Water Resources Program

OPEN-FILE TECHNICAL REPORT

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

SURVEY DATA REPORT
SEAWATER INTRUSION PROJECT

by

Christian Fromuth

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OFTR 89-1

This Open File Technical Report presents the results of a hydrologic investigation by the Water Resources Program, Department of Ecology. It is intended as a working document and has received internal review. This report may be circulated to other Agencies and the Public, but it is not a formal Ecology Publication.

Author: Christian Fromuth

Reviewed by: Linton Wildrick

Supervisor: Alan Wald

ABSTRACT

The Seawater Intrusion Project of 1988 included sampling of chlorides in seventeen wells in the Puget Sound region. Eleven of the wells were sampled more than once, and chloride concentrations varied from 225 mg/l to 4500 mg/l. Specific conductance values generally increased with higher chloride concentrations, ranging from a low of 165 umhos/cm to 8000 umhos/cm. Chloride concentrations in one well affected by ocean tides remained relatively constant at about 2400 mg/l while the specific conductance was found to increase from 1000 umhos/cm to 2800 umhos/cm over the course of a tidal cycle.

INTRODUCTION

The Seawater Intrusion (SWI) Project staff from the Department of Ecology surveyed chloride concentrations in selected wells in the Puget Sound Region. We sampled from June through November 1988 to:

- Provide current information on some high chloride concentrations that might be the result of seawater intrusion,
- To raise questions regarding future chloride sampling needs, and
- Initiate a sampling and analysis program that could be useful for future chloride investigations.

This report presents the data collected and methods used. The data collection process included well selection, sample collection, and laboratory analysis. The report is an internal document for use by the Seawater Intrusion Team in their discussions of data collection and chloride analysis.

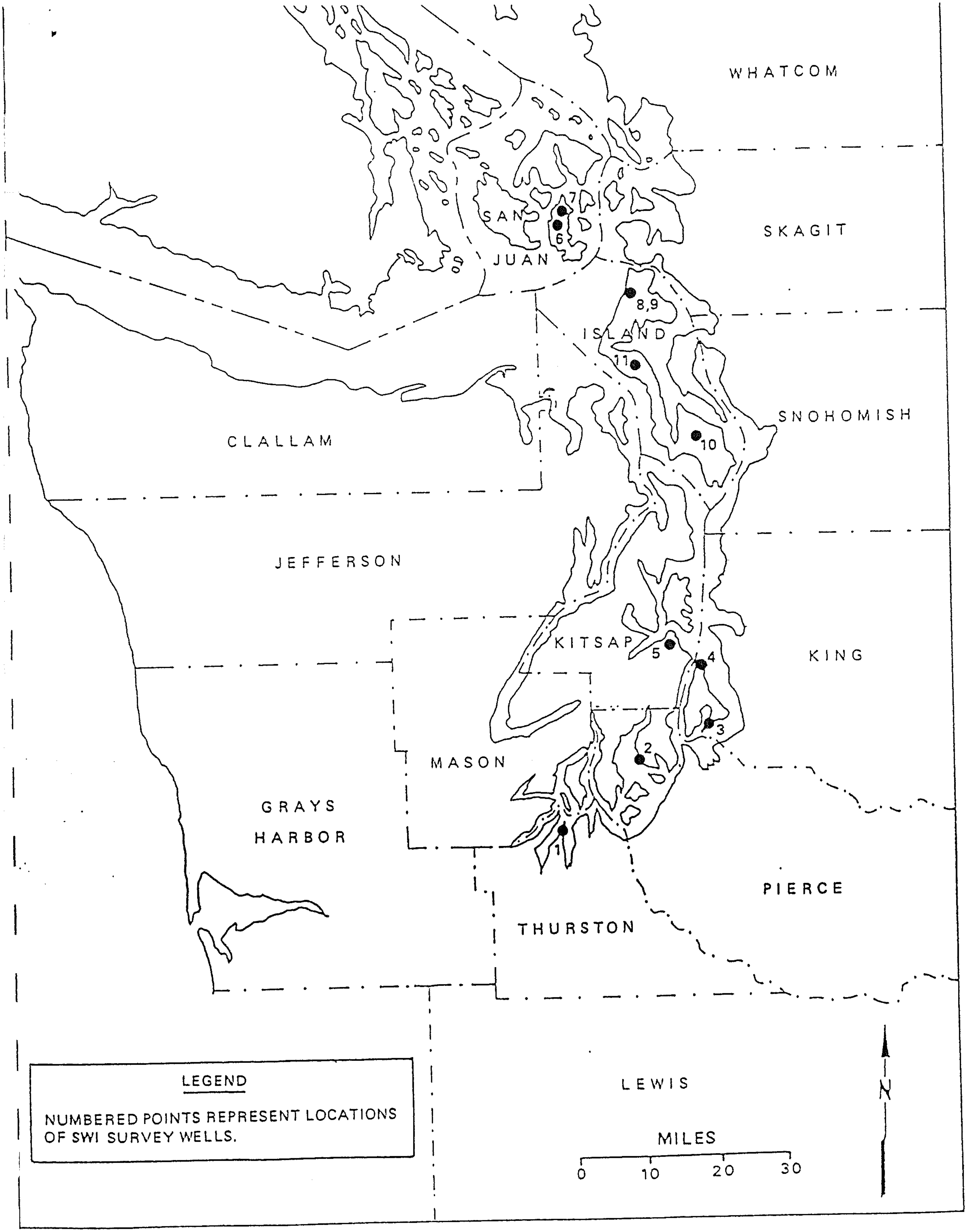


Figure 1. GENERALIZED MAP OF SWI SURVEY WELL LOCATIONS.

WELL SELECTION

The survey was limited to some representative coastal areas of the Puget Sound and selected wells within six current or pending Department of Ecology (Ecology) Ground Water Management Areas (GWMA's). These areas are the Gig Harbor Peninsula in Pierce County, Kitsap County, Thurston County, San Juan County, Island County, and Vashon Island in King County. An objective of the survey was to have one or two study wells in each of these focus areas. It was decided that a total of eleven wells would meet the needs of the survey and we selected individual wells using three criteria: indications of high chloride concentrations in previous analyses of the ground water, ease of access, and owner cooperation. Many resources were used in identifying these wells. Among these were USGS reports, county and state government data banks, and numerous well owners, drillers, consultants, and water purveyors in the given regions.

We selected State owned test wells in San Juan and Island Counties and privately owned wells in the remaining areas. Figure 1 shows the well locations in Western Washington. Table 1 contains a list of characteristics for the eleven wells used in the survey. These characteristics are defined below.

DEFINITION OF WELL CHARACTERISTICS IN TABLE 1

A) SWI ID#: An identification number given to the survey wells included in this report.
B) T-R-S: An abbreviation for Township, Range and Section map coordinates according to conventional USGS 1/4 - 1/4 section identification.
C) USGS MAP: United States Geological Survey Map ; (' = MIN) indicates the map series in minutes.
D) Elev: An abbreviation for elevation above sea level. These values were taken from USGS maps, land surveyors' records, and well logs. They include applicable ranges of accuracy.
E) Diam: An abbreviation for well casing diameter.

TABLE 1

SWI SURVEY WELL CHARACHTERISTICS

SWI ID#	OWNER	COUNTY	T-R-S	USGS MAP (' = MIN)	LAND ELEV. (FEET)	ELEV. OF OPEN INTERVAL (FEET)	ELEV. OF WELL BOTTOM (FEET)	WELL DEPTH (FEET)	WELL CODE*	LOG (Y/N)	WELL DIAM. (INCHES)	LITHOLOGY OF WATER BEARING MATERIAL (dimensions in feet below land surface)
1	WARD & ALICE MILES 8900 LIBBY RD NE OLYMPIA WA 98506	THURSTON	19N-01W-05	LONGBRANCH WA 7.5'	40 (+\- 5)	-79 TO -89 (+\- 5)	-89 (+\- 5)	129 (OWNER)	R	N	6	REMARKS: SOFT MUSH AT 117
2	FOREST BEACH COM. WATER SYSTEM; KNOWLES 3815 FOREST BCH. Dr. GIG HARBOR, WA	PIERCE	21N-01E-21-L	FOX ISLAND WA 7.5'	51	-106	-106	157	C	Y	10	SAND & GRAVEL / MEDIUM COURSE
3	SUSAN GRIFFITH ROUTE# 3, WICK RD BOX 255, VASHON, WA	KING	22N-03E-23-A	VASHON WA 7.5'	75 (+\- 25)	-145 (+\- 25)	-145 (+\- 25)	220	D	N	6	NO INFORMATION
4	NORTH CEDARHURST DRINKING WATER ASS. DON WOLFE; RTE# 1 BOX 859; VASHON WA	KING	22N-03E-18-D	VASHON WA 7.5'	150 (+\- 50)	0 TO -28 (+\-50)	-170 (+\- 50)	320	C	Y	6	135 TO 149: GRAVEL 149 TO 160: CLAY 160 TO 175: GRAVEL
5	LARRY VAN BOYENT 6800 BEACH DR. PT. ORCHARD, WA	KITSAP	24N-02E-09-M	BREMERTON EAST WA 7.5'	100 (+\- 20)	20 TO -212 (+\- 20)	-212 (+\- 20)	312	D	Y	6	23 TO 121: GRAY & BROWN SHALE STREAKS & BROWN SAND 121 TO 126: BROWN SAND 126 TO 280: DARK GRAY AND BROWN SHALE, BROKEN AREAS, STREAKS, SAND STONE 280 TO 312: LIGHT GRAY &GREEN SHALE
6	LOPEZ ISLAND OBSERVATION WELL #2 LOPEZ, WA (WA ST DOE)	SAN JUAN	35N-2W-11	SHAW ISLAND WA 7.5'	125	-275	-275	400	O	Y	6	357 TO 400: SALT & PEPPER SAND,POORLY SORTED W/ SOME BLACK & ANGULAR ROCK FRAGMENTS

* WELL CODES: O = State owned observation well; R = Retired well but not abandoned;
C = Community water system; D = Single family domestic well.

TABLE 1

SWI SURVEY WELL CHARACHTERISTICS

SWI ID#	OWNER	COUNTY	T-R-S	USGS MAP (' = MIN)	LAND ELEV. (FEET)	ELEV. OF OPEN INTERVAL (FEET)	ELEV. OF WELL BOTTOM (FEET)	WELL DEPTH (FEET)	WELL CODE*	LOG (Y/N)	WELL DIAM. (INCHES)	LITHOLOGY OF WATER BEARING MATERIAL (dimensions in feet below land surface)
7	LOPEZ ISLAND OBSERVATION WELL #3 LOPEZ, WA (WA ST DOE)	SAN JUAN	35N-2W-13	SHAW ISLAND WA 7.5'	90 (+\- 10)	-235 (+\- 10)	-235 (+\- 10)	325	O	Y	6	312 TO 317: BLACK ANGULAR - SUBANGULAR ROCK FRAGMENTS (PROBABLY BASALT) W/ SOME DARK GREY SAND AND SILT 317 TO 322: BLACK ANGULAR ROCK FRAGMENTS W/ SOME WHITE CARBONATE SECONDARY MINERALS. FRAGMENTS < 1/4 IN. & APPEAR SHALE LIKE (SOME ARE PHYLLITE) 322 TO 325: BLACK ROCK FRAGMENTS, VERY LIKELY BASALT.
8	ISLAND COUNTY OBSERVATION WELL #2 PIEZOMETER #1	ISLAND	33N-01E-26-D	OAK HARBOR WA 7.5~	130 (+/- 10)	-438 TO -506 (+/- 10)	-506 (+/- 10)	636	O	Y	2 TO 8	505 TO 580: CLAY & SILT W/ GRAVEL, W/ WOOD FRAGMENTS, COAL & SHELLS 580 TO 583: SAND W/ CLAY, WOOD & COAL FRAGMENTS 583 TO 600: FINE TO COARSE SAND W/ SOME GRAVEL & CLAY 600 TO 620: VERY FINE TO MEDIUM SAND W/ SOME GRAVEL & CLAY
9	ISLAND COUNTY OBSERVATION WELL #2 PIEZOMETER #2	ISLAND	33N-01E-26-D	OAK HARBOR WA 7.5'	130 (+/- 10)	-283 TO -341 (+/- 10)	-341 (+/- 10)	471	O	Y	2 TO 8	397 TO 430: CLAY & BLACK FOSSIL FRAGMENTS 430 TO 445: MEDIUM TO COARSE SAND. FOSSIL SHELL, WOOD, WATER @ 100 GPM 445 TO 460: FINE TO MEDIUM CLAY, SAND & GRAVEL. WATER @ 60 GPM 460 TO 480: MEDIUM TO COARSE SAND, FINE SAND & CLAY. WATER @ 60 GPM.

* WELL CODES: O = State owned observation well; R = Retired well but not abandoned;
C = Community water system; D = Single family domestic well.

TABLE 1

SWI SURVEY WELL CHARACHTERISTICS

SWI ID#	OWNER	COUNTY	T-R-S	USGS MAP (' = MIN)	LAND ELEV. (FEET)	ELEV. OF OPEN INTERVAL (FEET)	ELEV. OF WELL BOTTOM (FEET)	WELL DEPTH (FEET)	WELL CODE*	LOG (Y/N)	WELL DIAM. (INCHES)	LITHOLOGY OF WATER BEARING MATERIAL (dimensions in feet below land surface)
10	ISLAND COUNTY OBSERVATION WELL #5 PIEZOMETER #1	ISLAND	30N-03E-30-M	LANGLEY WA 7.5~	330 (+/- 10)	-575 TO -613 (+/- 10)	-613 (+/- 10)	943	O	Y	2 TO 8	905 TO 915: SILT & CLAY W/ FINE SAND & WOOD FRAGMENTS. 915 TO 923: CLAY, PLATY - FISILE FRAGMENTS W/ MINOR SHELL & WOOD FRAGMENTS. 923 TO 945: CLAY, SILTY W/ SAND & GRAVEL, WOOD FRAGMENTS. WOOD & GRAVEL FRAGMENTS INCREASE W/ DEPTH
11	ISLAND COUNTY OBSERVATION WELL #4 PIEZOMETER #2		31N-01E-11-H	COUPEVILLE WA 7.5~	190 (+/- 10)	-144 TO -198 (+/- 10)	-198 (+/- 10)	388	O	Y	2 TO 8	337 TO 345: GRAVEL, CLAY, COARSE TO FINE SAND, SHELL & SOME WOOD FRAGMENTS. METHANE GAS @ 340 345 TO 361: CLAY W/ FOSSIL SHELLS & WOOD FRAGMENTS. 361 TO 375: FINE TO MEDIUM SAND, SOME FOSSIL SHELL FRAGMENTS.

* WELL CODES: O = State owned observation well; R = Retired well but not abandoned;
C = Community water system; D = Single family domestic well.

SAMPLING PROCEDURE

We initially visited and collected one water sample each from seventeen wells. Six of these wells were later dropped from the survey because they either became unavailable for sampling or their chloride concentrations were too low to be included in this survey. The remaining eleven wells were sampled three or four times each using a progressively more refined sample-collection methodology. One of these wells (SWI #1) was selected for observation of changes in chloride concentrations during a tidal cycle.

Three sample collection methodologies were used for the survey. An outline of each is included below. Method 1 and Method 2 were used for the 17 wells in the main body of the survey. Method 3 was used for observing SWI #1 during the tidal cycle sampling period.

METHOD 1

Dedicated pump system (Owner's pump installed in well)
[SWI #2 - #5]

These systems were generally in use and usually it was not possible to pump large quantities of water before collecting a sample.

A) Calculate volume of water in casing
   1) Measure depth to static water level (SWL) with an electrical sensor and graduated cable (E-Tape)
   2) If water level cannot be measured review any preexisting records of water levels
   3) Note total well depth from driller's log or owner's report
   4) Measure inside diameter of well casing with an engineering tape
   5) Obtain volume per foot of casing from pipe-volume tables
   6) Calculate the volume of water in casing:

   $$\text{Volume} = (X - Y) \times P$$

   where:

   X = total depth
   Y = static water level
   P = volume/foot value for a given pipe diameter

B) If the system is in use and unavailable for extended pumping allow the discharge lines to be flushed (approximately ten minutes of pumping) and collect a one gallon sample at this time. If system is available for extended pumping proceed as in step (C) below.

C) Start pump and record time.
D) Obtain flow rate by measuring time required to fill container of known volume. Express flow rate in gallons per minute (GPM)
E) Every 20-30 minutes re-check flow rate and record field parameter values (temperature and specific conductivity) using field meter.
F) Maintain a continuous log of time, cumulative volume evacuated, and field parameters. Express the pumped volume in terms of percentage of well casings. Pump the greatest volume of water that time permits (up to three casing volumes) and as a minimum allow field parameters to stabilize (field meter values vary less than +/- 10% over four consecutive readings)*.
G) Collect a one gallon sample, record time, and raise pump.
H) Measure the water level as in step (A)1 above.

* NOTE: Convention calls for the removal of three consecutive casing volumes before the well may be presumed to have been adequately flushed for representative sampling of the aquifer. In most cases under both Method 1 and Method 2 neither time nor resources were sufficient to allow us to follow this convention (the Ecology deep well sampling pump has a flow rate between 0.5 GPM and 1 GPM). Therefore, because of the conservative nature of chloride values, stabilization of the field parameters was treated as an indicator that the pumped water was representative of the aquifer. One of the field parameter drift records has been included in Appendix B as an example.

METHOD 2

Portable Sampling Pump
[SWI #1,#6-#11]

A) Test equipment prior to leaving for the field.
B) Calculate volume of water in well casing as in Method 1, step (A).
C) Lower pump to depth of open interval or as close as possible. Record depth.
D) Start pump and record time.
E) The Ecology sampling pump (Bennet Pump) has a slow and varying flow rate. Collect water in a ten gallon bucket to measure pumped volume.
F) Record time, cumulative volume, and field parameters for every ten gallons.
G) When sampling wells with small diameter casings the pump may become lodged during lowering. Sometimes surging by the operating pump dislodges the pump and it can be lowered deeper. Any changes in pump depth should be recorded, and a new record of field parameters started.
H) Pump the greatest possible volume of water that time permits (up to three casing volumes), and as a minimum allow field parameters to stabilize (field meter values vary less than +/- 10% over four consecutive readings).
I) Collect a one gallon sample, and raise pump.
J) Measure the water level as in Method 1, step (A)1.

METHOD 3

Tidal cycle observation well

A) Arrive on site and set up equipment.
B) Record static water level with an "E-tape".
B) Purge well casing to depth of pump.
C) Allow water level to recover to near static water level (within two feet) as recorded above.
D) Repeat step (B).
E) Commence an hourly sample collection regiment as follows:
   1) Draw down water level to approximately the depth of the pump (approximately 30 minutes of pumping).
   2) Collect a one gallon sample.
   3) Shut off pump and allow water level to recover (approximately 30 minutes).
   4) Repeat this process for the necessary number of hours to cover a complete tidal cycle (in this case eleven hours).
F) At end of sampling period remove pump and clean-up.

EQUIPMENT USED

1) The field parameters (temperature and specific conductivity) were measured using a Yellow Springs Instrument (YSI) Model TLC - 3000 field meter.
2) Water level readings were taken using an Olympic Well Probe by Actat Corp. (commonly referred to as an "E-Tape").
3) The water samples under Method 2 were collected with a Bennett deep well sampling pump (Pump Model 1800-6, Reel Model RPD 105, Tube Bundle Model P-4).
4) The water samples under Method 3 were collected using a Flint and Walling submersible pump (model #4F05B03).
5) The sample collection bottles used were 1 gallon, Hedwin #7 containers.

LABORATORY PROCEDURE

The water samples were tested for chlorides, total hardness, pH, and specific conductivity using a small laboratory assembled at the Ecology Water Resources Program Office. We used electrical bench top meters and HACH Company test kits and followed the laboratory methods outlined below.

Chlorides

Initially two methods were used to analyze the samples for chloride concentration. The first was digital titration using the HACH Company's Mohr Argentometric Method (adapted from Standard Methods for the Examination of Water and Wastewater). The results by this method were not reproducible for us and we abandoned the method at an early stage after repeated attempts to determine the sources of error. The second method was also a version of the Mohr titration but used the HACH Company test kit Model 7-P for chloride. This second method uses silver nitrate in the titration with potassium chromate as the color change indicator (adapted from Standard Methods for the Examination of Water and Wastewater).

Both the above methods use the same general principle. A reagent is incrementally added to the sample until all the chloride is precipitated as silver chloride and the excess reagent causes a color change from yellow to reddish brown.

The test kit specifies a high-range procedure for samples with chloride concentrations falling in the 250 to 1000 mg/L range. We followed this high-range procedure except for samples exceeding 1000 mg/L chloride. Samples with chloride concentrations greater than 1000 mg/L require a large quantity of reagent to drive the color change. Therefore these samples were diluted by a ratio of 10:1 and the results multiplied by a factor of ten to compensate for the effect of dilution.

Total Hardness

Total hardness testing was done using the HACH Company test kit, Model HA-4P. This is another titration test with an indicator color change. As in the chloride test, we diluted the high range total hardness samples by a ratio of 10:1 and multiplied the results by ten.

We prepared a single 1:10 dilution from each well sample because the samples requiring a dilution for the total hardness test usually required a dilution for the chloride test. This dilution was mixed from 45 milliliters of deionized water and 5 milliliters of well water. Each of the sample volumes needed for the chloride and total hardness tests were then drawn from this single solution.

pH

Measurements of pH were done in the Water Resources Laboratory using the Presto-Tek Corporation multi-parameter instrument, model DP-36. For these measurements a probe is inserted into the sample and values are allowed to stabilize (approximately five minutes). For efficiency, we placed the pH probe in the sample while performing other tests. The pH meter was calibrated with a pH standard solution at the beginning and end of each laboratory session. The standard had a pH value of 10, which falls within two pH units of the majority of samples (manufacturer recommended calibration method). The pH values of ground water removed from an aquifer are known to change over time because of the transition in pressure going from an aquifer to the atmosphere. This pressure change affects the amount of carbon dioxide suspended in the water and the net effect is a change in the pH. Therefore, the pH values taken in the field will be slightly different from those actually occuring in the aquifer.

Specific Conductivity

We measured the specific conductivity of the samples with a Yellow Springs Instrument, YSI Model 33 conductivity meter. The meter is preadjusted by the manufacturer and can not be user calibrated. A reading is taken by inserting the meter's platinum probe into a sample and allowing the meter to stabilize (approximately thirty seconds).

Quality Control on Chloride Analyses

As a check on the chloride laboratory analyses done at the Water Resources Program Office duplicates of eleven samples were sent to the Ecology Manchester Laboratory for a second chloride test. The Manchester laboratory method is based on ion-chromotography. There was a significant disparity in the values obtained from the two laboratories. Concentrations obtained in the Water Resources Program laboratory were consistently higher than those obtained in the Manchester laboratory .

- 58% of the duplicate samples had differences less than or equal to 28%
- All but one of the duplicate samples had differences less than 49%

There appears to be a trend toward closer agreement in values with higher concentrations in chlorides. The compared data points are included in Appendix A.

Laboratory Analysis Suggestions

While completing our laboratory analysis we found the following steps to be helpful and suggest their use in future work of this kind.

1) Titration tests (chloride and total hardness)
   - When delivering drops from the eye dropper hold the dropper in a vertical position to maintain uniformity of drop size
   - Interpretation of what constitutes excess reagent as a color change involves an element of operator subjectivity. The use of color standards in spare bottles as references for color changes is recommended.
   - The degree of accuracy in these tests is limited by the titrant drop size and multiplication factors. For the chloride test each drop equals 30 milligrams/liter (mg/L). When a sample is diluted by a factor of 10 the value of each drop is equal to 300 mg/L. Similarly for the total hardness test each drop equals 17.1 and when used for samples diluted 10 to 1 it equals 171 mg/L. Therefore if it is desired to observe changes less than these amounts more sensitive laboratory methods must be used.
2) To reduce chances of operator error the following two steps are recommended:
   a) Complete all laboratory tests for a given well sample in a single, uninterrupted session, and
   b) Interrupt repetitive laboratory work with a break every two hours to reduce operator fatigue and the chance for error.
3) In light of our experience with the cross-check on chloride analyses from two different laboratories we recommend that any future monitoring program aimed specifically at charting small change in chlorides over space and/or time use a laboratory analysis methodology of known variability.

DATA

We selected eleven wells and sampled them three or four times during the survey*. Table 2 lists the data collected from these eleven wells and shows that the chloride values ranged from 225 mg/l to 4,500 mg/l and specific conductance ranged from 265 umhos/cm to 8,000 uhmos/cm. Figure 2 shows the range in chloride values per well, over the six month sampling period. We plotted the range of chloride values rather than each value as a discrete point because we did not know how much of the variability was due to unknowns in the laboratory technique and how much was due to changes in water quality. Six additional wells were sampled once each during the initial search for suitable survey wells. These wells were later dropped from the survey but their chloride values were included in Table 3*.

Previous records of water level changes for SWI #1 appeared to correlate with tidal fluctuations (field notes on Mile's well 1987-88, A. Wald, Ecology hydrogeologist). We sampled this well over the course of a tidal cycle and analyzed the samples for changes in chloride concentrations and specific conductance. We have noted that this non-agreement in trends is contrary to that normally found between these two values - no attempt has been made to explain its occurrence in this situation. Table 4 lists these values which ranged from 2400 mg/l to 2700 mg/l chloride. Figure 3 is a graph of the chloride and specific conductance analyses and shows that conductivity values increased from 1,000 umhos/cm to 2,800 uhmos/cm while the chloride values remained relatively constant. Figure 4 graphs the approximate eight foot change in the tidal elevation for the sampling period. The data did not show a variation in chloride that was in phase with the ocean tide for this well.

* NOTE: See section on well selection for more detail.

TABLE 2
DATA COLLECTED FOR SWI SURVEY WELLS

SWI Well I.D.#	Sampling Date	Water Level	Well Volume (WV)	Gallons Pumped	% of WV purged	Chloride (mg/L)	Spec.Con.(umhos)	pH	Tot.Hard.(mg/L)
01a	6-1-88	39.5 ft.	90 gallons	90	100%	2700	--	8.7	--
01b	8-1-88	39.7 ft.	90 gallons	84	93%	3300	2100	7.8	3082
01c	10-13-88					2700	1000		
02a	6-16-88	--	179 gallons	50	15%	1950	2600	9.2	1171
02b	8-5-88	107 ft.	170 gallons	180	105%	2100	1900	8.0	1370
02c	9-23-88	100.7ft.	179 gallons	360	200%	2100	1400	8.0	1370
03a	6-16-88	64 ft. DL	390 gallons	5 *	1% *	900	850	8.0	863
03b	8-5-88	64 ft.	384 gallons	5 *	1% *	1125	1000	8.0	1198
03c	9-23-88	60.1ft.	390 gallons	5 *	1% *	1200	380	8.1	1198
04a	6-10-88	48 ft.	447 gallons	264	59%	225	265	8.8	--
04b	8-2-88	48.4ft.	445 gallons	650	146%	450	--	8.6	342
04c	9-22-88	48.6 ft.	444 gallons	2925	660%	450	165	8.6	342
05a	6-21-88	41 ft. DL	365 gallons	20	5%	2250	4300	8.8	223
05b	8-2-88	156 ft.	235 gallons	276	117%	2700	2200	8.1	342
05c	9-22-88	68.6 ft.	365 gallons	277	76%	2700	4400	8.5	514
06a	8-9-88	105 ft.	442.5 gallons	130	29%	4500	5000	8.5	856
06b	9-7-88	105.4 ft.	441.9 gallons	123	28%	4500	6000	8.2	856
06c	10-5-88	105.5 ft.	441.8 gallons	90	20%	4200	8000	8.9	856
06d	11-2-88	128 ft.	408 gallons	130	32%	1050	700	8.5	342
07a	8-9-88	99.5 ft.	338 gallons	101	30%	2250	4000	7.9	730
07b	9-7-88	105 ft.	330 gallons	107	32%	2100	4000	7.8	1027
07c	10-5-88	105.3 ft.	330 gallons	61	19%	2100	4700	8.9	1027
07d	11-2-88	84.6 ft.	361 gallons	160	44%	600	420	9.0	171
08a	8-10-88	149 ft.	75.3 gallons	73	97%	2250	3100	9.4	608
08b	9-8-88	147.1 ft.	74.9 gallons	73	97%	1950	3200	9.3	685
08c	10-6-88	153.9 ft.	76.1 gallons	87	114 %	2250	4550	9.3	1027
09a	8-10-88	311.5 ft.	270 gallons	72	27%	4350	5000	11.1	487
09b	9-8-88	313.8 ft.	270.3 gallons	73	27%	4350	5250	10.4	428
09c	10-5-88	312.4 ft.	270.1 gallons	41	15 %	3900	3300	9.8	514
10a	8-3-88	126.1 ft.	171 gallons	109	64%	1050	1500	8.7	342
10b	8-24-88	126.4 ft.	170.4 gallons	143	126%	900	1200	9.0	342
10c	9-29-88	126.3 ft.	170.5 gallons	121	71%	1200	1200	9.3	342
11a	8-4-88	84.8 ft.	160 gallons	160	100%	750	1000	9.4	171
11b	8-25-88	84.8 ft.	160 gallons	154	96%	600	850	9.6	171
11c	9-30-88	84.9 ft.	160 gallons	170	105%	600	900	9.2	171.2

SMBOLS KEY: DL = Driller's Log
* = System in use. Water levels are dynamic.
Letters "a-d" = separate samples and analyses

FIGURE 2
RANGE OF CHLORIDE VALUES
COLLECTED FROM SWI SURVEY WELLS

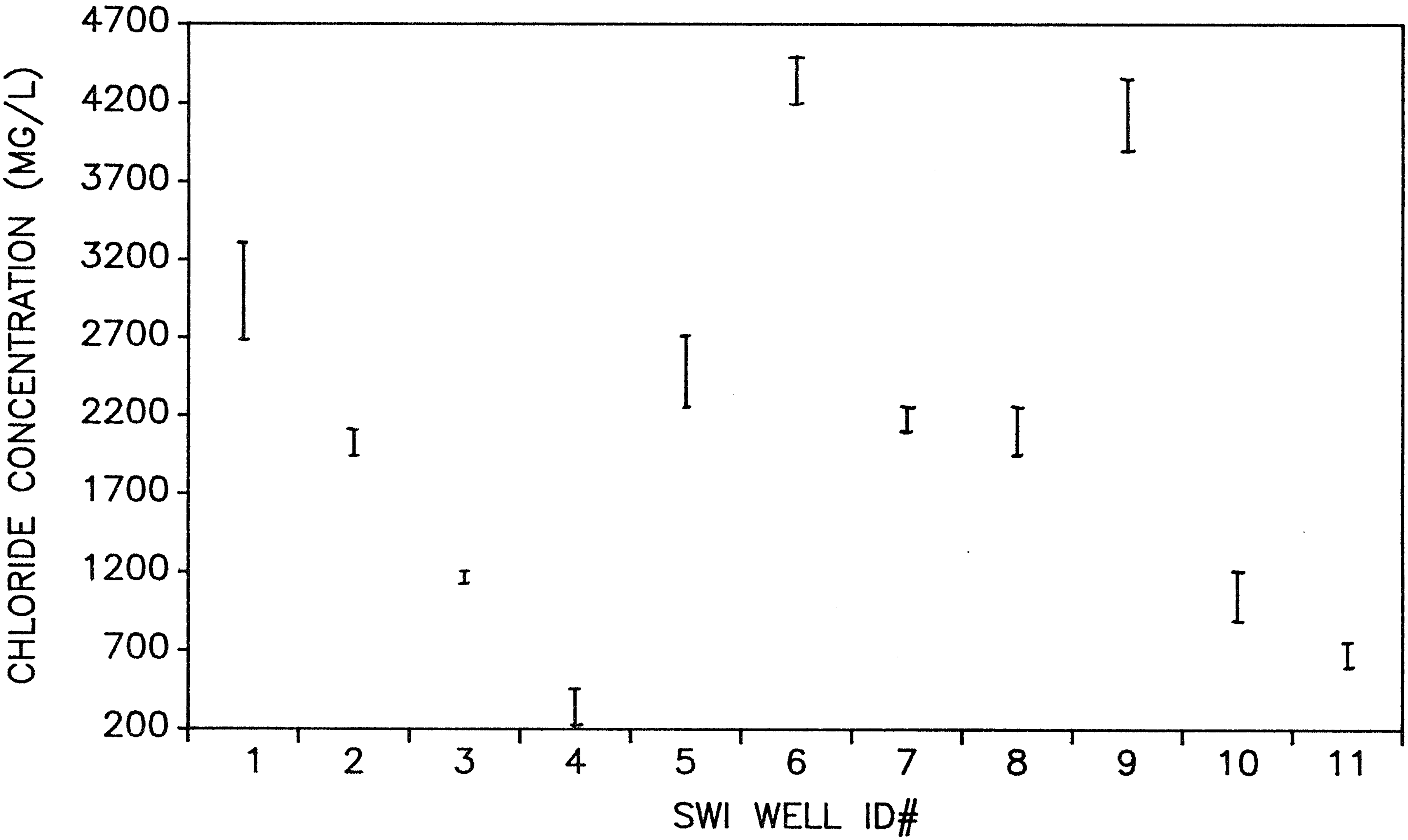


TABLE 3

CHARACTERISTICS FOR NON-SWI SURVEY WELLS

OWNER	COUNTY	T-R-S	LAND ELEV. (FEET)	ELEV. OF WELL BOTTOM (FEET)	WELL DEPTH (FEET)	WELL CODE*	WELL DIAM. (INCHES)	CHLORIDE (MG/L)
PT. ROBINSON COAST COAST GUARD STATION MAURY ISLAND	KING	22N-03E-23	91	-58	149	D	6	30
KIRO RADIO PORTAGE -ROBINSON RD MAURY, ISLAND	KING	22N-03-16	56	-406	462	D	6	30
WILLIAM HYDE 3006 HORSEHEAD BAY RD. ARLETTA, WA	PIERCE	21N-01E-28	100 (+/- 20)	-260 (+/- 20)	360	R	6	> 2000
MRS. PETERS 2822 115 ST, NW GIG HARBOR, WA	PIERCE	21N-01E-28	100 (+/- 20)	-----	-----	R	6	2075
DON KETCHEM 1085 13TH LANE FOX ISLAND, WA	PIERCE	----	----	----	~ 70 (OWNER)	D	6	500
JANELE & CLIFF DIESL 6485 E. HILLDALE RD	KITSAP	24N-02E-9	----	----	----	D	6	900

*WELL CODES: R = Retired well but not abandoned;
D = Single family domestic well

TABLE 4
DATA COLLECTED FROM A NEAR-SHORE WELL DURING A TIDAL CYCLE
SWI #1

SAMPLE DATA COLLECTION			TIDAL ACTIVITY	
TIME (10-13-88)	CHLORIDE (mg/L)	SPECIFIC CONDUCTIVITY (umhos)	TIME	HEIGHT
0.00	0.00	0.00	1:40	3.8
0.00	0.00	0.00	2:40	5.9
0.00	0.00	0.00	3:40	8.4
0.00	0.00	0.00	4:40	10.8
0.00	0.00	0.00	5:40	12.5
0.00	0.00	0.00	6:40	13.3
0.00	0.00	0.00	7:40	13.3
0.00	0.00	0.00	8:40	12.7
0.00	0.00	0.00	9:40	11.7
0.00	0.00	0.00	10:40	10.4
11:10	0.00	0.00	11:40	9.2
12:00	2700.00	1000.00	12:40	8.9
13:16	2700.00	1000.00	13:40	9.3
14:20	2400.00	1300.00	14:40	10.3
15:15	2400.00	1550.00	15:40	11.5
16:18	2400.00	1600.00	16:40	12.6
17:15	2400.00	1700.00	17:40	13.1
18:16	2400.00	1750.00	18:40	12.8
19:15	2550.00	2500.00	19:40	11.6
20:30	2400.00	2550.00	20:40	9.6
21:50	2400.00	2800.00	21:40	7.0
0.00	2400.00	2800.00	22:40	4.4
0.00	0.00	0.00	23:40	2.5
0.00	0.00	0.00	24:40	1.9

DATA CONVERTED FROM NOAA RECORD OF 10/13/88 SEATTLE TIDES
CORRECTION FACTOR FOR HEIGHT = +2.5 FT.
CORRECTION FOR TIME = +40 MINUTES (AVERAGED CORRECTION FOR HIGH & LOW TIDES)

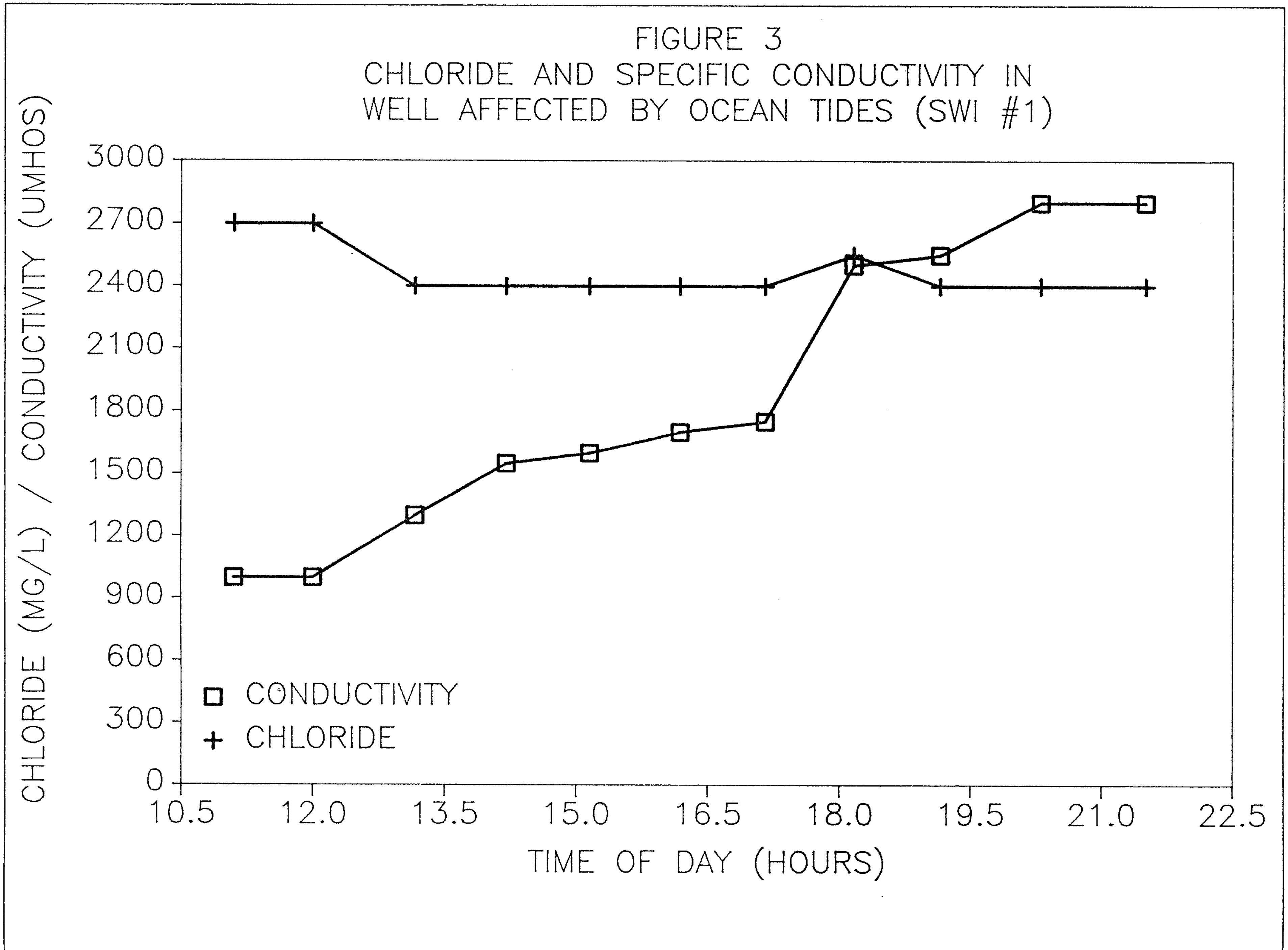
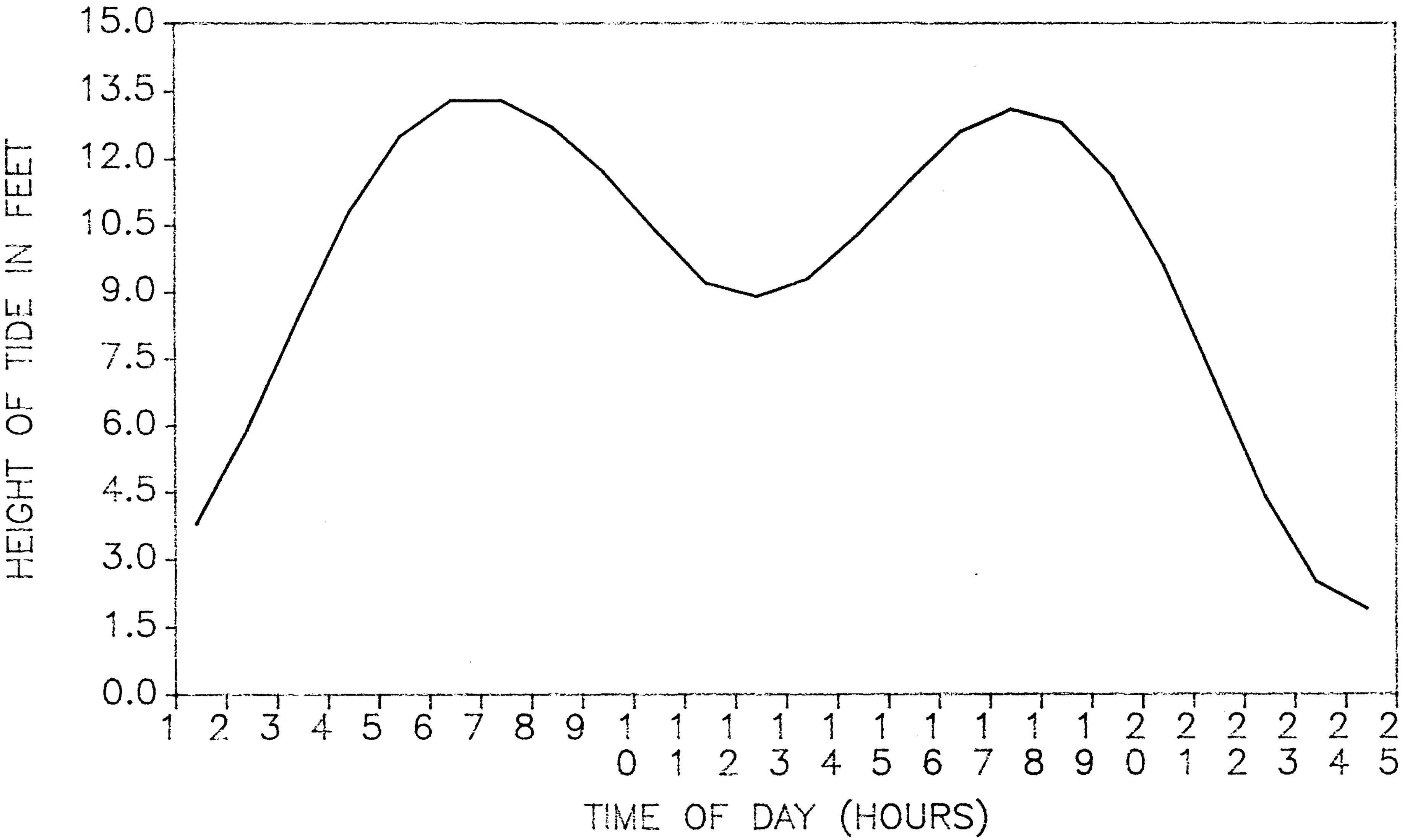


FIGURE 3
CHLORIDE AND SPECIFIC CONDUCTIVITY IN
WELL AFFECTED BY OCEAN TIDES (SWI #1)
CHLORIDE (MG/L) / CONDUCTIVITY (UMHOS)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
10.5
12.0
13.5
15.0
16.5
18.0
19.5
21.0
22.5
TIME OF DAY (HOURS)
CONDUCTIVITY
CHLORIDE

FIGURE 4
OCEAN TIDES FOR SHORELINE NEAR WELL
REPRESENTED IN FIGURE 3 (SWI #1)



DATA FROM 11–13–88 NOAA SEATTLE RECORD
CORRECTIONS FOR SOUTHERN PUGET SOUND:
HEIGHT = +2.5 FT; TIME = +40 MINUTES

SUGGESTIONS FOR FUTURE WORK

Future chloride monitoring

With the clear evidence of high chloride concentrations in study area groundwater it is recommended that additional data collection be done. Additional work ought to be broader in focus and monitor the extent and change of groundwater chlorides over space and time. Many additional geographic areas thought to be at risk to seawater intrusion could be included in such an expanded study. This increased information would broaden understanding of seawater intrusion and aid in the design of groundwater management plans. The planning for such a monitoring program should be guided by the SWI Project Team.

When conducting a monitoring program it is a good safeguard to maintain a large pool of study wells so that the disuse of one or more of the wells from a given area would not adversely affect the success of the study.

In selecting wells for a future monitoring program, it is advantageous to choose retired wells without dedicated pumps (not yet abandoned according to state code). These wells may be pumped without interrupting service to users.

Pumping methodology

The question below arose out of literature regarding pumping techniques used for collecting samples representative of aquifer water. Should pumping occur as the pump is lowered into a well casing, removing the topmost layer of water first, proceeding downward as the water level drops, or should the pump be lowered directly to the well bottom, well screen, or depth of greatest possible penetration and pumping commenced at this point?

In this study we found it appropriate to lower the pump to the greatest possible depth and then commence pumping. We maintained a record of the total pumped volume and the dynamic water level after removing the pump and this gave us confidence that our samples were drawn from the aquifer rather than from the well casing. Measurement of temperature and specific conductivity further verified that this pumping technique drew samples from the aquifer.

BIBLIOGRAPHY

1) Work Group 2 on Ground Water, 1980, National Handbook of Recommended Methods of Water Data Acquisition, reprinted by Washington State Department of Ecology, Water Resources Program.

2) Michael J. Barcelona et al.; A Guide to the Selection of Materials for Monitoring Well Construction and Ground Water Sampling; Illinois State Water Survey, 1983.

APPENDIX A

COMPARISON OF CHLORIDE CONCENTRATIONS DETERMINED BY TWO LABORATORIES

Chloride Concentrations In mg/L

SWI Survey Well I.D.#	Manchester Lab	Water Resources Lab	Percent Difference
1	2500	3300	27.5
2	1900	2100	10
3	730	1200	49
4	90	130	36
5	1900	2700	35
6	4400	4500	2.2
7	1700	2250	28
8	1700	2250	28
9	4200	4350	3.5
10	760	1050	32
11	360	750	70
Standard at 1000 mg/L	1100	1000	9.5

Formula used to calculate percent difference:

$$\frac{\text{Difference between the two laboratory results}}{\text{Average of the two laboratory results}}$$

C. Fromuth, S. Hirschey 9-7-88

Island County Test Hole #2
Piezometer #1

1:30 PM Arrival on site

SWL

	TC	198.6 ft.
	tape correction	-90.0 ft.
	TC > LS	- 3.2 ft
		105.4 ft

Volume

Total well depth	580 ft
SWL	- 105.4 ft
	474.6 ft

474.6 ft column of H_2O
x 0.163 gallon/ft for
77.4 gal 2" diameter casing

77.4 gal
+ 36.0 gal (test hole data)
113.4 g (total volume

Is. Co. Test Hole #2 9-7-88
Piezo #1 Page 2

Evacuation Record

1:44 pm Began pumping while lowering pump

2:09 PM 11 g
T = 16.6 °C
S.C. = 11.1 umhos/cm

Note: S.C. set @ 20mv/cm scale (3000 TLC meter)

2:22 PM 10 g
T = 16.0°C
S.C. = 11.061

2:32 PM 10 g
T = 15.5° C
S.C. = 11.0

2:43 PM 10 g
T = 15.9° C
S.C. = 11.05

Is. Co. Test Hole #2 9-7-88
Piezo #1 page 3

2:54 pm 10 g
T = 16.2°C
S.C. = 11.22

3:05 10 g
T = 16.2°C
S.C. = 11.24

3:16 11 g
T = 16.2°C
S.C. = 11.4

3:28 10 g
T = 16.6°C
S.C. = 11.4

3:43
T = 16.2°C 10 g
S.C. = 11.3

3:53 10 g
T = 16.1°C
S.C. = 11.3

Is. Co. Test Hole #2 9-7-88
Piezo #1 Page 4

4:04 10 g
T = 16.1°C
S.C. = 11.27

4:16 pm 11 g
Removed pump

Dynamic H_2O level

TC	205.8 ft
tape correction	-90.0 ft
TC > LS	- 3.2 ft
	112.6 ft

Total volume pumped
= 123 g
= 108 gal Storage Volume

KEY OF SYMBOLS FOR APPENDIX B

TC	=	top of well casing
TC > LS	=	height of TC above land surface
SWL	=	static water level below land surface
SC	=	specific conductivity (all units in umhos/cm)
umhos/cm	=	micro-mohs / centimeter
Tape correction	=	the correction factor (in length) for a given electric water level measurement tape