Reconnaissance Hydrogeology and Water Quality of the Swinomish Indian Reservation, Skagit County, Washington

By S. S. Embrey and J. L. Jones

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
	259.9	hectare
gallon (gal)	0.003785	cubic meter
acre	0.4047	hectare
	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic yard (yd^3)	0.7647	cubic meter

degree Celsius (°C) to degree Fahrenheit (°F): $°F = 9/5\ °C + 32$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Data were collected during 1990-91 from five wells in the north-central part of the Swinomish Indian Reservation, two of which are Swinomish Tribal Community wells, to describe the hydraulic characteristics and the extent of a newly found, coarse-grained aquifer that exists near sea level. This aquifer, called the sea-level aquifer, is confined and had water levels during the study period that were about 20 to 80 feet above the top of the aquifer. At the Tribal well field, the sea-level aquifer is 10 to 20 feet thick and extends at least one-half mile to the northwest and to the south. Median normalized specific capacity for the sea-level aquifer was 0.60 gallons per minute per foot of drawdown per foot of open interval. Gross estimated hydraulic conductivity for the sea-level aquifer ranged from 28 to 580 feet per day; gross estimated transmissivity ranged from 560 to 9,000 square feet per day. Withdrawals from the sea-level aquifer provided about 40 percent of the average 1991 withdrawal from the ground-water reservoir.

In general, water from the sea-level aquifer in the vicinity of the Tribal well field was hard and low in dissolved oxygen. Concentrations of trace elements and nitrate were commonly less than analytical reporting limits. Iron concentrations in water samples from three of the five wells and manganese concentrations in samples from all five wells exceeded U.S. Environmental Protection Agency's secondary maximum contaminant levels recommended for drinking water.

Water samples from ground-water seeps about 800 feet east of an inactive petroleum waste-disposal site did not contain detectable amounts of selected volatile organic compounds. On the basis of the chemistry of the samples, the seeps appeared to contain water with a relatively short residence time in the ground.

INTRODUCTION

During 1975-76, the U.S. Geological Survey (USGS) investigated the ground-water resources of the Swinomish Indian Reservation to (1) describe the hydrologic system on the Reservation, (2) provide information needed for long-range water conservation planning, and (3) aid the Swinomish Indian Tribe (the Tribe) in making management decisions regarding future development on the Reservation. That investigation (Drost, 1979) documented the existence of three major hydrogeologic units that contain productive aquifers in the upper 200 to 300 feet of a thick assemblage of unconsolidated sediments beneath the Reservation. These three units are an uppermost till unit, a middle unit of outwash, and a lower clay unit. At the time of the USGS investigation, all wells were completed in aquifers within one of these three units, and no well went completely through the clay unit. In the summary of the study, Drost (1979) reasoned that a coarse-grained layer might underlie the lower clay unit. During 1986-89, two of the Tribe's public-supply wells and three private domestic wells were drilled in the north-central part of the Reservation to depths greater than the clay unit, and a coarse-grained aquifer was indeed found at about 250 feet below land surface, or approximately at sea level. In this report the newly found aquifer is referred to as the sea-level aquifer.

In about 1981, an inactive waste-disposal site was discovered about a mile northeast of the Tribe's well field. The Tribe determined that the site had been used from 1961 to 1970 for the disposal of petroleum refinery wastes. A 1986 investigation by a private consultant to the Tribe found that soils at the waste-disposal site still contained polycyclic aromatic hydrocarbons, aliphatic hydrocarbons, and volatile organic compounds. The possibility of contamination of the three shallow aquifers and the deeper sea-level aquifer by the waste site was unknown.

In August 1990, the USGS began a second study for the Swinomish Indian Tribe. The objectives of the study were to describe, to the extent possible using limited information, the hydrogeologic characteristics of the sea-level aquifer and to assess any hazard to ground-water quality posed by the waste-disposal site.

Purpose

The purpose of this report, which is based on the results of a reconnaissance study, is to:

(1) update previous information about the shallow aquifers of the Swinomish Indian Reservation with newly collected data;

(2) determine ground-water flow directions in the sea-level aquifer;

(3) estimate the hydraulic characteristics of all aquifers beneath the Reservation;

(4) estimate present (1990-91) ground-water withdrawals from all aquifers; and

(5) assess the likely hazard to ground-water resources, especially near the Tribe's well field, from the refinery waste-disposal site.

Description of the Study Area

The study area is the Swinomish Indian Reservation. The Reservation is part of Fidalgo Island in northwestern Washington, about 50 miles north of Seattle (fig. 1) and covers about 17 square miles (mi^2). The study area can be considered a separate island because it is connected to the remainder of Fidalgo Island by only a small, low-lying landmass. As such, it has an independent hydrologic system (Drost, 1979). A north-south trending remnant of glacial drift forms the study area island. The land surface is composed mostly of till and ranges in altitude from sea level to about 330 feet above sea level.

The study area has a maritime climate with warm, dry summers and cool, wet winters. It is protected from severe coastal winter storms by the Olympic Mountains to the west and from cold continental air by the Cascade Range to the east. Prevailing southwesterly and northwesterly winds from October through April bring precipitation that falls mostly as rain. Long-term precipitation records are maintained at Anacortes, about 10 miles northwest of the Reservation. For the 30-year period 1951-80, average annual precipitation at Anacortes was 26 inches (National Oceanic and Atmospheric Administration, 1982). The average monthly precipitation at Anacortes ranges from about 1 inch in July to about 4 inches in December.

The population of the Reservation in 1976 was about 1,750, of which about 400 were members of the Swinomish and other tribes. Most of the population resided along the western shoreline of the Reservation and near Shelter Bay. The population in 1991 was about 2,500, of which about 400 were registered members of the Swinomish Indian Tribe (John Petrich, Swinomish Utility Authority, oral commun., August 1991). The 1991 population distribution was similar to that of 1976.

Well-Numbering System

The well-numbering system used by the USGS in the State of Washington is based on a rectangular division of land that indicates township, range, section, and 40-acre tract within the section. For example, in well number 34N/02E-15R03, the characters preceding the hyphen indicate the township (T 34N) and range (R 2E) north and east of the base line and Willamette Meridian, respectively. Because all townships mentioned in this report are north of the base line and east of the Willamette Meridian, the letters "N" and "E" are omitted in the text. The first number following the hyphen (15) indicates the section and the letter (R) designates the 40-acre tract within that section (fig. 2). The last number (03) is the serial number of the well and indicates that this is the third well inventoried in that 40-acre tract by USGS personnel. In this report, all leading zeroes are omitted from the numbers, and in the figures, only the 40-acre tract designation and sequence number are shown. Thus, well 34N/02E-15R03 is referred to in the text as 34/2-15R3 and is shown in the figures as R3.

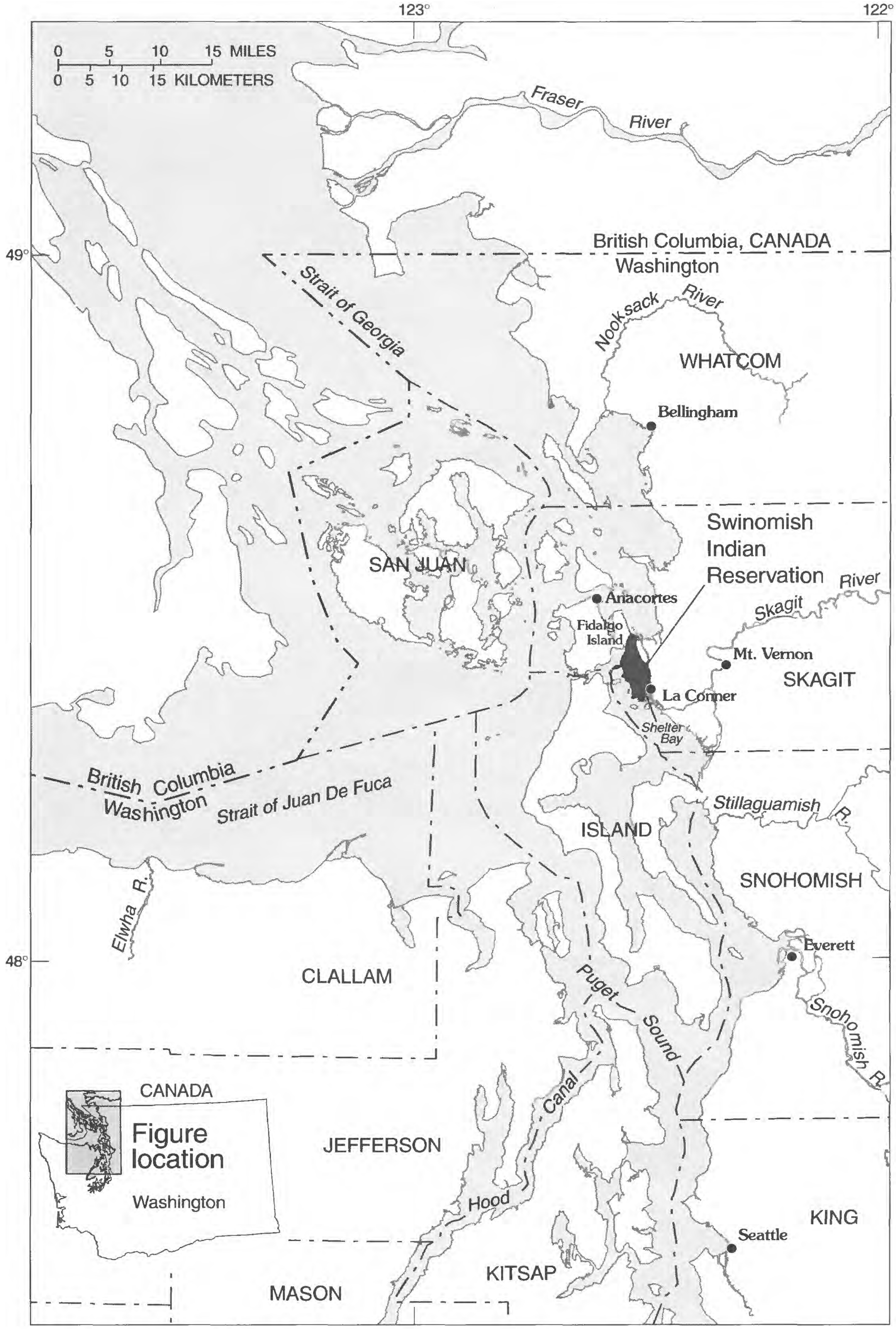

Figure 1. Location of the study area, Skagit County, Washington.

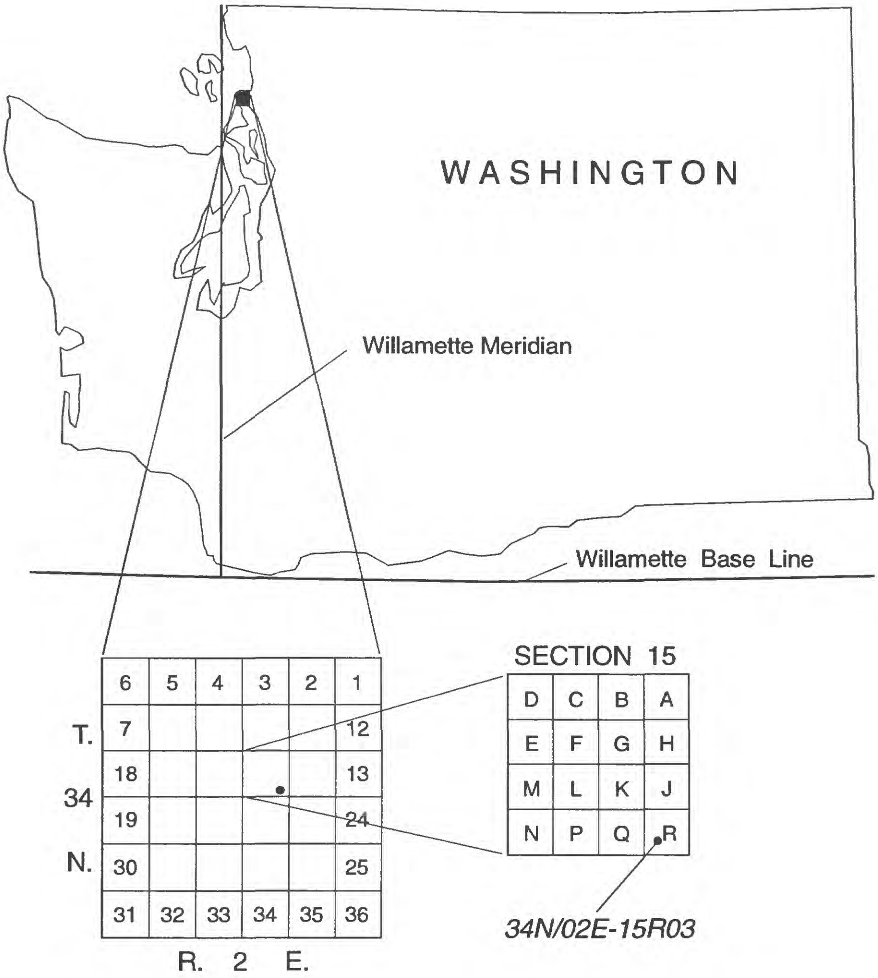

Figure 2. Well-numbering system used by the U.S. Geological Survey in the State of Washington.

Methods

Ground-water data collection consisted of an inventory of wells in 1990 and the verification of their locations as given in drillers' reports. The inventory included all wells believed to tap the sea-level aquifer and those wells drilled into the shallow units since the 1975-76 study. Where possible, static water levels were measured in the inventoried wells. Selected well data collected during the 1990 inventory are listed in appendix A. Drillers' reports also were used to determine the method of well construction, the aquifer to which a well was open, and the hydrologic characteristics of that aquifer. Five wells open to the sea-level aquifer and 48 wells finished in the shallow units were inventoried. Plate 1A shows the locations of wells inventoried by Drost (1979) and the additional wells inventoried as part of this study.

The hydraulic characteristics of the principal aquifers were assessed by calculating the specific capacity of individual wells. For this report, the specific capacity value, expressed in units of gallons per minute per foot of drawdown, was adjusted by dividing it by the length of well that is open to the aquifer. For the sea-level aquifer only, gross estimates of transmissivity and conductivity were based on information made available to the Tribe by the driller of the two wells in the Tribe's well field. The methods and procedures used to estimate these hydraulic characteristics are described in greater detail in the section dealing with the hydraulic characteristics of the sea-level aquifer.

In May 1991, samples for water-quality analyses were collected from the five wells finished in the sea-level aquifer and from two seeps that originate near the waste-disposal site. Field measurements of pH, specific conductance, temperature, dissolved-oxygen concentration, and alkalinity were made on all samples from the wells and seeps. All the samples were analyzed for concentrations of nitrite-plus-nitrate nitrogen (referred to as nitrate in this report), dissolved organic carbon, major ions, dissolved iron, dissolved manganese, and dissolved trace elements. In addition, samples from the seeps were analyzed for a number of volatile organic compounds. Standard USGS sampling methods (Sylvester and others, U.S. Geological Survey, written commun., September 1990) were used for this study, except at the seeps, where water was hand-dipped because of the small size of the seeps. After collection, all the samples were treated and preserved according to standard USGS procedures outlined in Sylvester and others (U.S. Geological Survey, written commun., September 1990), and Pritt and Jones (1989). All laboratory analyses were done at the USGS's National Water Quality Laboratory (NWQL) in Arvada, Colo. Analytical procedures used by the NWQL are described by Fishman and Friedman (1985) and Wershaw and others (1987).

On-site determinations of pH, specific conductance, dissolved-oxygen concentration, and temperature followed the procedures described by Wood (1976). Dissolved-oxygen concentrations were monitored with a meter; concentrations less than 1.0 mg/L (milligram per liter) were verified in the field using the Winkler titration method (American Public Health Association and others, 1989; Wood, 1976). On-site determinations of bicarbonate and carbonate concentrations (for assessing alkalinity) followed the incremental titration method described by Sylvester and others (U.S. Geological Survey, written commun., September 1990).

Ground-water samples collected from a distribution system were obtained from a faucet as close to the wellhead as possible. If feasible, samples were collected from a faucet ahead of any holding or pressure tank in the system. All samples were collected from a point before any water treatment such as chlorination, fluoridation, or softening. Sample water was fed from the faucet through nylon tubing to a stainless-steel flow-directing manifold mounted in the field vehicle, and then into a flow chamber. In the flow chamber, pH, temperature, specific conductance, and dissolved-oxygen concentration were monitored continuously. When readings were constant for 10 minutes, whole-water and filtered samples were collected. This procedure generally resulted in the well being pumped continuously for 15 to 45 minutes, depending on the individual well yield.

Water from a seep was dipped by hand with a 250-milliliter bottle and was composited in a churn splitter. Subsamples were taken from the churn splitter for whole-water analyses, and the remaining volume was filtered for the dissolved-constituent analyses. The vials for the volatile organic compounds were held in the seep flow and allowed to overfill by several volumes, then capped without air entrapment (Wershaw and others, 1987).

HYDROGEOLOGIC FRAMEWORK

The Swinomish Indian Reservation is underlain by as much as 900 feet of unconsolidated glacial and interglacial deposits of Quaternary age. The bedrock, which crops out near the edge of Fidalgo Island, is predominantly sedimentary and metamorphic rocks (Drost, 1979) of Tertiary age. Drost (1979) described the three major units of unconsolidated material known at that time, from youngest to oldest, as till, stratified drift, and clay. This description was based on field reconnaissance, drillers' logs, and seismic profiles. Since 1979, two deep wells owned by the Tribe and three deep domestic wells have been drilled into a layer of coarse deposit composed mostly of sand and gravel underlying the clay unit at an altitude near or below sea level. This layer, referred to as the sea-level aquifer in this study, is confined above and below by clay.

Because Puget Sound Quaternary deposits are difficult to identify in the subsurface, regional correlations among hydrogeologic units are not well established. The geologic units (excluding bedrock) observed in the vicinity of the Tribe's new wells are divided hydrogeologically, for the purposes of this report, into coarse-grained aquifers and fine-grained confining units, and correspond, for the most part, to the designations in Drost (1979). However, the unit referred to as stratified drift by Drost (1979) is primarily advance outwash and is referred to simply as outwash in this report. The coarse-grained units (aquifers) are believed to represent outwash deposited during glacial advances or coarse alluvium deposited during interglacial periods. The confining units are chiefly fine grained and are believed to represent lake deposits or, in places, till (Dion and others, 1988). The lithologic characteristics of the principal hydrogeologic units in the study area are presented in table 1. A generalized map of surficial geology (modified from M. A. Jones, U.S. Geological Survey, written commun., 1991, and Pessl and others, 1989) is presented in figure 3. This map shows the geographic distribution of all geologic units observed in the study area, including the principal hydrogeologic units described previously. Figure 4 (section A-A') shows the likely relations at depth among the sea-level aquifer, clay, outwash, and till. The orientation of section A-A' is shown on figure 3.

The sea-level aquifer most likely lies near the top of unit Qns (see fig. 4) but below the clay unit described by Drost (1979). The aquifer is underlain by clay and silt that extends to an unknown depth and is probably also part of unit Qns. There are several hundred feet of unconsolidated deposits between the sea-level aquifer and the bedrock. Although these deposits have not been identified in detail, they probably consist of clays, silts, sands, and gravels of both glacial and non-glacial origin. At the Tribe's well field, the layer of coarse sand and gravel that composes the sea-level aquifer is from 10 to 20 feet thick and extends out from the well field at least one-half mile to the northwest and to the south.

Table 1.--*Principal hydrogeologic units in the study area*
[--, no designation or data]

Symbol (as shown on figure 3)	Hydrogeologic unit	Lithologic characteristics
Qvt	till	Varying composition, mostly poorly sorted, compacted clay and silt.
Qva	outwash	Well-sorted sand and gravel.
Qns	clay	Interbedded clay and silt with local lenses of sand and gravel.
--[1]	sea-level aquifer	Gravel and sand; unit occurs near or below sea level.
--[1]	--	Several hundred feet of unconsolidated clay, silt, sand, and gravel.
Tb	bedrock	Consolidated sedimentary and metamorphic rocks.

[1] Unknown; possibly a continuation of Qns.

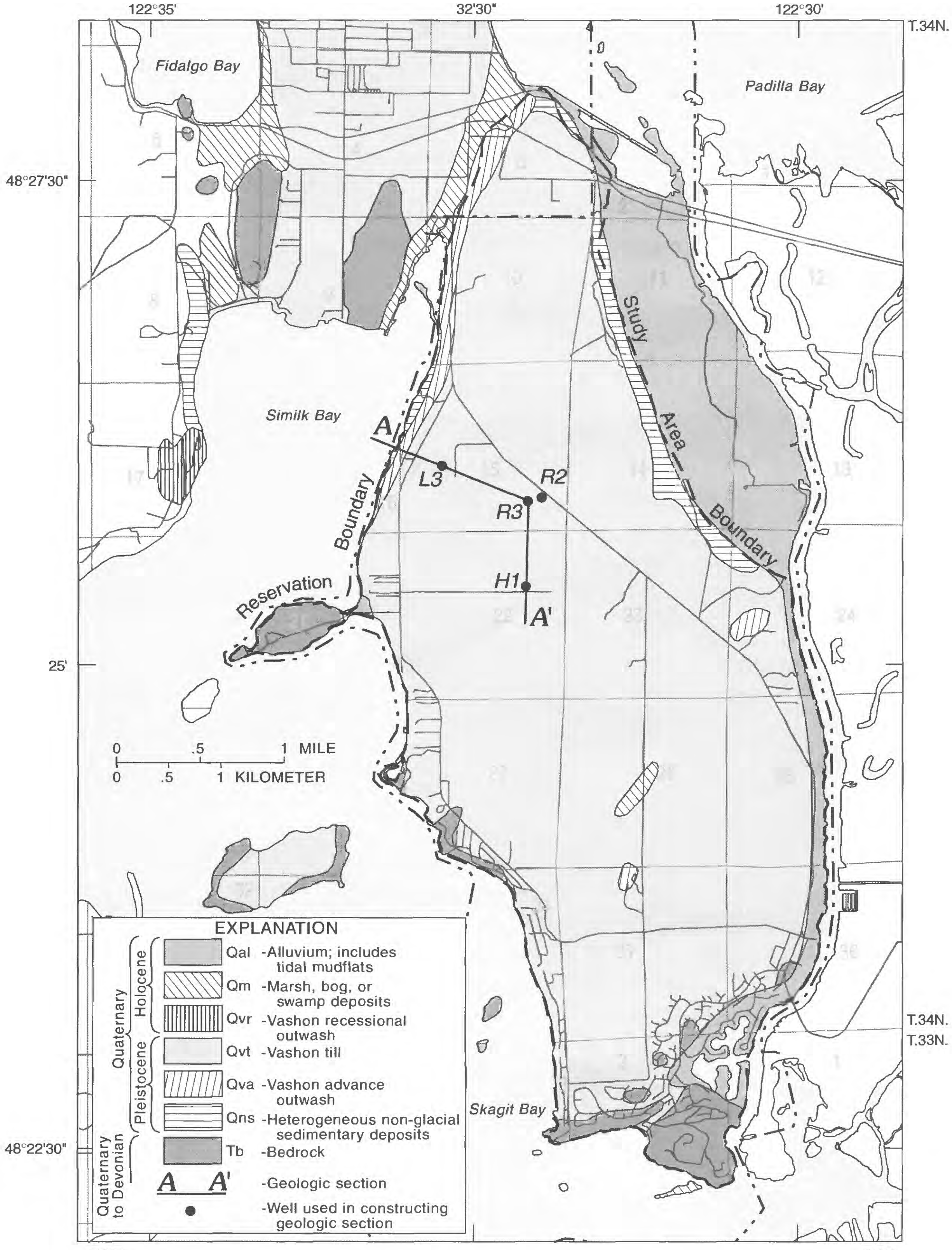

Figure 3. Generalized surficial geology of the Swinomish Indian Reservation, Skagit County, Washington, and location of geologic section A-A' (modified from M.A. Jones, U.S. Geological Survey, written communication, 1991; and Pessl and others, 1989).

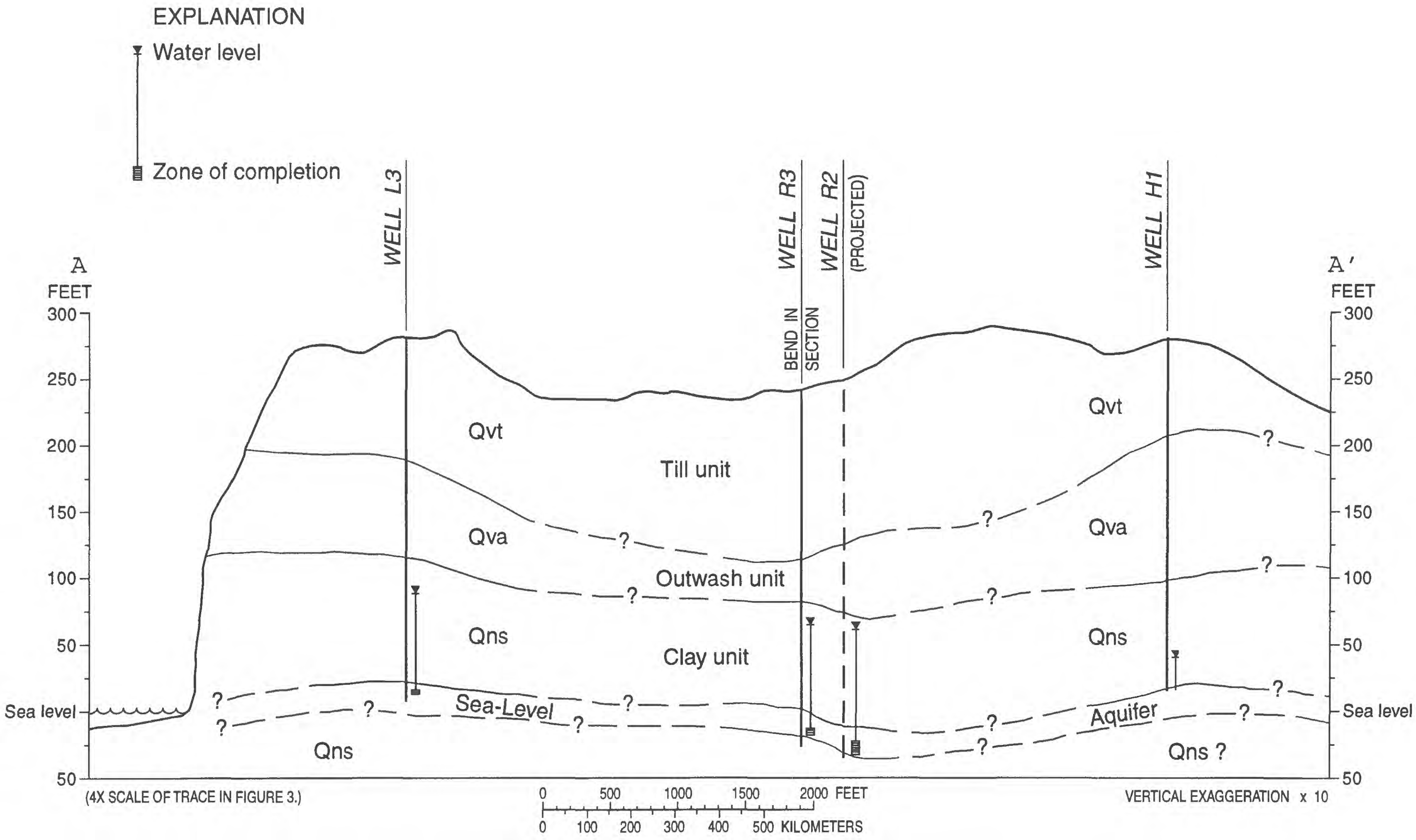

Figure 4. Geologic section A-A' showing likely relations at depth among hydrogeologic units in the north-central part of the Swinomish Indian Reservation.

The clay unit that overlies the sea-level aquifer is composed almost entirely of clay and silt of non-glacial origin, but it also contains some layers of fine sand, sand and gravel, and peat-like material. The clay unit is as much as 100 feet thick where it crops out at the northern end of the island; in the vicinity of the Tribe's well it is about 90 feet thick.

The outwash unit (Qva) that overlies the clay unit was deposited from glacial meltwater streams during a glacial advance. It is composed of moderately to well-sorted, stratified sand and gravel, with some layers of clay and silt and a few lenses of till. The outwash is thickest near the center of the Reservation where it is about 170 feet thick (Drost, 1979). Away from the center of the Reservation and along the western shoreline, the outwash is thin or absent.

The uppermost of the hydrogeologic units is the till unit (Qvt). It covers nearly all of the Reservation in a layer only a few feet thick in places to more than 150 feet thick along the western shoreline (Drost, 1979). The till is a compact, poorly sorted material ranging in composition and size from clay to boulders. The till also contains lenses of stratified sand and gravel and of clay and silt.

RECONNAISSANCE HYDROGEOLOGY

The till, outwash, and clay units and the sea-level aquifer are all used as sources of ground water on the Swinomish Indian Reservation; the bedrock is not known to yield important amounts of water to wells. Most wells inventoried in the study area are completed in the till and outwash units (plate 1B). At the time of Drost's study (1975-76), the outwash was the most productive of the three known units. However, the till was the principal source of water along the more densely populated western part of the study area. In this report, the till, outwash, and clay units are referred to collectively as the shallow ground-water system. This system is described at length in the report by Drost (1979) and the reader is referred to that report for additional or background information.

Ground-Water Conditions

Water-table conditions exist in much of the island's shallow ground-water system (Drost, 1979). In general, ground water moves downward in the center of the island, radially outward, and then upward along the coastline to discharge into adjacent salt-water bays and sea-level marshes and mudflats. Because of this flow pattern, inland wells that are open to deeper parts of the aquifer system have water levels with lower altitudes than wells open to shallower parts of the system. Conversely, coastal wells that are open to deeper parts of the system have water levels with higher altitudes than wells open to shallower parts of the system. Drost (1979) described the shape of the water table using water-level measurements and geophysical techniques. Water levels measured in 1990-91 suggest that ground water moves from the shallow ground-water system to the sea-level aquifer. Confined (artesian) conditions exist in the sea-level aquifer; water levels in that unit were 20 to 80 feet higher than the top of the aquifer, which corresponds to the bottom of the overlying and confining clay unit (plate 1C).

Recharge

Precipitation amounting to about 26 inches per year is the source of all fresh water in the study area and is also the source of recharge to the ground-water reservoir. Recharge is that portion of precipitation not lost as evaporation, transpiration, or surface runoff, or stored as soil moisture. Recharge values for the study area were estimated using regression analyses developed for other areas with similar climate and geology (D.G. Woodward, U.S. Geological Survey, written commun., 1993). For the Swinomish Indian Reservation, precipitation data for Anacortes, Wash., (U.S. Weather Bureau River Forecast Center, 1965), about 10 miles northwest of the study area, were correlated with the map of surficial geology (fig. 3). Using the regression values, estimates of recharge in the study area ranged from 3.5 inches per year on bedrock to 12.5 inches per year on alluvium and outwash (fig. 5). The total recharge to the Reservation is strongly affected by the preponderance of till at land surface; recharge through till in the study area ranged from 7.1 to 10.0 inches per year. These estimates of recharge are comparable to the value of 10.9 inches per year estimated by Drost (1979) using other methods.

Water Use

Of the estimated 2,500 people living on the Reservation during 1990-91, about 1,500 depended on ground water to meet domestic needs. The remainder, living primarily in the Shelter Bay development on the southeastern part of the island, received their water from a surface source located on the mainland. About 860 of the 1,500 ground-water users were connected to a public-supply system; the remaining 640 were self-supplied. Based on a per capita use of 68 gal/day (gallons per day),

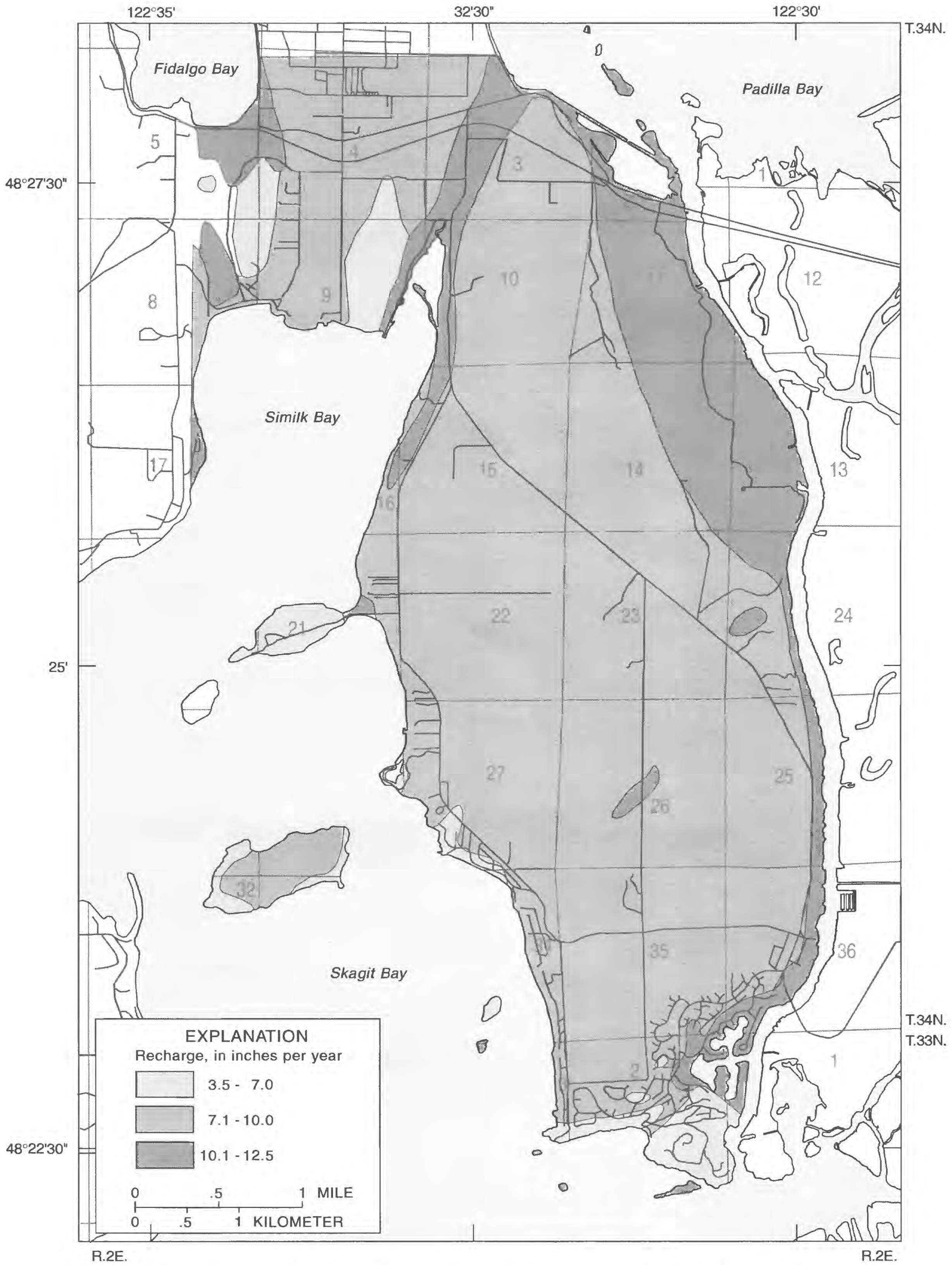

Figure 5. Estimated ground-water recharge from precipitation on the Swinomish Indian Reservation, Skagit County, Washington.

the value used by Drost (1979), the average withdrawal rate from the ground-water reservoir was about 102,000 gal/day. About 60 percent of that amount, or 61,000 gal/day, was withdrawn from the shallow ground-water system; the remainder, or 41,000 gal/day, was withdrawn from the sea-level aquifer. In his study, Drost (1979) estimated that 1,200 ground-water users withdrew about 80,000 gal/day, all of it from the shallow ground-water system. It appears, therefore, that with the discovery and development of the sea-level aquifer, withdrawals from the shallow ground-water system have decreased.

Hydraulic Characteristics

Specific capacity, defined as a well's yield divided by the drawdown produced by that yield, is a convenient method of assessing an aquifer's production potential. Specific capacity is usually expressed in terms of gallons per minute per foot of drawdown. As mentioned previously, for this report specific-capacity values were normalized by dividing them by the length of the well's open interval, that is, the difference between the top and bottom of the open interval (see appendix A). Thus, normalized specific-capacity values are expressed in units of gallons per minute per foot of drawdown per foot of open interval, or [((gal/min)/ft)/ft]. A summary of the normalized specific-capacity values is presented in table 2.

Shallow Ground-Water System

The median normalized specific capacities for the till and outwash, calculated with additional 1990-91 data, are similar to those reported by Drost (1979). The revised value for till is 0.08 [((gal/min)/ft)/ft]; the 1979 value was 0.06 [((gal/min)/ft)/ft]. The revised value for outwash is 1.0 [((gal/min)/ft)/ft]; the 1979 value was 1.0 [((gal/min)/ft)/ft]. New data for wells finished in sand or gravel lenses within the clay (the topmost part of Qns) resulted in a revised value of 0.03 [((gal/min)/ft)/ft], whereas the 1979 value was 0.02 [((gal/min)/ft)/ft].

Sea-Level Aquifer

The median normalized specific capacity for the five wells completed in the sea-level aquifer was 0.60 [((gal/min)/ft)/ft]; the range was 0.43 to 3.1 [((gal/min)/ft)/ft]. Well 34/2-15R2, with the highest value, is open to 7 feet of the sea-level aquifer, which is about 10 feet thick in this location.

Because the sea-level aquifer is likely to be the focus of most future ground-water development, additional hydraulic tests were made of that unit. The principal hydraulic characteristics of an aquifer are hydraulic conductivity, transmissivity, and storativity. Hydraulic

Table 2.--*Normalized specific capacities of the till, outwash, and clay units, and of the sea-level aquifer*
[1979 data from Drost (1979); --, no data]

Unit or aquifer	Normalized specific capacity[1] Number of wells tested		Minimum		Median		Maximum	
	1979	1990	1979	1990	1979	1990	1979	1990
Till unit	20	30	0.02	0.02	0.06	0.08	0.40	0.90
Outwash unit	18	33	0.13	0.04	1.0	1.0	2.6	3.0
Clay unit	14	19	0.01	0.00	0.02	0.03	0.09	0.83
Sea-level aquifer	--	5	--	0.43	--	0.60	--	3.1

[1] Expressed as specific capacity (gallons per minute per foot of drawdown) per foot of open interval of the well.

conductivity (K) can be thought of as the rate at which a volume of water will move through a unit cross-section of aquifer material under a unit gradient. It is usually expressed in dimensions of ft/day (feet per day), which is simplified from ft^3/ft^2/day (cubic feet per square foot per day). Transmissivity (T) is defined as the rate of flow through a vertical section of the aquifer 1 foot wide and extending the full saturated thickness of the aquifer under a unit gradient. It is usually expressed in dimensions of ft^2/day (square feet per day), which is simplified from ft^3/ft/day (cubic feet per foot per day). Storativity (S) is a dimensionless measure of the volume of water the aquifer will release from storage per unit surface area per unit decline in hydraulic head.

The approach chosen to estimate the hydraulic characteristics of the sea-level aquifer is one that requires that water be added to or removed from the aquifer while the pressure response (as reflected by water levels in wells) is monitored in one or more locations (wells) in the aquifer. With this approach, estimates of T and K can be made by observing the pressure response at the well from which water was removed. Data were available from aquifer tests made on wells 34/2-15R2 and 34/2-15R3 by the driller; these aquifer tests consisted of pumping water from each well at a constant rate and measuring the rate of water-level decline in the same well.

Several techniques, including the Theis curve (Theis, 1935) and Jacob straight line, were used to analyze the aquifer-test data. Numerous publications, notably Lohman (1979), describe in detail the estimation techniques. Different subsets of test data from the wells were also used, depending on the quality of the data. Because the resulting estimates of T and K used data of varying quality and different methods, the values are considered approximations at best. Using multiple analyses for the two wells, estimates of K for the sea-level aquifer range from 28 to 580 ft/day; estimates of T range from 560 to 9,000 ft^2/day.

The quality of the individual estimates were judged on how well the raw data matched a characteristic response curve and on how well the hydrogeologic conditions matched the assumptions of the estimation techniques and methods. The best estimates of T and K for well 34/2-15R2 were about 2,500 ft^2/day and 250 ft/day, respectively; for well 34/2-15R3 the best estimates were 600 ft^2/day and 30 ft/day, respectively. Over a distance of only a few hundred feet (from well 34/2-15R2 to 34/2-15R3), the estimates of T varied by a factor of about 4, and the estimates of K varied by a factor of about 8. This range is relatively small for a glacial environment.

The T and K values noted in the previous paragraph for the sea-level aquifer show that wells 34/2-15R2 and 34/2-15R3 are spaced far enough apart to avoid significant interference with each other when pumped at 40 gal/min, the maximum rate allowed with existing pump installations. There are not sufficient data, however, to quantify the hydraulic characteristics of the overlying clay unit or the amount of water moving through it to the sea-level aquifer. A test that would provide these data would require a much higher pumping rate, the installation of several small-diameter observation wells at varying distances from the pumped well, and a pumping period of at least several weeks.

Figure 6 illustrates the effects (estimated using Theis' analytical method; Lohman, 1979) that different values of T can have on water levels in the sea-level aquifer when water is pumped from one of the Tribe's wells. For selected values of T, the water-level drawdown out to 1,000 feet away from the pumped well is shown for a range of pumping rates. For purposes of this illustration, 2 days of constant pumping at the indicated rate (Q) and an aquifer storativity of $1.5x10^{-5}$ (a typical value for a confined aquifer) were assumed. Four different values of T were chosen to demonstrate water-level drawdowns:

- 600 ft^2/day, representative of the T estimated for well 34/2-15R3;
- 1,200 ft^2/day, an intermediate value of T for the two wells, 34/2-15R2 and 34/2-15R3;
- 2,500 ft^2/day, representative of the T estimated for well 34/2-15R2; and
- 5,000 ft^2/day, a large value relative to those listed above.

As shown in figure 6, smaller values of T result in greater water-level drawdown at the pumping well and beyond than do larger values of T. For example, at a pumping rate of 100 gal/min, the drawdown 50 feet from the pumped well is about 30 feet with a T of 600 ft^2/day but is only about 15 feet with a T of 1,200 ft^2/day. Increased pumping rates also affect the amount of drawdown. For a T of 600 ft^2/day, the drawdown associated with a pumping rate of 50 gal/min is about 15 feet, but at a pumping rate of 250 gal/min the drawdown is about 80 feet.

The extent of water-level drawdown is also affected by the duration of pumping. To illustrate these effects, values assumed to be representative of the hydraulic conditions of the sea-level aquifer and the Tribe's well field

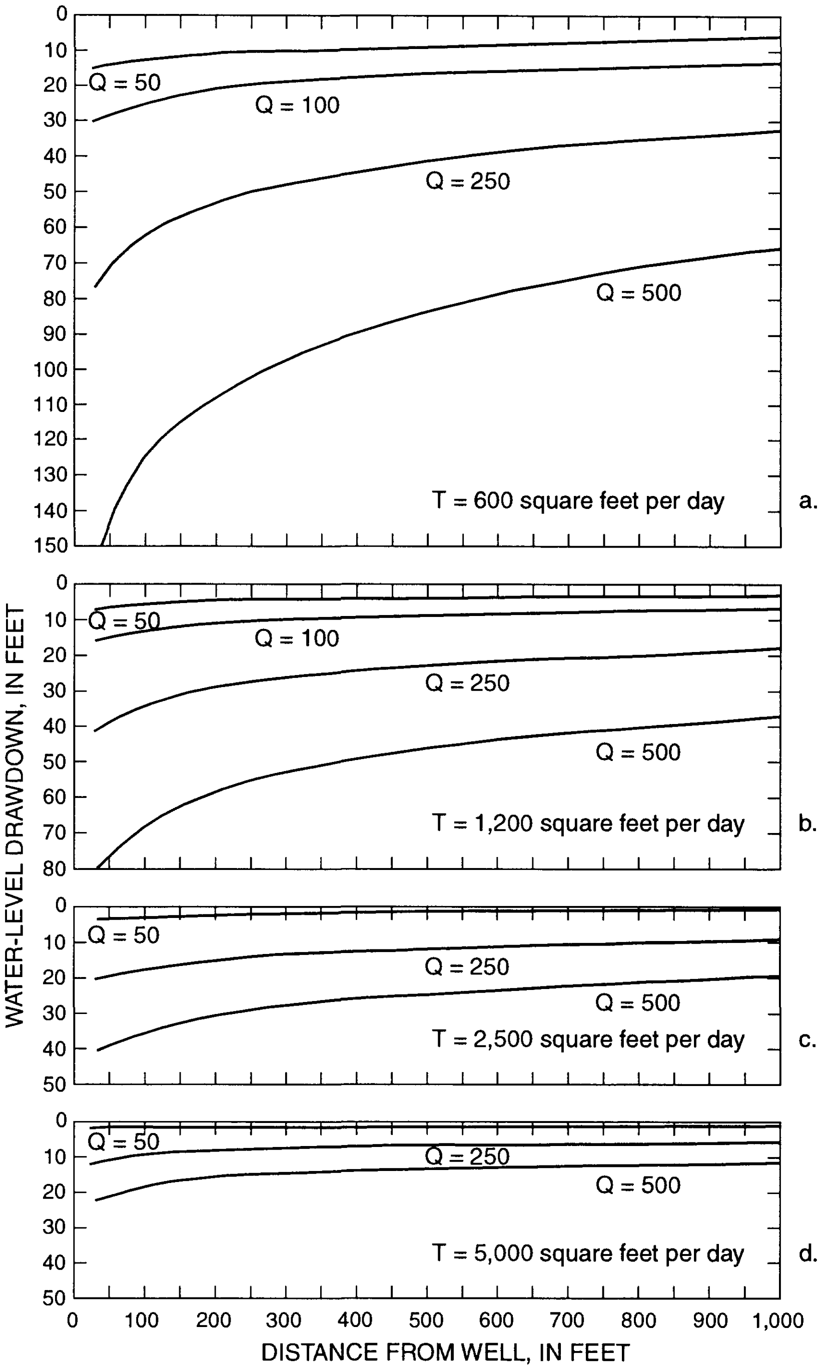

Figure 6. Water-level drawdown as a function of distance from well, pumping rate, and transmissivity (T) after two days of pumping and with a storativity of 1.5×10^{-5}. Q is pumping rate in gallons per minute. (a) with a T of 600 square feet per day; (b) with a T of 1,200 square feet per day; (c) with a T of 2,500 square feet per day; and (d) with a T of 5,000 square feet per day.

were chosen: a T of 1,200 ft^2/day, a Q of 100 gal/min, an S of $1.5x10^{-5}$, and a well spacing of 500 feet between pumping and observation wells. Under these conditions, the rate of water-level decline is initially large, with most of the decline occurring during the first 2 or 3 days of constant pumping (fig. 7). As time progresses, the rate of decline becomes smaller.

WATER QUALITY

The quality and chemical characteristics of ground water on the Swinomish Indian Reservation are described in this section, using the results of chemical analyses of water samples. The samples were analyzed for specific conductance, pH, and concentrations of dissolved oxygen, alkalinity, major ions, nitrate, and selected trace elements. The constituent concentrations and characteristics were compared to applicable drinking water standards. Primary drinking water standards (U.S. Environmental Protection Agency, 1991a) generally address chemicals that affect human health and can be enforced by specific regulating agencies. Secondary drinking water standards (U.S. Environmental Protection Agency, 1991b) pertain to the aesthetic quality of water and are recommended guidelines only. Both sets of regulations directly apply only to public supplies, but they can also be useful in assessing the water quality of private systems. Of the constituents determined in this study, nitrate and fluoride concentrations and trace-element concentrations such as copper, lead, and mercury are governed by primary drinking water standards that specify a maximum contaminant level (MCL). Dissolved solids, sulfate, chloride, fluoride, iron, manganese, zinc, and pH are governed by secondary drinking water standards that recommend a secondary maximum contaminant level (SMCL).

Data describing the general chemistry of water samples from the sea-level aquifer and seeps are presented in appendixes B and C, respectively. A statistical summary of chemical data for the sea-level aquifer is presented in table 3, as are the MCLs and SMCLs in mg/L (milligrams per liter) or µg/L (micrograms per liter). For some constituents, the concentrations are reported as less than (<) a given value where the given value is the reporting limit of the analytical method. This means the constituent might be present at a lower concentration or not present at all.

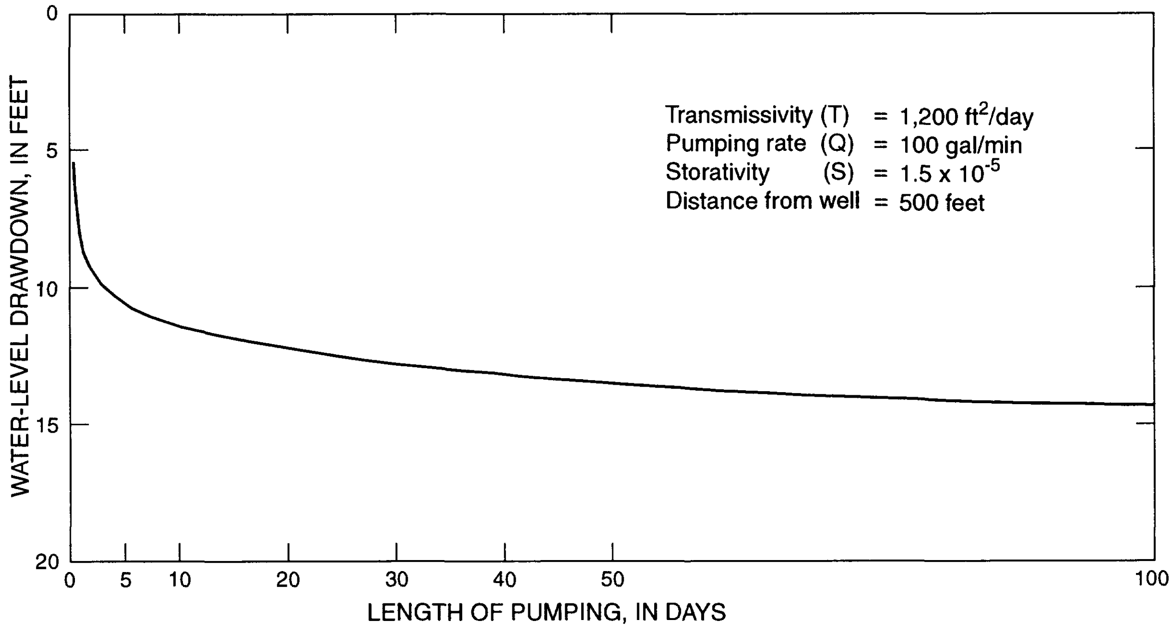

Figure 7. Idealized relation between water-level drawdown and duration of pumping period for constant values of transmissivity, pumping rate, storativity, and distance from pumping well.

Table 3.--*Summary of constituents and properties determined in water samples from five wells open to the sea-level aquifer*

[Concentrations in milligrams per liter (mg/L) unless otherwise noted; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L, micrograms per liter; <, less than; --, no value or no U.S. Environmental Protection Agency (USEPA) drinking water regulation; SMCL, secondary maximum contaminant level; MCL, primary maximum contaminant level. All are dissolved concentrations except bicarbonate, carbonate, and alkalinity]

Constituent or property	Minimum	Maximum	USEPA SMCL	USEPA MCL	Number of wells exceeding SMCL or MCL
Specific conductance (µS/cm)	344	401	--	--	--
pH (standard units)	7.3	7.9	6.5-8.5	--	0
Oxygen	0	0.1	--	--	--
Hardness as $CaCO_3$	140	180	--	--	--
Calcium	27	33	--	--	--
Magnesium	15	25	--	--	--
Sodium	16	17	--	--	--
Potassium	2.8	5.0	--	--	--
Bicarbonate	200	214	--	--	--
Carbonate	0	0	--	--	--
Alkalinity as $CaCO_3$	162	175	--	--	--
Sulfate	<0.1	28	250	--	0
Chloride	13	19	250	--	0
Fluoride	0.2	0.2	2.0	4.0	0
Total dissolved solids	224	267	500	--	0
Nitrite + nitrate, as nitrogen	<0.05	<0.05	--	10.0	0
Organic carbon	1.0	2.0	--	--	--
Arsenic (µg/L)	<1	<1	--	50	0
Barium (µg/L)	47	93	--	1,000	0
Cadmium (µg/L)	<1.0	<1.0	--	10	0
Chromium (µg/L)	<1	<1	--	50	0
Copper (µg/L)	<1	1	--	1,000	0
Iron (µg/L)	180	3,300	300	--	3
Lead (µg/L)	<1	1	--	50	0
Manganese (µg/L)	59	120	50	--	5
Mercury (µg/L)	<0.1	<0.1	--	2	0
Selenium (µg/L)	<1	<1	--	10	0
Silver (µg/L)	<1.0	<1.0	--	50	0
Zinc (µg/L)	5	680	--	5,000	0

General Characteristics of Water-Quality Analyses

Two properties of water commonly measured in water samples are specific conductance and pH. Specific conductance is a measure of the electrical conductance of the water (corrected for water temperature), and increases with the amount of dissolved minerals. Specific conductance is a good indicator of what is commonly referred to as dissolved-solids concentration. The pH of a substance, in this case water, is a measure of the hydrogen-ion activity and is gaged on a scale from 0 to 14. The pH is high in alkaline, or basic, solutions and is low in acidic solutions; a pH of 7.0 is considered neutral. Because the scale is logarithmic, water with a pH of 6.0 has 10 times the activity of hydrogen ions, or is 10 times more acidic, than water with a pH of 7.0. Water with low (acidic) pH values can be corrosive to plumbing and can result in increased concentrations of trace elements such as copper, lead, and zinc. Water with high (basic) pH values can interfere with the chlorination process and contribute to the deposition of carbonate in pipes. The U.S. Environmental Protection Agency (1991b) recommends a pH of 6.5 to 8.5 for water used for domestic purposes.

Dissolved-oxygen concentrations determine in part the types of chemical reactions that can occur in water. Small dissolved-oxygen concentrations indicate that a chemically reducing reaction can occur whereas large concentrations indicate that a chemically oxidizing reaction can occur. In particular, the concentrations of iron and manganese (discussed in a later paragraph) are determined largely by the amount of oxygen dissolved in water. In some instances, large dissolved-oxygen concentrations might be caused by aeration of the water by pumps or by leaking tanks or pipes. Sampling methods that minimized aeration were used in this study.

Dissolved solids that typically are measured in water samples include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica. Other constituents, such as carbonate and fluoride, and metals such as iron and manganese, are also dissolved solids, but their concentrations are usually too small to make a substantial contribution to dissolved-solids concentration. Most of the dissolved-solids are ions. Cations are ions with a positive charge and include calcium, magnesium, sodium, potassium, and most metals. Anions are ions with a negative charge and include bicarbonate, sulfate, chloride, nitrate, carbonate, and fluoride. Silica has no charge and is the only typical dissolved solid that is not a cation or anion.

Water hardness is calculated from the concentrations of calcium and magnesium. Increasing water hardness requires that a larger amount of soap be used to produce a lather and can result in scale deposit on the inside of plumbing pipes and boilers. Water hardness can be classified in terms of an equivalent concentration of calcium carbonate ($CaCO_3$) (Hem, 1989).

Description	Hardness Range (mg/L of $CaCO_3$)
Soft	0 - 60
Moderately Hard	61 - 120
Hard	121 - 180
Very Hard	Greater than 180

Nitrogen is found in water as anions of nitrite or nitrate, as ammonium cations, as ammonia, and at intermediate oxidation states as part of organic solutes (Hem, 1989). Nitrogen in reduced or organic forms is unstable in water with dissolved oxygen present; it is converted readily by soil bacteria into nitrite and then to nitrate. In this study, the analysis for nitrate nitrogen included both the nitrite and nitrate forms. However, because nitrite concentrations in ground water are typically negligible and temporary, the analytical values can be considered as entirely nitrate and are referred to in this discussion as nitrate concentrations.

Large concentrations of dissolved iron and manganese are common in ground water of western Washington and are due largely to natural processes. These processes are dependent on ambient geochemical conditions, particularly the concentration of dissolved oxygen. Water that is nearly anoxic (low in dissolved-oxygen content) will dissolve iron or manganese from the surrounding minerals as a chemically reduced form. If the water is reoxygenated, the iron or manganese is oxidized to a less soluble form than the reduced form and will precipitate as an oxide or a carbonate. Because of these oxygen-sensitive reactions, concentrations of dissolved iron and manganese can vary considerably in a given area. In addition, the iron and manganese content of aquifer material is highly variable. Large concentrations of dissolved iron and manganese can cause objectionable taste in drinking water and can stain laundry and plumbing fixtures.

Sea-Level Aquifer

In general, water from the sea-level aquifer near the Tribe's well field was hard; hardness averaged 160 mg/L as $CaCO_3$. Concentrations of dissolved solids were moderate ranging from 224 to 267 mg/L (table 3). Because the water was nearly anoxic, it contained relatively large concentrations of dissolved iron ranging from 180 to 3,300 µg/L, and of dissolved manganese, ranging from 59 to 120 µg/L. The pH of the water was nearly neutral with values ranging from 7.3 to 7.9.

Calcium and magnesium were the most prevalent cations, with average concentrations of 30 and 20 mg/L, respectively. Bicarbonate was the most prevalent anion, with an average concentration of 204 mg/L. Sodium accounted for most of the remaining cation contribution to the dissolved-solids concentrations whereas sulfate and chloride accounted for most of the remaining anion contribution.

The percent contribution of the major ions to the dissolved-solids content can be used to characterize the water type. Cation and anion percentages (in milliequivalents per liter) were plotted on a trilinear diagram to show the composition of the five water samples from the sea-level aquifer (fig. 8). One (triangular) plot defines the dominant cation, the other the dominant anion. The individual cation and anion plots were then projected into the diamond-shaped plot. If an analysis plots near one of the vertices of the cation or anion triangle, that ion will account for at least 60 percent or more of the cation or anion sum and can be defined as a sole dominant ion. As shown in figure 8, calcium and magnesium combined made up about 80 percent of the cations, and bicarbonate accounted for more than 70 percent of the anions. The results indicate a mixed water type of calcium-magnesium or magnesium-calcium bicarbonate. These mixed water types are typical of the glacial deposits of western Washington (Van Denburgh and Santos, 1965; Turney, 1986).

Iron concentrations as large as 3,300 µg/L and manganese concentrations as large as 120 µg/L, found in the study water samples, are typical of western Washington ground waters (Van Denburgh and Santos, 1965; Turney, 1986, 1990). Samples from all five wells had manganese concentrations that exceeded the U.S. Environmental Protection Agency (USEPA) SMCL of 50 µg/L, and samples from three wells had iron concentrations that exceeded the SMCL of 300 µg/L (table 3).

Concentrations of most trace elements and of nitrate were typically less than analytical reporting limits; all trace-element and nitrate concentrations were substantially less than the USEPA MCLs. Zinc was detected in all five samples in concentrations ranging from 5 to 680 µg/L (appendix B). Likely sources of zinc in the samples were galvanized pipe used in wells and home plumbing systems (N. P. Dion, U.S. Geological Survey, written commun., June 1991). Barium also was detected in all five samples in concentrations ranging from 47 to 93 µg/L, with a median of 63 µg/L.

Seeps Near Inactive Waste-Disposal Site

An inactive petroleum waste-disposal site is located at the northeastern end of the Swinomish Indian Reservation in Sections 10 and 11 of Township 34, Range 2 (see plate 1A). The site is about 1 mile northeast of the Tribe's well field at an altitude of about 140 feet above sea level. The waste-disposal site covers about 7 acres.

The site was prepared by a major oil company in the early 1960's to dispose of petroleum refinery wastes (Jeff Whidden, Ecology and Environment, Inc., written commun., June 1986). Soils at the site are 3 to 5 feet thick and are underlain by about 40 feet of till, 60 feet of outwash, and 100 feet of the clay unit. Ground water at the site is about 40 feet below land surface and generally flows in a north-northeastward direction (Jeff Whidden, Ecology and Environment, Inc., written commun., June 1986). In the construction phase, three waste-disposal pits were dug to a depth of about 2 feet into the soil and bermed with the excavated soil. Several shallow ponds eventually formed in these pits and the ponds persisted until the site was closed in 1970. Since the site closure in 1970, brush and deciduous trees have grown over the area. The total quantity of waste dumped in the ponds is unknown, but one refinery alone reportedly dumped more than 8,300 cubic yards of material. Several refineries used the dump before it was closed, and unauthorized private parties also were dumping there as of 1986 (Jeff Whidden, Ecology and Environment, Inc., written commun., June 1986).

Soil and water samples at the site were collected by a consulting firm in February 1986. Soil samples contained polycyclic aromatic hydrocarbons, aliphatic hydrocarbons, toluene, benzene, xylene, pentane, hexane, and octane, but these contaminants were not found in water samples from a large puddle near the site or from surface runoff near the top of the bluff (Jeff Whidden, Ecology and Environment, Inc., written commun., June 1986).

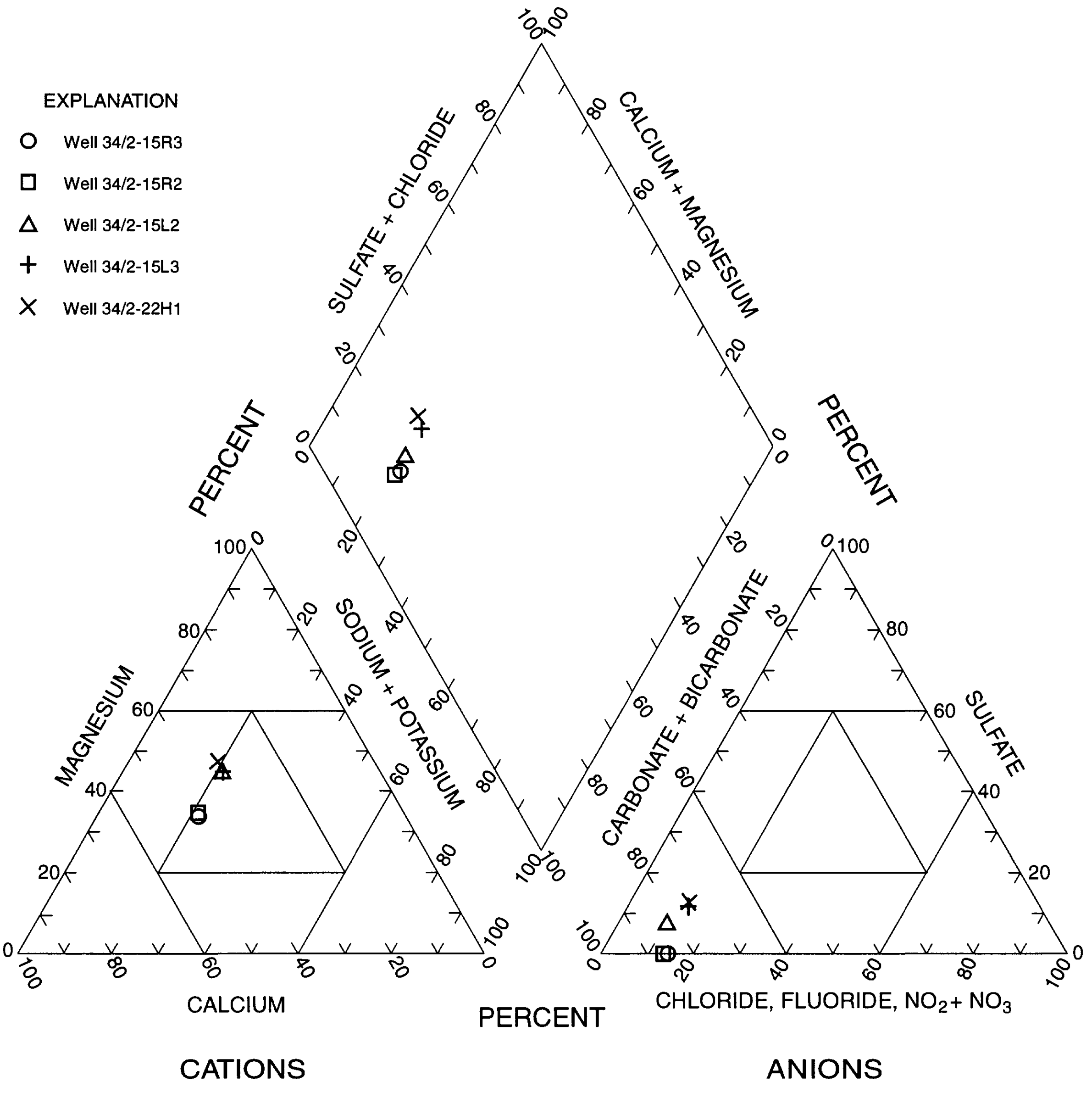

Figure 8. Percent composition of major ions in water samples from wells completed in the sea-level aquifer.

Water samples from two seeps in a ravine about 800 feet east of the disposal site (see plate 1A) were collected in late May 1991 after the spring rains had subsided and direct runoff down the ravine from the land surface had ceased. These seeps offered the closest available sampling points in an area with the potential of receiving contamination from the waste site. Analyses for a variety of volatile organic compounds (VOCs), including those contaminants mentioned in the previous paragraph, did not detect any VOCs in water samples from sites 1 or 2 (appendix C). Sample analyses showed the water in the seep flow to be a mixed type in that no one cation was dominant; bicarbonate was the dominant anion. The total dissolved-solids concentrations were small and the water was soft. In general, the water carried slightly larger concentrations of dissolved substances than are typical of surface-water runoff in the Puget lowland area (David P. Dethier, U.S. Geological Survey, written commun., January 1982) or of direct runoff on the Swinomish Indian Reservation (Drost, 1979). However, the concentrations of dissolved substances were slightly less than those reported by Drost (1979) for streamflow water that was a mix of direct runoff plus spring flow. On the basis of concentrations of dissolved solids and other constituents, the seeps appeared to contain ground water with a relatively short residence time in the ground.

The effects of the disposal site on the aquifers in general and the Tribe's well field in particular cannot be fully determined without additional hydrologic and water-quality data from points closer to the waste-disposal site. The fact that contaminants were not detected in samples collected from the two seeps does not preclude the possibility that other contaminants not analyzed for are present in the samples, nor does this mean that contaminants from the disposal pits have not yet reached the seeps. Although it is logical to assume the contaminants are moving generally north-northeastward, it is possible that various hydrologic factors, including patterns of recharge and ground-water withdrawals, could change the hydraulic gradients and the direction of contaminant transport.

SUMMARY

In 1979, Drost described the aquifer system in the upper 200 to 300 feet of a 900-foot assemblage of unconsolidated sediments on the Swinomish Indian Reservation. Since that time, five wells have been drilled into a deeper, coarse-grained aquifer layer that exists beneath the shallow units at an altitude near sea level. The purposes of this study, in part, were to describe the extent and hydraulic characteristics of the newly found sea-level aquifer, and to update previous (1975-76) information about the overlying, shallow aquifers with data collected in 1990-91.

Four unconsolidated hydrogeologic units were defined using descriptions of the deposits in drillers' reports; these units were correlated with the major hydrogeologic units described by Drost (1979). The four units included till, outwash, and clay units as defined by Drost (1979), and the sea-level aquifer. At the Swinomish Indian Tribe's well field, the sea-level aquifer is from 10 to 20 feet thick and extends out from the well field at least one-half mile to the northwest and to the south.

The till, outwash, and clay units, and the sea-level aquifer are all used for public and domestic water supply. Most of the wells in the study area are finished in the till and outwash. At the time of Drost's study (1975-76), the outwash was the most productive of the three known units. Data for 1990-91 indicated a median normalized specific capacity of 1.0 (gal/min)/ft per foot of open interval for the outwash and of 0.60 (gal/min)/ft per foot of open interval for the sea-level aquifer. The estimated withdrawal from the sea-level aquifer provided about 40 percent (41,000 gal/day) of the 1991 average daily withdrawal (102,000 gal/day) from the ground-water reservoir.

The sea-level aquifer is a confined aquifer; water levels were about 20 to 80 feet above the top of the aquifer at the time of this study. Ground water in the sea-level aquifer probably flows radially outward from near the center of the island toward the coast. The pattern is consistent with generalized flowlines associated with an island aquifer system in which ground water moves radially outward and discharges into adjacent saltwater bays and sea-level mudflats. With data from only five wells, however, the regional flow pattern of the sea-level aquifer could not be determined adequately.

Hydraulic characteristics of the sea-level aquifer were estimated using data collected by the driller from the Swinomish Indian Tribe's wells 34/2-15R2 and 34/2-15R3 at the time they were completed. Hydraulic conductivity was estimated to range from 28 to 580 ft/day, and transmissivity ranged from 560 to 9,000 ft^2/day. Data to calculate the storativity of the sea-level aquifer and the hydraulic characteristics of the overlying clay unit were not available at the time of this study.

Water samples for chemical analyses were collected from all five wells finished in the sea-level aquifer. In general, water from the sea-level aquifer near the Tribe's well field was anoxic and hard; average hardness was

160 mg/L. Concentrations of trace elements and of nitrate were small in that they were commonly less than analytical reporting limits. On the basis of the percent composition of the major ions, water from the sea-level aquifer was a mixed water type of calcium-magnesium or magnesium-calcium bicarbonate, which is typical of western Washington ground water in glacial deposits. Largely because of the anoxic conditions, the water contained relatively large concentrations of dissolved iron and of dissolved manganese. Iron concentrations in three of the five wells, and manganese concentrations in all five wells, exceeded U.S. Environmental Protection Agency secondary maximum contaminant levels recommended for drinking water.

Water samples from ground-water seeps about 800 feet east of an inactive petroleum waste-disposal site located northeast of the Swinomish Indian Tribe's well field did not contain detectable amounts of selected volatile organic compounds. Their chemistry of the water samples indicated that the seeps contain ground water with a relatively short residence time in the ground. Without additional hydrologic and water-quality data from points closer to the waste-disposal site, however, the effects of the waste products on the ground-water aquifers cannot be assessed.

NEED FOR ADDITIONAL STUDY

The data and insights generated by this reconnaissance study of limited scope point to the need for additional, in-depth studies to more fully describe and assess the ground-water resources of the Swinomish Indian Reservation. In particular, a more thorough knowledge of the thickness, geographic extent, and configuration of the newly discovered sea-level aquifer is needed to properly assess its long-term potential as a source of ground water. Estimates of the aquifer's hydraulic characteristics provided in this report could be used to determine the locations and depths of future production and observation wells. The testing of these wells, in turn, would provide more accurate values of the aquifer's hydraulic characteristics.

Because the Reservation is on an island, the danger of seawater intrusion from excessive ground-water withdrawals is a constant threat. The threat is even more significant given the relatively low water levels observed in the sea-level aquifer as part of this study. Persons responsible for the long-term management of the sea-level aquifer will have to consider the benefits derived from the water withdrawn and the potential dangers of over-withdrawal. These considerations can best be addressed with the use of a digital ground-water model.

The thick, unconsolidated sediments that overlie the bedrock could be explored to determine if they contain important aquifers and, if so, the quality of the water produced. Such an effort would require a great deal of exploratory drilling, usually an expensive undertaking. Exploratory drilling would also be required to more fully describe the sea-level aquifer.

Should residential development extend to the vicinity of the inactive waste-disposal site and should that development be dependent on ground water to meet domestic needs, it would be necessary to determine if ground-water contamination from that site has occurred and, if so, the nature and extent of that contamination. Again, such an effort would require exploratory drilling and extensive water-quality testing.

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Appendix A.--*Selected physical and hydrologic data for wells inventoried in 1990*

[--, no data; gal/min, gallons per minute; gal/min/ft, gallons per minute per foot of drawdown; S, screen; O, open end; P, perforations; altitude is in feet above sea level; measurements of well depth, casing, intervals, and water level are in feet below land surface; 1 = till; 2 = outwash; 3 = clay; 4 = sea-level aquifer]

Local well number	Site identification number	Hydro-geologic unit code	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)	Type of finish	Top of open interval (feet)	Bottom of open interval (feet)	Water level (feet)	Date water level measured	Discharge (gal/min)	Date discharge measured	Specific capacity (gal/min/ft)
33/2-2D3	482253122311401	3	120	179	174	S	174	179	73.80	09-07-90	5	01-27-81	--
33/2-2D4	482254122311401	2	120	59	54	S	54	59	30.25	09-07-90	8	03-18-81	--
33/2-3H8	482245122315201	2	40	45	41	S	40	45	18.45	08-27-90	16	03-29-79	5.33
34/2-14Q1	482547122311001	--	220	118	118	O	--	--	--	--	--	--	--
34/2-15L2	482606122324001	4	280	280	274	S	274	280	220.00	08-27-90	28	07-13-78	2.59
34/2-15L3	482601122324101	4	280	272	264	S	267	272	214.9	11-19-86	15	11-19-86	3
34/2-15R2	482549122315701	4	240	273	266	S	266	273	178.30	01-23-87	125	01-23-87	21.55
34/2-15R3	482549122320201	4	240	261	248	S	253	258	174.87	01-12-89	151	01-12-89	2.94
			--	--	253	--	--	--	--	--	--	--	--
			--	--	261	--	--	--	--	--	--	--	--
34/2-16R1	482550122330801	2	165	90	85	S	85	90	63.63	09-06-90	15	09-30-86	--
34/2-22E4	482522122325701	2	140	179	176	S	176	179	77.50	08-29-90	10	12-21-87	1.67
34/2-22F1	482517122323901	2	240	125	125	O	--	--	109.91	08-31-90	15	01-22-81	1.50
34/2-22F2	482520122324101	--	220	137	110	P	110	137	111.17	08-28-90	4	05-10-90	--
			--	--	137	--	110	137	--	--	--	--	--
34/2-22F3	482521122322901	--	280	198	193	S	193	198	177.97	08-29-90	5	04-23-82	0.31
34/2-22F4	482520122323301	3	260	150	150	O	--	--	139.82	08-31-90	6	09-10-90	1.00
34/2-22H1	482521122320401	4	280	263	263	O	--	--	238.90	09-06-90	10	03-31-87	2.00
34/2-22N8	482453122330001	1	40	71	71	O	--	--	17.46	08-30-90	4	03-23-87	0.25
34/2-22N9	482455122330401	1	30	85	80	S	80	85	12.88	08-31-90	8	09-30-81	--
34/2-23A1	482537122305201	--	195	160	160	O	--	--	--	--	--	--	--
34/2-23A2	482537122304801	--	175	180	180	--	--	--	--	--	--	--	--
34/2-23C2	482529122311601	2	240	160	160	O	--	--	100	09-06-90	60	12-13-78	--

Appendix A.--*Selected physical and hydrologic data for wells inventoried in 1990--Continued*

Local well number	Site identification number	Hydro-geologic unit code	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)	Type of finish	Top of open interval (feet)	Bottom of open interval (feet)	Water level (feet)	Date water level measured	Discharge (gal/min)	Date discharge measured	Specific capacity (gal/min/ft)
34/2-23P2	482500122312001	2	265	159	154	S	154	159	139.24	08-28-90	7	11-08-77	--
34/2-23P3	482452122311701	2	270	170	165	S	165	170	144.46	08-30-90	15	01-30-81	1.50
34/2-24F8	482523122301201	--	80	140	140	--	--	--	--	--	--	--	--
34/2-24P1	482500122302001	3	140	70	65	S	65	70	40	08-30-90	30	05-10-79	--
			--	--	--	--	--	--	--	--	26	spring '90	3.71
34/2-25C2	482444122301401	2	145	60	55	S	55	60	26.50	09-06-90	12	09-27-85	2.67
34/2-25C3	482443122300401	3	75	123	117	S	117	123	68	09-06-90	15	07-10-85	0.47
34/2-26A1	482445122305201	2	245	169	164	S	164	169	139.19	08-30-90	20	06-26-85	--
34/2-26B1	482449122310901	2	270	48	48	O	--	--	38.04	09-06-90	12	06-15-84	2.00
34/2-26F4	482427122311601	3	260	200	200	O	--	--	--	--	--	--	--
34/2-27C1	482446122323201	1	140	160	155	S	155	160	72.08	08-29-90	20	08-28-78	0.40
34/2-27C2	482440122320901	1	100	66	66	O	--	--	53.53	08-27-90	9	04-23-85	0.90
34/2-27C3	482438122324601	1	85	125	125	O	--	--	56.52	08-30-90	5	01-30-90	0.17
34/2-27E3	482433122324901	1	50	53	50	S	50	53	7	08-30-90	23	02-14-78	3.29
34/2-27F3	482433122324601	1	65	150	142	S	142	150	41.92	09-05-90	10	07-25-84	0.20
34/2-27K6	482412122322902	1	60	--	--	--	--	--	--	--	--	--	--
34/2-27K7	482415122333101	1	60	74	69	S	69	74	32.12	08-30-90	7	05-28-87	0.17
34/2-27K8	482414122322901	1	60	65	60	S	60	65	21.05	08-30-90	6	07-12-89	0.21
34/2-27L3	482421122324601	1	45	73	68	S	68	73	27.16	09-06-90	4	02-07-84	--
34/2-27R1	482355122320701	3	100	72	69	S	69	72	26.71	08-28-90	5	10-13-72	0.13
34/2-27R4	482357122315501	3	150	78	73	S	73	78	45.10	08-28-90	11	07-18-80	0.55
34/2-34A6	482343122320901	3	25	58	58	O	--	--	14.52	09-07-90	10	12-12-75	--
34/2-34A7	482348122320901	3	50	85	85	O	--	--	52.12	08-28-90	15	11-04-81	0.83
34/2-34H2	482335122320401	1	90	97	92	S	92	97	53.47	08-30-90	15	05-24-83	0.75
34/2-34H3	482337122320401	1	80	67	62	S	62	67	42.05	08-31-90	12	12-29-81	0.60

Appendix A.--*Selected physical and hydrologic data for wells inventoried in 1990--Continued*

Local well number	Site identification number	Hydro-geologic unit code	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)	Type of finish	Top of open interval (feet)	Bottom of open interval (feet)	Water level (feet)	Date water level measured	Discharge (gal/min)	Date discharge measured	Specific capacity (gal/min/ft)
34/2-34R11	482313122315501	2	45	60	55	S	55	60	30.45	09-07-90	15	01-29-85	--
34/2-35F3	482338122313201	2	240	149	144	S	144	149	118.30	08-27-90	15	08-03-79	15.00
34/2-35F4	482342122311601	--	250	304	304	O	--	--	--	--	--	--	--
34/2-35L2	482325122311601	2	220	120	115	S	115	120	100	08-28-90	12	12-14-87	1.00

Appendix B.--*Water-quality data for samples from wells completed in the sea-level aquifer*

[--, no data; <, less than; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate. Concentrations are dissolved unless otherwise noted]

Local well number	34/2-15L2	34/2-15L3	34/2-15R2	34/2-15R3	34/2-22H1
Date sampled	05-20-91	05-20-91	05-20-91	05-20-91	05-20-91
Land surface altitude (feet above sea level)	280	280	240	240	280
Total well depth (feet below land surface)	280	272	273	261	263
Specific conductance (µS/cm)	381	390	359	344	401
pH (standard units)	7.5	7.6	7.8	7.9	7.3
Temperature (degrees Celsius)	13.5	11.0	11.0	11.5	11.5
Oxygen (mg/L)	0	0	0.1	0.1	0
Hardness (mg/L as $CaCO_3$)	160	160	150	140	180
Calcium (mg/L)	27	27	33	32	29
Magnesium (mg/L)	22	22	16	15	25
Sodium (mg/L)	17	17	17	17	16
Percent sodium	18	18	20	20	16
Sodium adsorption ratio	0.6	0.6	0.6	0.6	0.5
Potassium (mg/L)	4.9	5.0	2.8	2.8	5.0
Bicarbonate (mg/L as $CaCO_3$)	202	202	214	200	203
Carbonate (mg/L as $CaCO_3$)	0	0	0	0	0
Total alkalinity (mg/L as $CaCO_3$)	164	166	175	162	166
Sulfate (mg/L)	16	26	<0.1	0.3	28
Chloride (mg/L)	13	18	18	19	18
Fluoride (mg/L)	0.2	0.2	0.2	0.2	0.2
Silica (mg/L)	46	45	39	39	44
Sum of dissolved constituents (mg/L)	248	264	--	224	267
Nitrite plus nitrate nitrogen (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05
Arsenic (µg/L)	<1	<1	<1	<1	<1
Barium (µg/L)	93	79	48	47	63
Cadmium (µg/L)	<1.0	<1.0	<1.0	<1.0	<1.0

Appendix B.--*Water-quality data for samples from wells completed in the sea-level aquifer--Continued*

Local well number	34/2-15L2	34/2-15L3	34/2-15R2	34/2-15R3	34/2-22H1
Chromium (μg/L)	<1	<1	<1	<1	<1
Copper (μg/L)	1	1	1	<1	1
Iron (μg/L)	2,700	3,300	180	180	1,600
Lead (μg/L)	1	<1	1	<1	1
Manganese (μg/L)	120	120	79	59	120
Mercury (μg/L)	<0.1	<0.1	<0.1	<0.1	<0.1
Selenium (μg/L)	<1	<1	<1	<1	<1
Silver (μg/L)	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc (μg/L)	93	680	5	40	310
Organic carbon (mg/L)	1.1	1.0	2	1.8	1.1

Appendix C.--*Water-quality data for samples from seeps*

[<, less than; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; ww, whole water. Concentrations are dissolved unless otherwise noted]

Seep-flow site name	Seep site 1	Seep site 2
Date sampled	05-21-91	05-21-91
Land surface altitude (feet above sea level)	70	10
Specific conductance (µS/cm)	93	98
pH (standard units)	7.2	7.4
Temperature (degrees Celsius)	9.5	9.5
Oxygen (mg/L)	10.7	10.6
Hardness (mg/L)	31	32
Calcium (mg/L)	6.6	6.8
Magnesium (mg/L)	3.5	3.6
Sodium (mg/L)	6.1	6.4
Percent sodium	29	29
Sodium adsorption ratio	0.5	0.5
Potassium (mg/L)	1.3	1.3
Bicarbonate (mg/L as $CaCO_3$)	28	33
Carbonate (mg/L as $CaCO_3$)	0	0
Total alkalinity (mg/L as $CaCO_3$)	23	27
Sulfate (mg/L)	11	10
Chloride (mg/L)	4.6	4.9
Fluoride (mg/L)	0.1	<0.1
Silica (mg/L)	18	18
Solids, residue at 180°Celsius (mg/L)	85	95
Sum of dissolved constituents (mg/L)	68	68
Nitrite plus nitrate nitrogen (mg/L)	0.070	0.087
Iron (µg/L)	230	290
Manganese (µg/L)	25	37
Organic carbon (mg/L)	11	11
Dibromomethane (ww, µg/L)	<0.20	<0.20
Dichlorobromomethane (ww, µg/L)	<0.20	<0.20
Carbon tetrachloride (ww, µg/L)	<0.20	<0.20
1,2-Dichloroethane (ww, µg/L)	<0.20	<0.20
Bromoform (ww, µg/L)	<0.20	<0.20
Chlorodibromomethane (ww, µg/L)	<0.20	<0.20
Chloroform (ww, µg/L)	<0.20	<0.20
Toluene (ww, µg/L)	<0.20	<0.20
Benzene (ww, µg/L)	<0.20	<0.20

Appendix C.--*Water-quality data for samples from seeps--Continued*

Seep-flow site name	Seep site 1	Seep site 2
Chlorobenzene (ww, µg/L)	<0.20	<0.20
Chloroethane (ww, µg/L)	<0.20	<0.20
Ethylbenzene (ww, µg/L)	<0.20	<0.20
Methylbromide (ww, µg/L)	<0.20	<0.20
Methylchloride (ww, µg/L)	<0.20	<0.20
Methylenechloride (ww, µg/L)	<0.20	<0.20
Tetrachloroethylene (ww, µg/L)	<0.20	<0.20
Trichlorofluoromethane (ww, µg/L)	<0.20	<0.20
1,1-Dichloroethane (ww, µg/L)	<0.20	<0.20
1,1-Dichloroethylene (ww, µg/L)	<0.20	<0.20
1,1,1-Trichloroethane (ww, µg/L)	<0.20	<0.20
1,1,2-Trichloroethane (ww, µg/L)	<0.20	<0.20
1,1,2,2-Tetrachloroethane (ww, µg/L)	<0.20	<0.20
1,2-Dichlorobenzene (ww, µg/L)	<0.20	<0.20
1,2-Dichloropropane (ww, µg/L)	<0.20	<0.20
1,3-Dichlorobenzene (ww, µg/L)	<0.20	<0.20
1,4-Dichlorobenzene (ww, µg/L)	<0.20	<0.20
Dichlorodifluoromethane (ww, µg/L)	<0.20	<0.20
trans-1,3-Dichloropropene (ww, µg/L)	<0.20	<0.20
cis-1,3-Dichloropropene (ww, µg/L)	<0.20	<0.20
Vinyl Chloride (ww, µg/L)	<0.20	<0.20
Trichloroethylene (ww, µg/L)	<0.2	<0.2
1,2-Dichloroethene (whole recoverable, µg/L)	<0.2	<0.2
Styrene (ww, µg/L)	<0.2	<0.2
1,1-Dichloropropene (ww, µg/L)	<0.2	<0.2
2,2-Dichloropropane (ww, µg/L)	<0.20	<0.20
1,3-Dichloropropane (ww, µg/L)	<0.20	<0.20
2-Chlorotoluene (ww, µg/L)	<0.20	<0.20
4-Chlorotoluene (ww, µg/L)	<0.20	<0.20
1,2,3-Trichloropropane (ww, µg/L)	<0.20	<0.20
1,1,1,2-Tetrachloroethane (ww, µg/l)	<0.20	<0.20
1,2-Dibromoethane (ww, µg/L)	<0.2	<0.2
Xylene (total recoverable, µg/L)	<0.2	<0.2
Bromobenzene (ww, µg/L)	<0.20	<0.20

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