log/Source	Location known?	WATER SAMPLES Source	Date	Cl⁻ (mg/L)	Conduct. µmhos	water level (feet below LSD)	elevation (feet) S=surveyed A=altimeter	depth
34/1W										
18G1	Petersen	DOE files	✓	driller	3/74			76	80	132
				USGS	4/81	148	1120			
				"	9/81	166	1032	78.1		
				DOE	7/86	148	1200			
18G2	Swanson	"	✓	driller	5/72			43	50 A 60 topo	114
		sample from neighbor's well (Gallanger)		DOE	8/86	lab	lab			
18G3	Thompson	DOE files	✓	driller	5/74			43	50 A 60 topo	123
				DOE	8/86	133 Gallanger 1090 Thompson not back from lab		44.4		
18G4	Hughes (Mud Bay)	DOE files	✓ approx	driller	8/73			26	~30	225
18G5	Leyson	"	NO	"	8/79			61	?	82
18H1	Walvatne	"	✓	"	8/73			71	95	115
		numerous measurements; see USGS records		USGS	1981-86	46-56	731-830	71-72		
18L1	Laporte	DOE files	✓	driller	1/77			63	80-85	85
				USGS	4/81	100	900	61.1		
				"	9/81	119	845	61.5		
18L2	Post	"	✓	driller	7/77			26	~36	92
				DOE	'80			? measured in pump test		
18L3	Aldrich	"	✓	driller	5/73			0	10 A	71
				DOE	80			pump test		
				"	7/86	120	925	0		
18L4	Vietske	"	✓	driller	8/72			8	23 A	68
				DOE	7/86	120	876	7.4		
18L5	J+L Johnson upper well	"	✓	driller	5/84			12	14A	109
				DOE	7/86	120	896	3.5		
18L6	J+L Johnson lower well	"	✓	driller	5/84			6		46
				DOE	7/86	100	911	2.0		
18M1	Strain	DOE Bull. 46	?							70
18M2	Rawson	"	✓	DOE	7/86	110	992	36.0	37 hand level survey	53
18M3	Allen (now Thompson)	DOE files	✓	driller	9/83			1½ psi +2.9 above ground	5A	6
				DOE	7/86	120	988			
18M4	Hendrickson	"	✓	driller	6/84			6	~5	48
				"	5/76			10	38(S)	59
18P1	Jans			DOE	?/80			11.4		
				USGS	4/81			20		
				"	9/81			12.1		
18P2	Buzzard (Alec Bay Maint.)	DOE Bull. 46	✓	DOE	?/81 pump test			19	47	5
				"	7/86	89	916			
					11/79	93-98				
18P3	Holmes	DOE files	✓	"	12/80			24.5	7(S)	96
				"	9/80	120	875			
					4/81	120				
				"	7/86	120	1020			

USGS well #	Name	Log/Source	Location known?	WATER SAMPLES Source	Date	Cl⁻ (mg/L)	Conduct. µmhos	water level (feet below LSD)	elevation (feet) S=surveyed A=altimeter	Depth
34/1W										
18P4	Lopez Island Mut. Co. (Hughes)	DOE files	✓	driller	8/77			9.5 psi	10(S)	80
				DOE	12/80	[158 wildrick?]		+14'		
				"	7/86	100	961			
18P5	Mohrmann	"	✓	driller	8/78			22	43(S)	52
				DOE	12/80			15.6		
18P6	Allen	L. Arnot (verbal) sample from Winchell (50' away)	✓	driller (Arnot)	7/86			24	45	66
→18P7				DOE	7/86	110	870			
18Q1	Roe (Mackaye Harbor Water Co.)	DOE files	✓	driller	8/78			27	55(S)	64
				DOE	12/80			26.1		
				"	8/86	97	847	29.8		
19A1	Reese	DOE files	✓	driller	1/85			30	45	92
					7/86	140	1160	31.2		
19C1	Nestlund	"	✓	driller	10/79			4		
				DOE	7/86	210	1260	1.8	30(A)	28
19D1	Bear	DOE Bull. 46	✓	USGS	8/78	83	730		30	200
19E1	Chivers	DOE files	✓	driller	11/80			18	16-17 (channel level)	1
				DOE	8/86	310	5410	34.1		
20A1	Sangster	"	✓	driller	6/75			50	"	189
				USGS	8/78	110	940			
				"	4/81	150	1390			
				"	9/81	113	852			
20C1	Anderson	"	✓	driller	6/69			37	100(A)	101
				DOE	7/86			41		
20D1	Weeks	DOE Bull. 46	NO							37
20G1	Morison	DOE files	✓	DOE	7/86	210	1380	77	95	101
20E1	Jans	DOE Bull. 46	✓	USGS	8/78	42	510		40	16
					4/81	73	558			
					9/81	71	545			
34/2W								17	60	21
24K1	Goss	DOE files	✓	driller	12/75					
				USGS	8/78	77	685			
24K2	Isaksen	"	✓	driller	9/78			5	110	30
				USGS	4/81	172	960			
				"	9/81	204	930			
24K3	Meagher	"	✓						102	2
24L1	Lehman	"	✓	driller	8/79			19	~60	8
24L2	Johnson	"	✓	"	6/78			37	50	2
				DOE	8/86	144	947			
24L3	Jevick	USGS; DOE files	✓	USGS	4/81	76	541		40	6
					9/81	74	677			
↑18P7	Norman	no log	✓							

USGS Well #	Name	Log/Source	Location known?	WATER SAMPLES				water level (feet below LSD)	elevation (G S=surveyed A=altimeter	
				Source	Date	Cl⁻ (mg/L)	Conduct. μmhos			
34/2W										Dept
24L4	Tralmas	DOE files	✓	driller	1/83			14	~80	171
24L5	Brentson	"	✓	DOE	8/86	235	1450	34	85	230
24P1	Kottsick	"	NO	driller	2/81			140		402