Ground-Water Hydrology of the Tacoma-Puyallup Area, Pierce County, Washington

By M. A. Jones, L. A. Orr, J. C. Ebbert, and S. S. Sumioka

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
square foot (ft^2)	0.0929	square meter
acre	0.4047	hectare
	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second per mile ($ft^3/s/mi$)	0.0176	cubic meter per second per kilometer
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
cubic foot (ft^3)	28.32	liter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature: To convert temperature given in this report in degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation: °C = 5/9(°F-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.

Altitude: In this report, altitude is measured in feet above sea level.

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ABSTRACT

The northwestern part of Pierce County, Washington, is undergoing growth in population and in urban development, creating increased demands for municipal and domestic water supplies. Because most surface waters are already appropriated, ground-water resources are expected to meet the increasing demands. This report describes the ground-water system in the Quaternary deposits of this area.

The 88-square-mile study area is underlain by unconsolidated Quaternary deposits as much as 1,800 feet thick. Subsurface stratigraphy was delineated by extrapolating information from published surficial geologic maps and from 255 drillers' lithologic logs. The preparation of 17 sections aided in defining 10 hydrogeologic units--5 aquifers 5 semiconfining units--and 1 undifferentiated unit. Maps of the five uppermost units show the extent and topography of the tops of those units. The two major aquifers are units Qc1 and Qc2.

Precipitation over the study area averages an estimated 38 inches per year. Of this, 14 inches per year enters the ground-water system as recharge. Ground water generally moves northward to Puget Sound and east and northeast to the Puyallup River. Locally, the ground water discharges to streams, creeks, and springs within the study area. Discharge from these areas is estimated at 11 inches per year. Another 4.5 inches per year is withdrawn from wells.

During the 1996 water year, 22 billion gallons of water were used to supply the study area's needs. Of this, 15 billion gallons were imported from surface-water sources outside the study area. Approximately 9 billion gallons of water were used for commercial and industrial supplies and 8 billion gallons for public supplies. Much of the remainder was used for domestic supplies, agriculture, aquaculture, and irrigation.

The overall quality of the ground water in the study area is good based on information from the sampled site. Four constituents were found at concentrations above primary drinking water standards or guidelines. Two of the four constituents, the pesticide dieldrin in water from one well and total coliform bacteria in water from four wells or springs, were at levels exceeding standards or guidelines related to human health. Concentrations of iron or manganese in water from eight wells and springs exceeded secondary drinking water standards. Concentrations of iron or manganese in ground water above secondary drinking water standards are common for the Puget Sound region. Concentrations of the other constituents were below drinking water standards or guidelines.

INTRODUCTION

The northwestern part of Pierce County (fig. 1) is one of several areas in the Puget Sound region of western Washington that is experiencing rapid growth in population and urban development and therefore has increasing demands for water for public supply, domestic, commercial, and industrial uses. Historically, the area has relied on surface water from the Green River and ground water from local springs and wells to meet water demands. However, increasing demands have resulted in several municipalities in northwestern Pierce County drilling additional public-supply wells or replacing older wells with more productive wells to satisfy both normal and peaking water demands.

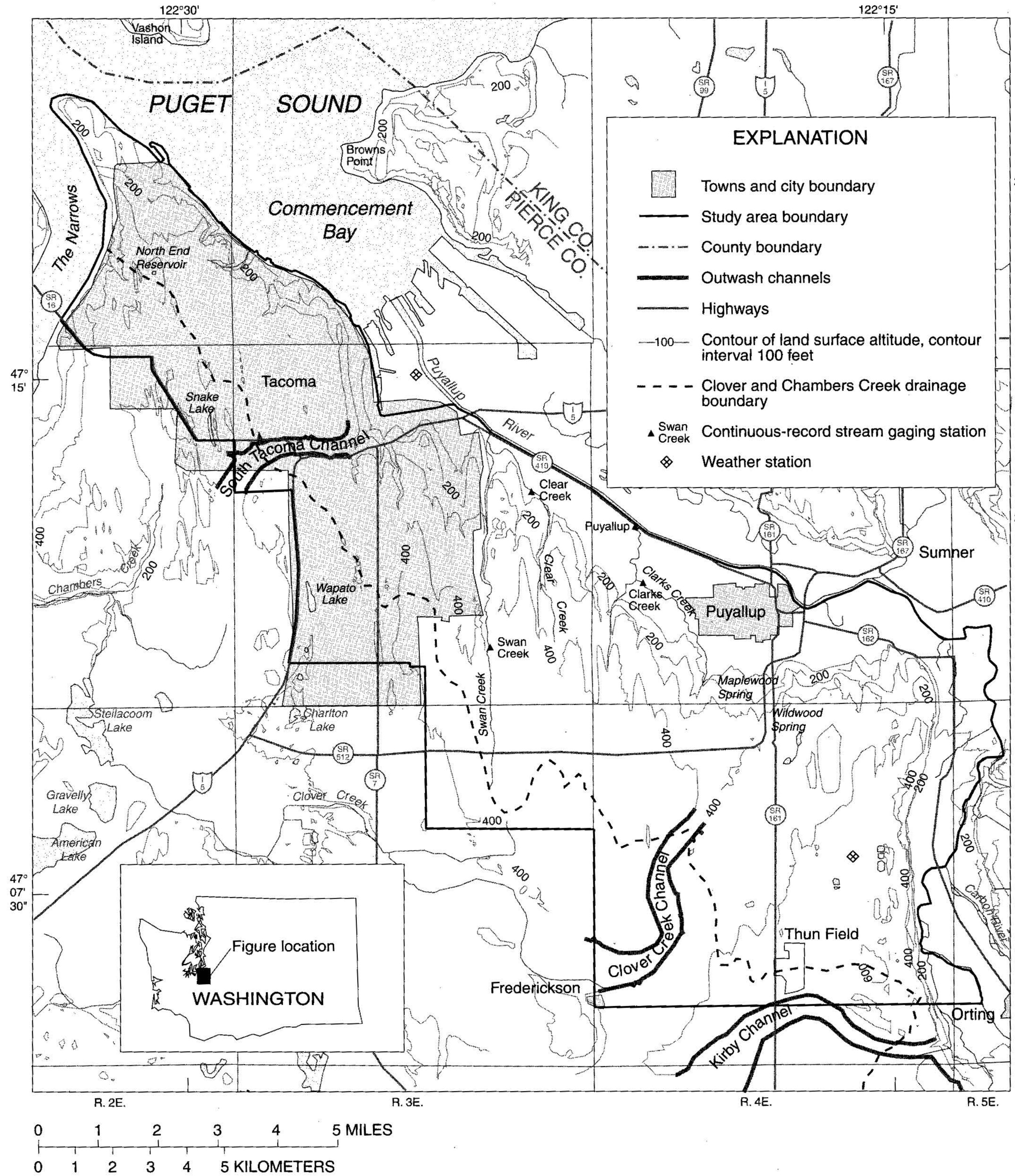


Figure 1. Location of the study area.

The availability of ground water and the effects of withdrawals from wells on nearby wells, lakes, springs, and wetlands are becoming important issues. The Washington Department of Ecology (Ecology), which manages the State's water resources and issues rights for both ground- and surface-water withdrawals, has currently limited appropriations for ground water within the study area and no longer issues them for surface water there because these rights have been fully appropriated. Thus, many municipalities have transferred appropriations from older, less productive wells to newly drilled, more productive wells. Another concern is that ground-water recharge may be reduced by current land development that impedes precipitation from infiltrating downward into the ground, thus increasing surface runoff and the potential of flooding during large storms.

In addition, ground-water quality is of concern. These concerns include potential contamination related to industrial and waste-disposal practices, the distribution and large number of septic systems in the area, land-use practices, the potential for seawater intrusion along the shore of Puget Sound, and large iron and manganese concentrations that naturally occur in some of the wells completed in Quaternary deposits.

In order to plan for the development, use, and management of the water resources of the area, a better understanding of the entire natural hydrologic system is needed, including the geometry of the aquifers and semiconfining units, directions of the ground-water movement system, water-quantity characteristics, recharge rates, and the water budget.

Concerns about how to effectively plan and provide for the increased water demand for the rapidly increasing industrial and residential growth in northwestern Pierce County are not new. Regional studies evaluating the ground-water resources in the Tacoma-Pierce County area were conducted in the mid 1930's (LaRocque and Piper, 1938; and Piper and LaRocque, 1938) and continued through the late 1960's (Griffin and others, 1962; and Walters and Kimmel, 1968).

Since the completion of these studies, state and local agencies responsible for managing the water resources have become increasingly concerned about ground-water quantity and quality problems. Thus, in 1995, the U.S. Geological Survey (USGS) began a cooperative study to assess the ground-water system of the Quaternary deposits that underlie northwestern Pierce County. Agencies cooperating with the USGS in this study include Ecology, the Tacoma-Pierce County Health Department, the City of Puyallup, and the City of Tacoma. The objectives of the study were to

(1) describe and quantify the ground-water system to the extent allowed using available and readily collectible data;

(2) describe the general water chemistry of the major hydrogeologic units and any regional patterns of contamination; and

(3) prepare a water budget of the study area.

Purpose and Scope

This report describes and quantifies the ground-water system in the Quaternary deposits in northwestern Pierce County, based on the objectives listed in the Introduction section. The report includes descriptions of the geometry and physical characteristics of selected hydrogeologic units, ground-water movement system, recharge, water use, water-level fluctuations, and general ground-water chemistry.

Description of the Study Area

The northwestern Pierce County study area is irregularly shaped and covers 88 mi^2 (square miles) (fig. 1). The area is bounded on the northwest by The Narrows and on the north by Puget Sound and Commencement Bay. The Puyallup River forms the boundary from Commencement Bay on the north, along the east side of the study area to just west of the town of Orting. The southern boundary extends from Orting west to the town of Frederickson. The southwestern boundary approximately follows the northeastern drainage divides of Clover and Chambers Creeks (fig. 1).

The physiography of the study area is a product of the most recent glaciation and the more recent alluvial processes of the Quaternary Period. The study area consists of an upland drift plain that covers most of the study area and has been transected by three glacial outwash channels and of an alluvial valley on the east that is part of the Puyallup River Valley.

The upland drift plain ranges from 200 to 600 ft (feet) above sea level and is generally composed of fine-grained deposits. The outwash channels that traverse the upland drift plain are from north to south, the South Tacoma, Clover Creek, and Kirby Channels (Bretz, 1913; and Walters and Kimmel, 1968) (fig. 1). The outwash channels were cut by meltwater streams formed when successively lower outlets from an ice-dammed lake were exposed as a glacier receded from the Puget Sound Lowland. As lower outlets formed, the outwash filled channels with coarse-grained sand and gravel deposits.

The Puyallup River Valley ranges in altitude from sea level near Tacoma to 150 ft near Orting (fig. 1). The valley floor is composed of coarse- to fine-grained deposits that include alluvial, marine, and mudflow deposits (Walters and Kimmel, 1968; Dragovich and others, 1994).

The study area has a temperate marine climate with warm, dry summers and cool, wet winters; the mean annual temperature is about 52°F. The warmest month of the year is July, with an average temperature of about 63°F, and the coolest month of the year is January, with an average temperature of about 38°F (National Oceanic and Atmospheric Administration, 1995 and 1996).

About 70 percent of the precipitation in the area occurs during the months of October through March, based on long-term data from the McMillin Reservoir and the Tacoma weather stations (1941 to 1996) (National Oceanic and Atmospheric Administration, 1996). Although the seasonal distribution of precipitation is similar throughout the area, annual precipitation totals vary with altitude. Precipitation at the Tacoma weather station, altitude 25 ft, has averaged 37 inches a year, and at McMillin Reservoir, altitude 579 ft, it has averaged 42 inches a year (Daly and others, 1994; National Oceanic and Atmospheric Administration, 1996).

The area is transected by several creeks whose headwaters originate within the study area, and the area is bordered on the east by the Puyallup River, which originates at Mount Rainier in the Cascade Range. The creeks include Swan, Clear, and Clarks Creeks, which flow northward into the Puyallup River and out to Commencement Bay, and Clover and Chambers Creeks, which flow southwest into the Puget Sound (fig. 1).

Much of the area is urban, with most of the population concentrated in the cities. Seventy-three percent of the estimated 1996 population of 228,000 within the study area reside within the incorporated Cities of Puyallup and Tacoma (Puget Sound Regional Council, 1997). The population increased 5.6 percent from 1990 to 1996, with most of the growth occurring in the cities. Most of the water supplied to the area is from eight public-supply systems. About 97 percent of water use is for residential, commercial, and industrial purposes. About 3 percent of the water is used for agriculture, aquaculture, irrigation, and system losses. About 75 percent of the population in the study area are on municipal sewer systems. The sewered areas include the Cities of Puyallup and Tacoma and a small portion of the unincorporated part of the study area. Treated water from Tacoma and the unincorporated part of the study area sewer systems is discharged into Commencement Bay, and treated water from the Puyallup sewer system is discharged into the Puyallup River.

Well-Numbering System

The USGS assigns numbers to wells and springs in Washington that identify their location in a township, range, and section. Well number 19N/03E-10P02 indicates, successively, the township (T. 19 N.) and range (R. 03 E.) north and east of the Willamette base line and meridian. The first number following the hyphen indicates the section (10) within the township, and the letter following the section number gives the 40-acre subdivision of the section, as shown below (fig. 2). The number (02) following the letter is the sequence number of the well within the 40-acre subdivision. This number indicates that the well was the second one inventoried by the USGS personnel in that 40-acre tract. An "S" following the sequence number indicates that the site is a spring, a "D1" after the sequence number indicates that the original reported depth of the well has been changed once, and successive numbers indicate the number of changes in the well depth.

Acknowledgments

The authors wish to express their appreciation to the many well owners and well drillers who supplied well records and other information and allowed access to their wells. We also acknowledge the assistance and information supplied by managers and owners of the public water-supply systems and water districts; these include the Cities of Puyallup and Tacoma, the Summit Water and Supply Company, Fruitland Mutual Water Company, Firgrove Mutual Water Company, Parkland Light and Water Company, Southeast Tacoma Mutual Water Company, and Valley Water District. We express our appreciation to Lynn Gooding of the Washington Department of Ecology and Bryant Adams at Matsushita Semiconductor Corporation of America for information obtained for some sites. Numerous consulting firms working in cooperation with petroleum and industrial distributors were helpful by providing information and reports of their investigations. The petroleum and industrial distributors providing data and reports from their sites are the Atlantic Richfield Company (ARCO), British Petroleum (BP), Chevron Oil Company, Shell Oil Company, Texaco Oil Company, Union Oil

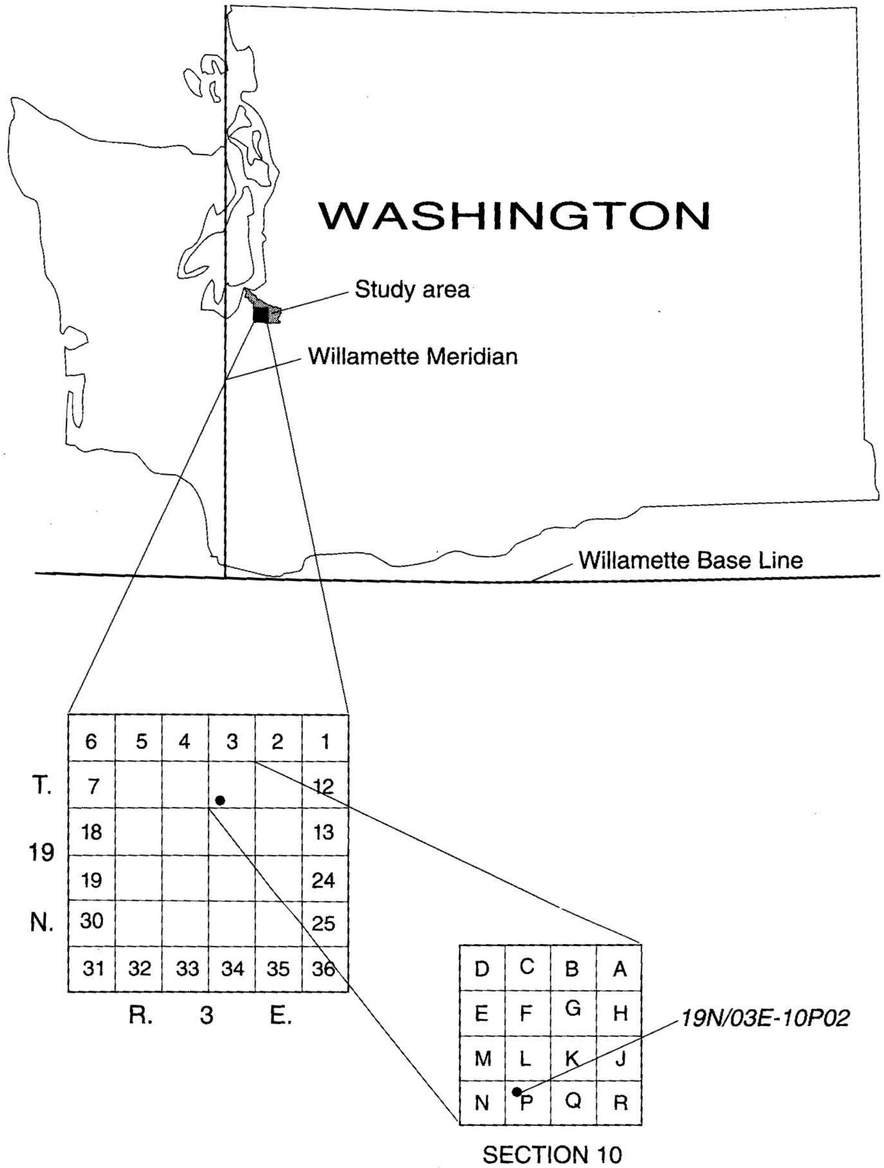


Figure 2. Well- and spring-numbering system used in Washington.

Company (UNOCAL), and American Smelting and Refining Company (ASARCO). Consultants that provided information and reports from their investigations of these sites are K.V. Lew of Agra Earth and Environmental, Kurt Fraese of Geo-Engineers, Howard Small of Texaco Environmental Services, Gary Gunderson of UNOCAL, John Johnson of Pacific Environmental Group, Al Thatcher of Dames and Moore, and Rens Verburg of Hydrometrics, Inc. These individuals and firms provided information for sites within municipal boundaries where ground-water data are sparse.

STUDY METHODS

This study began with the compilation of existing spring, well, piezometer, test hole, and bridge boring records obtained from files of the USGS, Ecology, consulting firms, and well owners. Beginning in March of 1995, more than 1,750 records were reviewed; from these records 400 sites were selected for field inventory. The selection of wells to be inventoried was based on the well owner's or tenant's permission to visit the well, the location and depth of the well, the availability of a driller's log or equivalent, and the ease of access to the well. Priority was also given to wells previously inventoried by the USGS and wells that were open to only one hydrogeologic unit.

An attempt was made to inventory an even areal distribution of the wells within the study area. But this was not possible for the entire study area. Because of a lack of wells in the northwestern part of the study area, a few wells were inventoried in an adjacent area outside the study area. In many instances, only one or two wells in a given section were available to inventory, which limited the areal distribution. However, where several wells were available, field personnel inventoried the most readily accessible well. As a result, a well may have been inventoried simply because the owner was home.

The springs selected for inventory were primarily from the list of previously inventoried springs published in Walters and Kimmel (1968). A few additional springs identified by water purveyors and USGS field personnel were also inventoried.

During the summer of 1995, 318 sites were inventoried by USGS field personnel; of these, 287 were wells and 31 were springs. Ten of the springs had been destroyed (fig. 3 and appendix 1). General information gathered at all inventoried sites included site location, land surface altitude, specific conductance and temperature (when available) of the water, primary use of water, owner's or tenant's comments on water quality and yield, surrounding land-use practices, and construction details of the site. Site locations were plotted on USGS 1:24,000-scale topographic maps. Altitudes of the land surface at each well or spring were interpolated from the topographic maps with an accuracy of plus or minus 10 ft. Latitude and longitude locations were also estimated from the topographic maps with an accuracy of plus or minus 5 seconds (a few hundred feet). Randomly selected wells were cross checked using a satellite-based Global Positioning System (GPS) with a horizontal accuracy of 10 feet. Specific conductance and temperature measurements were determined for water samples from 129 wells and 18 springs with a field meter that was calibrated daily. Washington Department of Ecology identification tags were attached to 112 wells and 1 spring after obtaining the owner's permission. Information collected during the inventory was entered into the USGS National Water Information System (NWIS) data base.

In addition, the depth to water in the wells was measured when possible (appendix 1) using a graduated steel tape accurate to plus or minus 0.01 ft or an electric tape accurate to 0.1 ft. The accuracy of the water-level altitudes (land surface altitude of the well minus depth to water) depends primarily on the accuracy of the land surface altitudes of the wells. The land surface altitudes were interpolated from topographic maps; thus the accuracy of the water-level altitude is plus or minus 10 feet.

At spring sites, discharge measurements and hydrogeologic unit identifications were made. Depending on the amount and location of the spring discharge, measurements were made with one or more of the following: a 3-inch Parshall flume (U.S. Geological Survey, 1983), a 5-gallon bucket and a stopwatch, a standard 90 degree V-Notched weir, or a standard rectangular weir. Discharge measurements at springs were made twice, once during the fall of 1995 and again in the spring of 1996. Hydrogeologic unit assignments were made by noting the location and altitude of the spring and by examining the type and thickness of exposed geologic deposits above and below the spring.

A network of 36 inventoried wells was selected for bimonthly measurements of water level and, when possible, specific conductance and temperature to track seasonal water-level variations. Closely spaced wells, for example, 20N/03E-20P1 and 20N/03E-20P2, completed at different depths, 117 ft and 254 ft, respectively, were selected to evaluate the vertical differences between the two aquifer units. Because data were sparse in the northwestern part of the study area, three wells (20N/02E-12M01, 20N/02E-12M02, and 20N/02E-12Q1) just outside the study area were selected for bimonthly visits. One of the bimonthly sites, well 19N/04E-03K02, was destroyed 16 months after the inventory began.

Hydrogeologic Methods

Information from previous publications on the surficial geology (Walters and Kimmel, 1968), coastal and bluff outcrop geology (Washington Department of Ecology, 1979; Crandell and Mullineaux, 1965), and nearby lithologic sections (Brown and Caldwell, 1985) was used along with the driller's lithologic logs and information from field observations to approximately delineate the hydrogeologic units of the area. From the inventoried wells, 153 wells were used to construct 17 hydrogeologic sections trending north-south and east-west across the study area. From these 17 sections, 5 representative sections are presented in this report (see Hydrogeologic Framework). The 71 lithologic logs used to construct the 5 sections are provided in appendix 2. The sections were used to identify and correlate the continuity of aquifer and semiconfining hydrogeologic units in the study area. Starting at land surface and moving downward through the unconsolidated Quaternary deposits, each hydrogeologic unit was extrapolated laterally to the extent available data would allow. Generally, the thinner or deeper the hydrogeologic unit, the less certain is its correlation. Because the hydrogeologic units identified are a generalization of the lithologies based on their hydrologic properties, they do not necessarily represent time-stratigraphic geologic units.

Information from the sections, surficial geology, and the remaining 102 inventoried wells with drillers' logs that were not used in the construction of the 17 sections was then used to construct maps of the altitudes of the tops of the uppermost hydrogeologic units. These altitudes are listed in table 15 (at end of text). The tops of the units commonly reflect the trend of the surface topography. The thicknesses reported in the text are based on interpretations of these same inventoried wells. The surficial hydrogeologic map was constructed by combining similar lithologies of the surficial geologic map, interpretations from the sections, and information from the driller's lithologic logs.

Horizontal hydraulic conductivities were estimated based on pump or bail-test specific-capacity data reported in the drillers' logs. Information was available for 138 inventoried wells and 14 noninventoried wells in the study area (appendix 1). All wells used to estimate the hydraulic conductivity were open to one hydrogeologic unit, and all but 14 wells had complete specific-capacity information (discharge rate, drawdown, time, well-construction data, and a geologic log). The test duration at the 14 wells was not reported but was assumed to be 1 hour, which is typical for specific-capacity tests in the area (appendix 1). If the actual time for the specific-capacity test was longer, the hydraulic conductivity of the well would have been greater than the one calculated for these wells.

Two different methods were used to calculate the horizontal hydraulic conductivity. For those wells constructed with screened or perforated intervals, the modified Theis equation (Theis, 1963) for nonleaky artesian aquifers (Ferris and others, 1962) was first used to estimate test transmissivity values. This equation is

$$T = \frac{Q}{4\pi s}\ln\frac{2.25Tt}{r^2S}, \qquad (1)$$

where

T = transmissivity of the hydrogeologic unit, in ft^2/d (square feet per day);
Q = discharge, or pumping rate, of the well, in ft^3/d (cubic feet per day);
s = drawdown in the well, in feet;
t = length of time the well was pumped, in minutes;
r = effective radius of the well, in feet; and
S = storage coefficient, a dimensionless decimal.

The modified Theis equation also requires an assumed value for the storage coefficient; a value of 0.0002 was used for wells in confined aquifers, and a value of 0.2 was used for wells in unconfined aquifers. The potential error to the calculated hydraulic conductivity is directly proportional to the error in the assumed storage coefficient value. In general this might amount to a factor of 2 or less. To then estimate an average hydraulic conductivity, the transmissivity value was divided by the length of open-interval of the well.

$$K_h = T/b, \qquad (2)$$

where

Kh = horizontal hydraulic conductivity of the hydrogeologic unit, in ft/d;
T = transmissivity, as calculated above; and
b = thickness of the hydrogeologic unit, in feet, approximated by the length of the open interval as described on the driller's log.

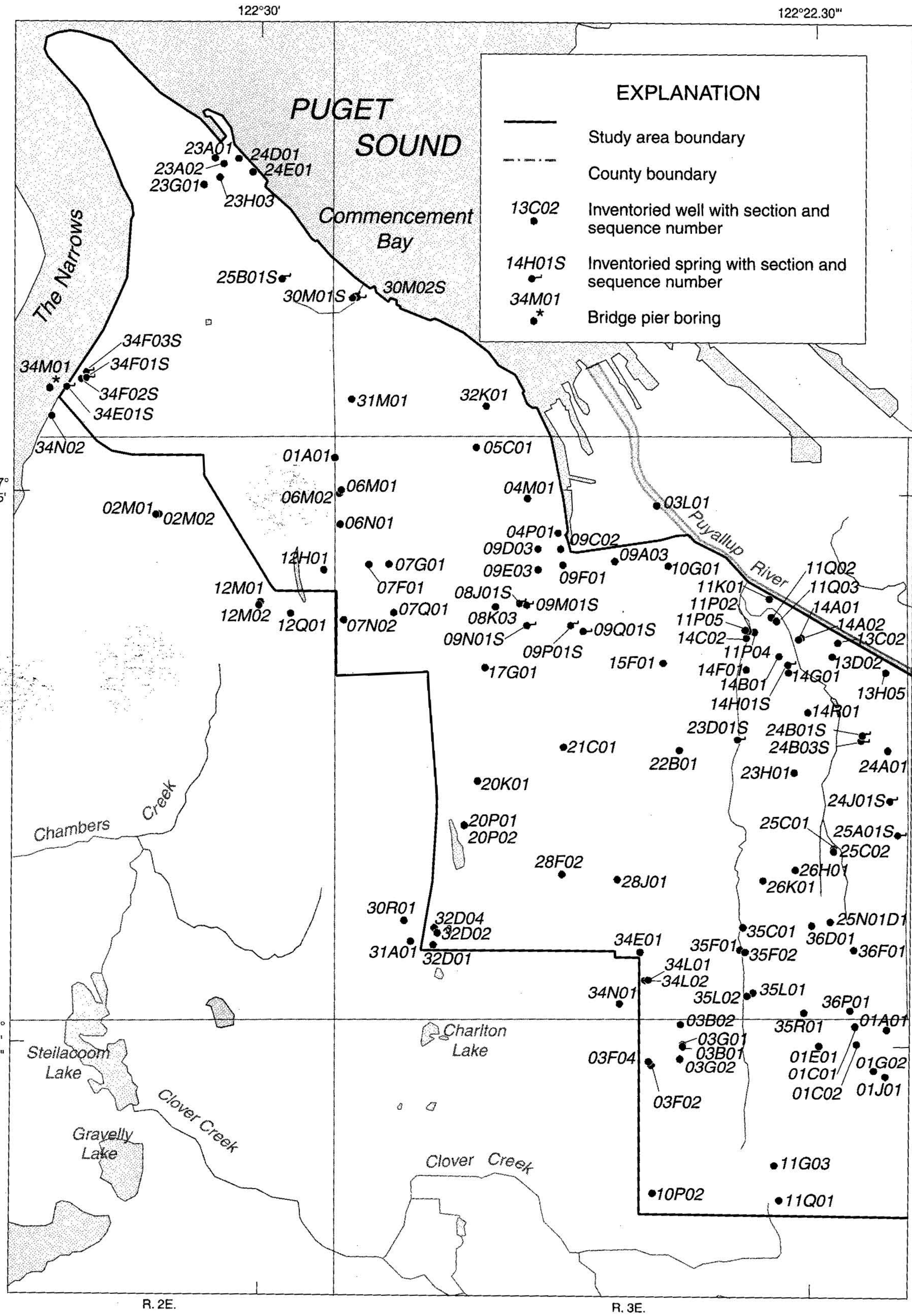
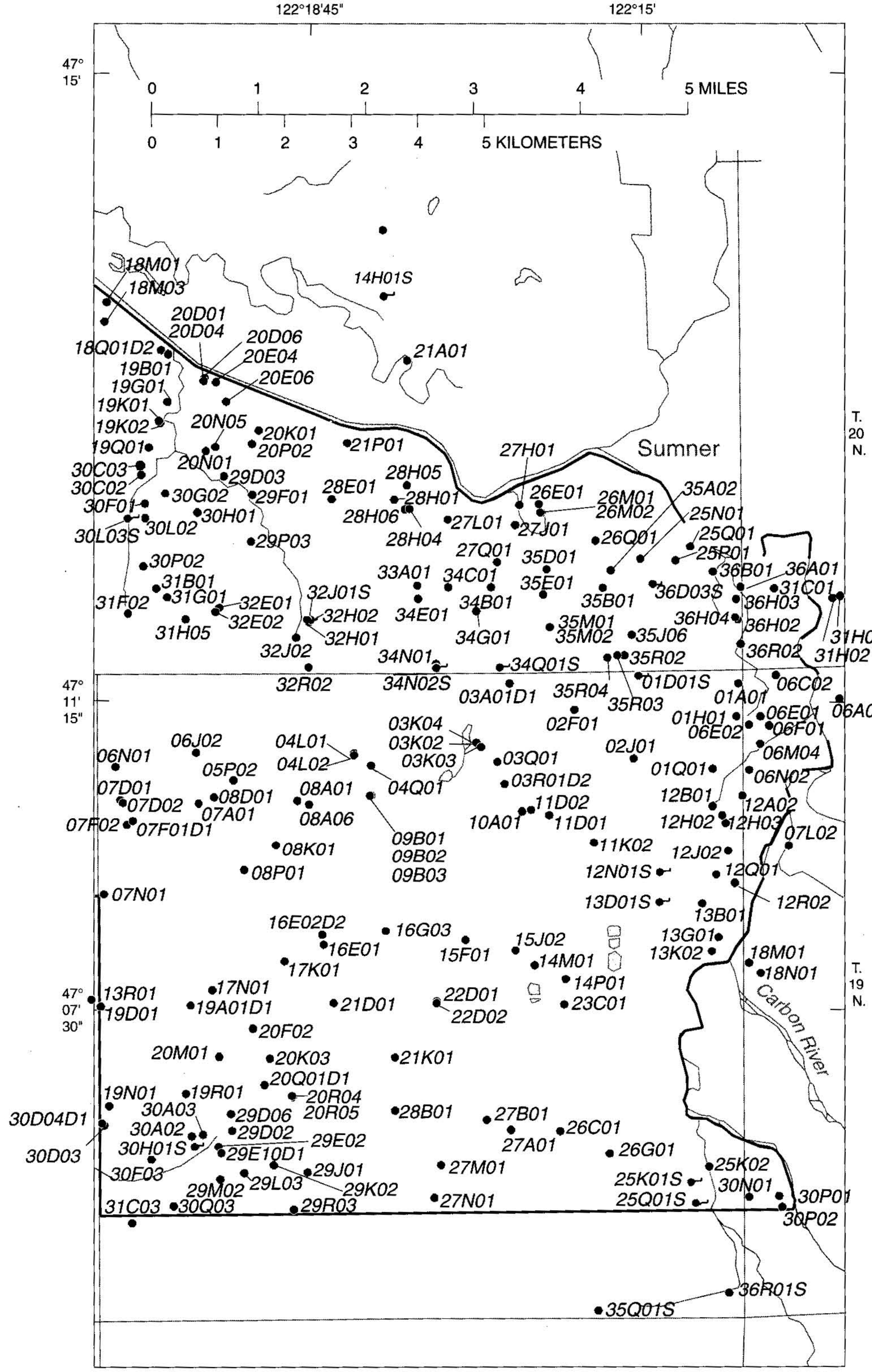


Figure 3. Locations of wells and springs inventoried in the Tacoma-Puyallup area, Washington.


122°18'45"
122°15'
47° 15'
47° 11' 15"
47° 07' 30"
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
Sumner
Carbon River
T. 20 N.
T. 19 N.
R. 4E.
R. 5E.
18M01
18M03
14H01S
20D01
20D04
20D06
20E04
20E06
18Q01D2
19B01
19G01
19K01
19K02
21A01
20N05
20K01
20P02
21P01
19Q01
27H01
30C03
30C02
20N01
29D03
28H05
30G02
29F01
28E01
28H01
26E01
26M01
26M02
35A02
30F01
30H01
28H06
27L01
27J01
25N01
30L03S
30L02
28H04
26Q01
25Q01
29P03
27Q01
35D01
25P01
30P02
33A01
34C01
36B01
36A01
31B01
35E01
36D03S
31C01
31F02
31G01
32E01
32J01S
34B01
35B01
36H03
32E02
32H02
34E01
36H04
36H02
31H05
32H01
35M01
35M02
35J06
31H03
32J02
34G01
36R02
31H02
34N01
35R02
32R02
34N02S
34Q01S
01D01S
06C02
03A01D1
35R04
01A01
35R03
06A01
03K04
02F01
01H01
06E01
06J02
04L01
03K02
06E02
06F01
06N01
03K03
03Q01
02J01
06M04
04L02
01Q01
05P02
04Q01
03R01D2
06N02
07D01
08D01
08A01
12B01
07D02
07A01
11D02
12A02
07F02
07F01D1
08A06
10A01
11D01
12H02
12H03
07L02
09B01
08K01
09B02
11K02
12J02
08P01
09B03
12N01S
12Q01
07N01
13D01S
12R02
13B01
16E02D2
16G03
15J02
13G01
16E01
15F01
14M01
13K02
18M01
17K01
18N01
14P01
17N01
13R01
22D01
19D01
19A01D1
21D01
22D02
23C01
20F02
20M01
20K03
21K01
20Q01D1
19N01
19R01
20R04
30A03
20R05
28B01
27B01
30D04D1
29D06
30A02
29D02
26C01
29E02
30H01S
27A01
26G01
29E10D1
30D03
25K02
30F03
29J01
27M01
25K01S
30N01
29M02
29L03
29K02
30P01
25Q01S
27N01
31C03
30Q03
29R03
30P02
36R01S
35Q01S

This method assumes that well entrance losses are negligible, that the well is screened across the full thickness of the aquifer, and that flow into the well is sustained by withdrawal from storage within the screened interval of the well. In reality some of the water flows vertically to the well from above and below the well screen. Even though neglecting the vertical flow conditions may result in an overestimation of the horizontal hydraulic conductivity and aquifer transmissivity, the amount of error is probably small because the layering within the hydrogeologic units tends to make horizontal flow easier than vertical flow.

For wells having only an open end and thus no vertical dimension to the open interval, Bear (1979) provides for an equation for hemispherical flow of a well just penetrating a hydrogeologic unit. When modified for spherical flow to an open-ended well within a unit, the equation to estimate the hydraulic conductivity becomes

$$K_h = \frac{Q}{4\pi sr}, \qquad (3)$$

where

Kh = horizontal hydraulic conductivity of the hydrogeologic unit, in ft/d;

Q = discharge, or pumping rate of the well, in ft^3/d;

s = drawdown in the well, in feet; and

r = radius of the well, in feet.

This equation assumes that ground water can flow equally in all directions and specifically that horizontal and vertical hydraulic conductivities are equal. This is not likely to be true for aquifers in the study area, given their heterogenous nature. However, the errors associated with violating this assumption for open-ended wells are thought to be less than those resulting from using the modified Theis equation described above.

Ground-water recharge from precipitation was estimated based on the results obtained from a deep-percolation recharge model (Bauer and Vaccaro, 1987) completed in southwest King County, just northeast of the study area in similar lithologic deposits (Woodward and others, 1995). The regression equations from this model were used to create two curves based on precipitation, recharge, and lithology for a study completed in east King County (Turney and others, 1995). These two curves and more recent publications on recharge in till-mantled catchments by Bauer and Mastin (1997) were used to calculate the recharge for the study area. The equations and interpretation are discussed in greater detail in the section on recharge (Ground-Water Recharge).

Water-Use Methods

Water-use data for this study were determined for water year 1996 (October 1995 through September 1996). Most of the data collected were obtained by telephone canvassing of the major water users in the study area. Major categories of water use included metered and estimated pubic-supply systems, public-supply systems water loss, domestic, irrigation, agriculture, aquaculture, commercial, and industrial uses. Information on the water users in the study area was obtained from Ecology, Washington State Department of Health, available drillers' logs or equivalents, and information gathered from owners or water managers during field inventory. Because some water users may not have been contacted, all water-use totals represent minimum values. Selected water-use data collected from all sites included owner's name, mailing address, site location address, contact person, sources of water, actual or estimated ground-water withdrawal, and whether the ground-water withdrawal from the well or spring was metered. Depending on the use of the site, additional information was gathered that included the percent of commercial, industrial, water loss, and residential use, both permanent and seasonal; the amount of land irrigated; the types of crops grown; and the types and number of livestock using the water. The quantity of ground water withdrawn was then categorized by hydrogeologic unit based on the open-interval of the well.

Water-use estimates were made for all public-supply systems in the study area. Public water systems at the time of this study were divided into two classes, Group A and Group B, by the Washington Department of Health (Washington Department of Ecology, 1994). Group A systems are defined as having 15 or more connections and are subject to federal and state regulations. Group B water systems are defined as having 2 to 14 connections and are subject only to state and local regulations. Within the study area, 8 Group A and 12 Group B public-water systems were identified. Data available from six Group A systems and eight Group B systems were metered, and the actual ground-water withdrawal data were used. For the remaining two Group A and four Group B water systems, for which metered withdrawal values were unavailable, water managers provided estimates of the number of connections and average number of persons per connection. The withdrawal and population data from the metered systems were used to determine the average water use per person per day (93.5 gallons). This data and the information provided by the water managers were then entered into the following formula from which water-use estimates were made for the nonmetered systems.

$$W = C \times P \times 93.5 \text{ gallons per person per day} \times 366 \text{ days} \quad (4)$$

where

W = estimated annual system withdrawal, in gallons;
C = number of connections;
P = average number of persons per connections;
93.5 gallons per person per day = per capita rate based on average water use per person per day for Group A and B metered systems; and
366 days = number of days in 1996 water year.

The average estimated water loss was 7 percent, based on information from the public-supply systems inventoried in the study area.

Annual ground-water withdrawals from privately owned wells and springs for domestic use were calculated by first determining the population of the study area whose homes were supplied by Group A or Group B public-supply systems (172,000 people) and subtracting the number from the total population of the study area (228,000 people). The difference (56,000) was then multiplied by 366 days and then by the per capita rate of 93.5 gal/d (gallons per day).

Ground-water withdrawals for irrigation, agriculture, and aquaculture activities were based on the operators' estimates. Information on water use for irrigated acreage and herd size were obtained by telephone and personal contact with farmers identified by USGS personnel during the well-inventory process. If estimates were unknown or uncertain, withdrawals were calculated by one of the following methods. For crop irrigation, one of two methods were used: (1) the pumping capacity of the irrigation well was multiplied by the owner's estimate of duration of pumping; or (2) an application rate of water specific to the crop being raised (W. R. Bidlake, U.S. Geological Survey, written commun., 1997; and James and others, 1988) was multiplied by the estimates of irrigated acreage per year (irrigation season). To determine agricultural and aquacultural consumption, the number of stock or fish was multiplied by the estimated daily consumption per animal and the number of days of consumption (U.S. Soil Conservation Service, 1975).

Water-use estimates for commercial and industrial use were supplied either by operators whose water supply was self-supplied from the company's privately owned well or by managers of public-supply systems who supply water for commercial and industrial use. It is unlikely, however, that all commercial and industrial wells in the study area were identified and inventoried during this study.

Water-Quality Methods

Water samples were collected from 33 sites, which included 29 wells and 4 springs, in late June and early July of 1996. Samples from all 33 sites were analyzed for concentrations of major ions, bacteria, arsenic, and nitrates. In addition, on-site measurements of carbonate, bicarbonate, alkalinity, temperature, specific conductance, pH, and dissolved-oxygen concentrations were made at all sites. Subsets of the samples from 33 sites were analyzed for additional constituents. In urban areas where septic tank density was generally high, samples from 22 sites were analyzed for boron and methylene blue active substances (MBAS). Samples from 12 sites, generally springs and shallow wells (generally less than 100 ft), were analyzed for trace elements, which included arsenic, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc (table 1 and appendix 3). When a trace element analysis was performed, a separate analysis for arsenic was not done because arsenic is included in the trace element analysis. Another group of samples from 12 sites composed of springs and shallow wells was analyzed for volatile organic compounds (VOCs) (table 2). Samples from 12 sites, of generally shallow wells and springs, were analyzed for pesticides (table 3). Samples from 11 sites were analyzed for radon, and samples from 12 sites were analyzed for total organic carbon (TOC).

Many factors played a role in the selection of sampling sites and the analysis performed on these samples. Sampling sites were selected on the basis of surficial geology and land use, which included agriculture, forested, urban, and rural areas; of previous sampling of wells; of well location, whether in a sewered or nonsewered area; and of permission by the owner to sample. Because of the regional nature of this study, no attempt was made to sample sites affected by known small-scale or point source problems. However, an effort was made to sample sites that might be representative of widespread water-quality problems. Thus, areas of potential ground-water-quality problems, such as elevated nitrate, bacteria or the presence of pesticides, were considered in the site-selection process. An effort was also made to collect samples near large commercial or industrial areas for analysis of VOCs, TOCs, and trace metals. However, only two such wells could be found.

Table 1.--*Chemical Abstract Services registry number and minimum reporting level for selected major ions, trace elements, and other constituents in the Tacoma-Puyallup area, Washington*
[mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; col./100 mL, colonies per 100 milliliters]

Constituent	Chemical Abstract Services (CAS) registry number	Minimum reporting level	
Major ions			
Bicarbonate (measured onsite)	none	1	mg/L
Calcium (dissolved)	7440-70-2	0.02	mg/L
Carbonate (measured onsite)	3812-32-6	1	mg/L
Chloride (dissolved)	16887-00-6	0.1	mg/L
Fluoride (dissolved)	16984-48-8	0.1	mg/L
Magnesium (dissolved)	7439-96-5	0.01	mg/L
Nitrite + nitrate (dissolved)	none	0.05	mg/L
Potassium (dissolved)	7440-09-7	0.1	mg/L
Sodium (dissolved)	7440-23-5	0.2	mg/L
Sulfate (dissolved)	14808-79-8	0.1	mg/L
Trace elements			
Arsenic (dissolved)	7440-38-2	1	µg/L
Barium (dissolved)	7440-39-3	2	µg/L
Boron (dissolved)	7440-42-8	4	µg/L
Cadmium (dissolved)	7440-43-9	1	µg/L
Chromium (dissolved)	7440-47-3	1	µg/L
Copper (dissolved)	7440-50-8	1	µg/L
Iron (dissolved)	7439-89-6	3	µg/L
Lead (dissolved)	7439-92-1	1	µg/L
Manganese (dissolved)	7439-96-5	1	µg/L
Mercury (dissolved)	7439-97-6	0.1	µg/L
Radon-222 (total)	14859-67-7	80	pCi/L
Selenium (dissolved)	7782-49-2	1	µg/L
Silver (dissolved)	7440-22-4	1	µg/L
Zinc (dissolved)	7440-66-6	3	µg/L
Bacteria			
Escherichia coli	none	1	col./100 mL
Streptococci, Fecal	none	1	col./100 mL
Total coliform	none	1	col./100 mL
Other constituents			
Alkalinity (measured onsite)	471-34-1	1	mg/L
Dissolved solids	none	computed value	mg/L
Methylene blue active substances (MBAS)	none	0.02	mg/L
Organic carbon (total)	none	0.1	mg/L
Silica (dissolved)	7631-86-9	0.1	mg/L

Table 2.--*Volatile organic compound analyzed for, Chemical Abstract Services registry number, and minimum reporting level*
[µg/L, micrograms per liter]

Volatile organic compounds	Chemical Abstract Services (CAS) registry number	Minimum reporting level (µg/L)
1,1,1,2-Tetrachloroethane	630-20-6	0.2
1,1,1-Trichloroethane	71-55-6	0.2
1,1,2,2-Tetrachloroethane	79-34-5	0.2
1,1,2-Trichloroethane	79-00-5	0.2
1,1,2-Trichlorotrifluoroethane	76-13-1	0.2
1,1-Dichloroethane	75-34-3	0.2
1,1-Dichloroethene	75-35-4	0.2
1,1-Dichloropropene	563-58-6	0.2
1,2,3-Trichlorobenzene	87-61-6	0.2
1,2,3-Trichloropropane	96-18-4	0.2
1,2,4-Trichlorobenzene	120-82-1	0.2
1,2,4-Trimethylbenzene	95-63-6	0.2
1,2-Dibromo-3-chloropropane (DBCP)	96-12-8	1
1,2-Dibromoethane (EDB)	106-93-4	0.2
1,2-Dichlorobenzene (ortho)	95-50-1	0.2
1,2-Dichloroethane	107-06-2	0.2
1,2-Dichloropropane	78-87-5	0.2
1,3,5-Trimethylbenzene	108-67-8	0.2
1,3-Dichlorobenzene (meta)	541-73-1	0.2
1,3-Dichloropropane	142-28-9	0.2
1,4-Dichlorobenzene (para)	106-46-7	0.2
2,2-Dichloropropane	594-20-7	0.2
2-Chlorotoluene	95-49-8	0.2
4-Chlorotoluene	106-43-4	0.2
Benzene	71-43-2	0.2
Bromobenzene	108-86-1	0.2
Bromochloromethane	74-97-5	0.2
Bromodichloromethane	75-27-4	0.2
Bromoform	75-25-2	0.2
Bromomethane	74-83-9	0.2
n-Butylbenzene	104-51-8	0.2
Carbon tetrachloride	56-23-5	0.2
Chlorobenzene	108-90-7	0.2
Chloroethane	75-00-3	0.2
Chloroform	67-66-3	0.2
Chloromethane	74-87-3	0.2
Chlorodibromethane	124-48-1	0.2

Table 2.--*Volatile organic compound analyzed for, Chemical Abstract Services registry number, and minimum reporting level--Continued*

Volatile organic compounds	Chemical Abstract Services (CAS) registry number	Minimum reporting level (µg/L)
Dichlorodifluoromethane (CFC 12)	75-71-8	0.2
Ethylbenzene	100-41-4	0.2
Hexachlorobutadiene	87-68-3	0.2
Isopropylbenzene	98-82-8	0.2
Methylene chloride	75-09-2	0.2
Methyl tert-butyl ether (MTBE)	1634-04-4	0.2
Naphthalene	91-20-3	0.2
n-Propylbenzene	103-65-1	0.2
p-Isopropyltoluene	99-87-6	0.2
Styrene (total)	100-42-5	0.2
Tetrachloroethene	127-18-4	0.2
Toluene	108-88-3	0.2
Trichloroethene	79-01-6	0.2
Trichlorofluoromethane (CFC 11)	75-69-4	0.2
Vinyl chloride	75-01-4	0.2
Xylenes (total)	1330-20-7	0.2
cis-1,2-Dichloroethene	156-59-2	0.2
cis-1,3-Dichloropropene	10061-01-5	0.2
sec-Butylbenzene	135-98-8	0.2
tert-Butylbenzene	98-06-6	0.2
trans-1,2-Dichloroethene	156-60-5	0.2
trans-1,3-Dichloropropene	10061-02-6	0.2

Table 3.--*Pesticide target analytes, Chemical Abstract Services registry number, method detection limits, and drinking water standards*

[µg/L, micrograms per liter; H, herbicide; I, insecticide; M, metabolite; F, fungicide; --, no data; drinking water standards are U.S. Environmental Protection Agency (USEPA) maximum contaminant levels for drinking water from USEPA (1996), unless otherwise footnoted]

Pesticide target analyte	Trade or common name(s)	Type of pesti-cide	Chemical Abstract Services registry number	Method detection limit (µg/L)	Drinking water standard or guideline (µg/L)
		Analyzed by Gas Chromatography/Mass Spectrometry			
Acetochlor	Surpass	H	34256-82-1	0.002	--
Alachlor	Lasso	H	15972-60-8	0.002	2
Atrazine	AAtrex	H	1912-24-9	0.001	3
Azinphos-methyl[1]	Guthion	I	86-50-0	0.001	--
Benfluralin	Balan, Benefin	H	1861-40-1	0.002	--
Butylate	Sutan +, Genate Plus	H	2008-41-5	0.002	[2]350
Carbaryl[1,3]	Sevin, Savit	I	63-25-2	0.003	[2]700
Carbofuran[1,3]	Furadan	I	1563-66-2	0.003	40
Chlorpyrifos	Lorsban	I	2921-88-2	0.004	[2]20
Cyanazine	Bladex	H	21725-46-2	0.004	[2]1
DCPA	Dacthal	H	1861-32-1	0.002	[2]4,000
p,p'-DDE	none	M	72-55-9	0.006	[4]0.1
Desethylatrazine[1]	none	M	6190-65-4	0.002	--
Diazinon	several	I	333-41-5	0.002	[2]0.6
Dieldrin	Panoram D-31	I	60-57-1	0.001	[4]0.002
2,6-Diethylanaline	none	M	579-66-8	0.003	--
Dimethoate[5]	Cygon	I	60-51-5	0.004	--
Disulfoton	Di-Syston	I	298-04-4	0.017	[2]0.3
EPTC	Eptam, Eradicane	H	759-94-4	0.002	--
Ethalfluralin	Sonalan, Curbit EC	H	55283-68-6	0.004	--
Ethoprop	Mocap	I	13194-48-4	0.003	--
Fonofos	Dyfonate	I	944-22-9	0.003	[2]10
alpha-HCH	none	M	319-84-6	0.002	[4]0.006
gamma-HCH	Lindane	I	58-89-9	0.004	0.2
Linuron[3]	Lorox, Linex	H	330-55-2	0.002	--
Malathion	several	I	121-75-5	0.005	[2]200
Methyl parathion	Penncap-M	I	298-00-0	0.006	[2]2
Metolachlor	Dual, Pennant	H	51218-45-2	0.002	[2]100
Metribuzin	Lexone, Sencor	H	21087-64-9	0.004	[2]100
Molinate	Ordram	H	2212-67-1	0.004	--
Napropamide	Devrinol	H	15299-99-7	0.003	--
Parathion	several	I	56-38-2	0.004	--
Pebulate	Tillam	H	1114-71-2	0.004	--
Pendimethalin	Prowl,Stomp	H	40487-42-1	0.004	--
cis-Permethrin	Ambush, Pounce	I	57608-04-5	0.005	--
Phorate	Thimet, Rampart	I	298-02-2	0.002	--
Prometon	Pramitol	H	1610-18-0	0.018	[2]100

Table 3.--*Pesticide target analytes, Chemical Abstract Services registry number, method detection limits, and drinking water standards--Continued*

Pesticide target analyte	Trade or common name(s)	Type of pesti-cide	Chemical Abstract Services registry number	Method detection limit (µg/L)	Drinking water standard or guideline (µg/L)
		Analyzed by Gas Chromatography/Mass Spectrometry--Continued			
Pronamide	Kerb	H	23950-58-5	0.003	[2]50
Propachlor	Ramrod	H	1918-16-7	0.007	[2]90
Propanil	Stampede	H	709-98-8	0.004	--
Propargite	Comite, Omite	I	2312-35-8	0.013	--
Simazine	Aquazine, Princep	H	122-34-9	0.005	4
Tebuthiuron	Spike	H	34014-18-1	0.01	[2]500
Terbacil[1]	Sinbar	H	5902-51-2	0.007	[2]90
Terbufos	Counter	I	13071-79-9	0.013	[2]0.9
Thiobencarb	Bolero	H	28249-77-6	0.002	--
Triallate	Far-Go	H	2303-17-5	0.001	--
Trifluralin	Treflan, Trilin	H	1582-09-8	0.002	[2]5

Pesticide target analyte	Trade or common name(s)	Type of pesti-cide	Chemical Abstract Services registry number	Reporting level (µg/L)	Drinking water standard or guideline (µg/L)
		Analyzed by High-Performance Liquid Chromatography			
2,4-D	several	H	94-75-7	0.15	70
2,4-DB	none	I	94-82-6	0.24	--
2,4,5-T	several	H	93-76-5	0.035	[2]70
2,4-5-TP[7]	Silvex	H	93-72-1	0.021	50
3-Hydroxy-carbofuran[7]	none	M	1563-38-8	0.014	--
Acifluorfen	Blazer	H	50594-66-6	0.035	[4]1
Aldicarb[6,7]	Temik	I	116-06-3	0.55	7
Aldicarb sulfone[6,7]	Standak	M	1646-88-4	0.10	7
Aldicarb sulfoxide[6]	none	M	1646-87-3	0.021	7
Bentazon	Basagran	H	25057-89-0	0.014	[2]20
Bromacil	Hyvar, Urox B	H	314-40-9	0.035	[2]90
Bromoxynil	Buctril, Brominal	H	1689-84-5	0.035	--
Carbaryl[3,7]	Sevin, Savit	I	63-25-2	0.008	[2]700
Carbofuran[3,7]	Furadan	I	1563-66-2	0.12	40
Chloramben	Amiben, Vegiben	H	133-90-4	0.42	[2]100
Chlorothalonil[6]	Bravo	F	1897-45-6	0.48	[4]1.5
Clopyralid	Stinger, Lontrel	H	1702-17-6	0.23	--

Table 3.--*Pesticide target analytes, Chemical Abstract Services registry number, method detection limits, and drinking water standards--Continued*

Pesticide target analyte	Trade or common name(s)	Type of pesti-cide	Chemical Abstract Services registry number	Reporting level (µg/L)	Drinking water standard or guideline (µg/L)
		Analyzed by High-Performance Liquid Chromatography--Continued			
Dacthal, mono-acid)	none	M	887-54-7	0.017	--
Dicamba	Banvel	H	1918-00-9	0.035	[2]200
Dichlobenil[6]	Barrier, Casoron	H	1194-65-6	1.2	--
Dichlorprop	2,4-DP, Seritox 50	H	120-36-5	0.032	--
Dinoseb	DNBP, Dinitro	H	88-85-7	0.035	7
Diuron	Karmex, Direx	H	330-54-1	0.02	[2]10
DNOC[6]	Trifocide, Elgetol 30	I, F, H	534-52-1	0.42	--
Fenuron	Beet-Kleen	H	101-42-8	0.013	--
Fluometuron	Flo-Met, Cotoran	H	2164-17-2	0.035	[2]90
Linuron[3]	Lorox, Linex	H	330-55-2	0.018	--
MCPA	Metaxon, Kilsem	H	94-74-6	0.17	[2]10
MCPB	Can-Trol, Thistrol	H	94-81-5	0.14	--
Methiocarb[7]	Grandslam, Mesurol	I	2032-65-7	0.026	--
Methomyl	Lannate, Nudrin	I	16752-77-5	0.017	[2]200
Neburon	Neburex, Noruben	H	555-37-3	0.015	--
Norflurazon	Evital, Solicam	H	27314-13-2	0.024	--
Oryzalin	Surflan	H	19044-88-3	0.31	--
Oxamyl[7]	Vydate	I	23135-22-0	0.018	200
Picloram[7]	Tordon	H	1918-02-1	0.05	500
Propham	Chem-Hoe, IPC	H	122-42-9	0.035	[2]100
Propoxur	Baygon	I	114-26-1	0.035	--
Triclopyr[7]	Garlon, Grazon	H	55335-06-3	0.25	--

[1] Concentrations for these pesticides are qualitatively identified and reported with an E code (estimated value) because of problems with gas chromatography or extraction (Zaugg and others, 1995).

[2] U.S. Environmental Protection Agency lifetime-health advisory for a 70-kilogram adult, from Nowell and Resek (1994).

[3] Analyzed by both gas chromatography/mass spectrometry and high-performance liquid chromatography methods.

[4] U.S. Environmental Protection Agency risk-specific dose health advisory associated with a cancer risk of 10^{-6} (one in a million), from Nowell and Resek (1994).

[5] Pesticide demonstrated small and variable recovery and was removed from the method schedule in November 1994. All data for dimethoate were removed from the data base in July 1996.

[6] The concentration values for these analytes are qualitatively identified and reported with an E code because of poor overall recovery and precision (NAWQA/NWQL Quality Assurance Committee for the Schedule 2050/2051 Pesticide Analysis Method, written commun., 1995).

[7] Pesticide target analyte is heat and light sensitive and therefore susceptible to degradation. This may result in poor overall recovery and precision (NAWQA/NWQL Quality Assurance Committee for the Schedule 2050/2051 Pesticide Analysis Method, written commun., 1995).

The plumbing and construction characteristics of a well were also considered in the selection of sites to be sampled and in determining the type of samples that could be taken. Where possible, sites with submersible pumps were selected over those with turbine or centrifugal pumps. Samples taken from sites with centrifugal pumps were not analyzed for VOC compounds. The ground-water sampling system was connected to the well or spring distribution system as close to the wellhead or spring as possible. All samples were collected before they were treated by chlorination, fluoridation, or softening. Where possible, samples were collected before they entered any holding tank or copper plumbing. Samples for trace elements were not taken at sites where they encountered any copper before they reached the sampling point.

In a mobile water-quality laboratory, all samples were collected and prepared using USGS protocols. Sample water flowed from the hose bib through teflon tubing to a flow-directing stainless-steel manifold that allowed the sample water to flow into either a flow chamber, raw-water line, or filtration unit (fig. 4). Selected constituents and properties that included temperature, pH, specific conductance, and dissolved-oxygen concentrations were monitored continuously at the flow chamber. Once the constituent's readings stabilized, filtered and unfiltered samples were collected from the appropriate manifold outlet (fig. 4). Temperature and raw samples to be analyzed for concentrations of bacteria were collected last directly from the hose bib.

Based on the constituent, sample analysis occurred at one of three locations: on-site; at the USGS Washington District laboratory in Tacoma, Wash., or at the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. Temperature, pH, specific conductance, and alkalinity were measured on-site with meters using methods outlined by Wood (1981) and Fishman and Friedman (1989). Dissolved-oxygen concentrations were also determined on-site with a meter, but concentrations of 1.0 mg/L (milligram per liter) or less were verified on-site using the Rhodazine-D method (White and Others, 1990). Bacteria samples were analyzed for concentrations of fecal *strepto-cocci*, total coliform, and *Escherichia coli* at the USGS Washington District laboratory in Tacoma. Fecal *strepto-cocci* were analyzed using the KF Streptococcus agar method (Myers and Wilde, 1997). Analyses of both total coliform and *Escherichia coli* were performed using the membrane filter procedure with M-endo media as outlined by the Environmental Protection Agency (EPA) office of water (U.S. Environmental Protection Agency, 1991). Analysis of *Escherichia coli* was also conducted using NA-mug media (U.S. Environmental Protection Agency, 1991). Except for the bacteria analysis, all laboratory analyses were done by the USGS NWQL in Arvada, Colorado. Analytical procedures used at the NWQL are described by Fishman and Friedman (1989) and Wershaw and others (1987).

As part of the study's quality-assurance program, measurement instruments were calibrated daily, and sampling equipment was cleaned before the collection of each sample. The accuracy of the on-site measurements of pH, specific conductance, and alkalinity was ensured by daily calibration of the meters with known standards. Dissolved-oxygen meters were also calibrated daily using the water-saturated air technique (Wood, 1981). The manifold and sampling lines were cleaned by flushing with a 0.02 percent solution of phosphate-free detergent and deionized water. Before a sample was collected, the manifold was flushed with sample water and new filters were flushed according to inorganic protocol (Horowitz and others, 1994). Except for bacteria, VOC compounds, radon, or pesticides sampling, all containers were rinsed prior to sampling with sample water.

In accordance with the project's quality-assurance plan, an equipment blank, duplicate samples, and field blanks were collected at some sampling sites. Duplicate samples for analysis by the NWQL were collected on a random basis. One duplicate sample was collected for every 7 sites sampled for MBAS and boron, 1 duplicate sample was collected for every 12 sites sampled for nitrate, and 1 duplicate sample was collected for every 6 sites sampled for radon. Blank samples of deionized water were also collected on a random basis. Three field blanks were collected for 32 sites sampled for major ions and nitrates. One field blank was collected for every 12 sites sampled for trace metals and pesticides. One field blank was collected for every 22 sites sampled for boron and MBAS. Duplicate samples and blanks of deionized water were processed in the same manner as ordinary ground-water samples and were submitted to the laboratory as ground-water samples.

Duplicate bacteria samples from randomly selected sites were analyzed at the USGS laboratory in Tacoma, Wash., each day of sampling in accordance with the project's quality-assurance plan.

Standard quality-assurance procedures were used at the NWQL. The resulting data were reviewed by laboratory personnel, then released to the local USGS District office in Tacoma, Wash., by electronic data transfer. The laboratory data were reviewed further by district and project personnel, and computer programs and statistical

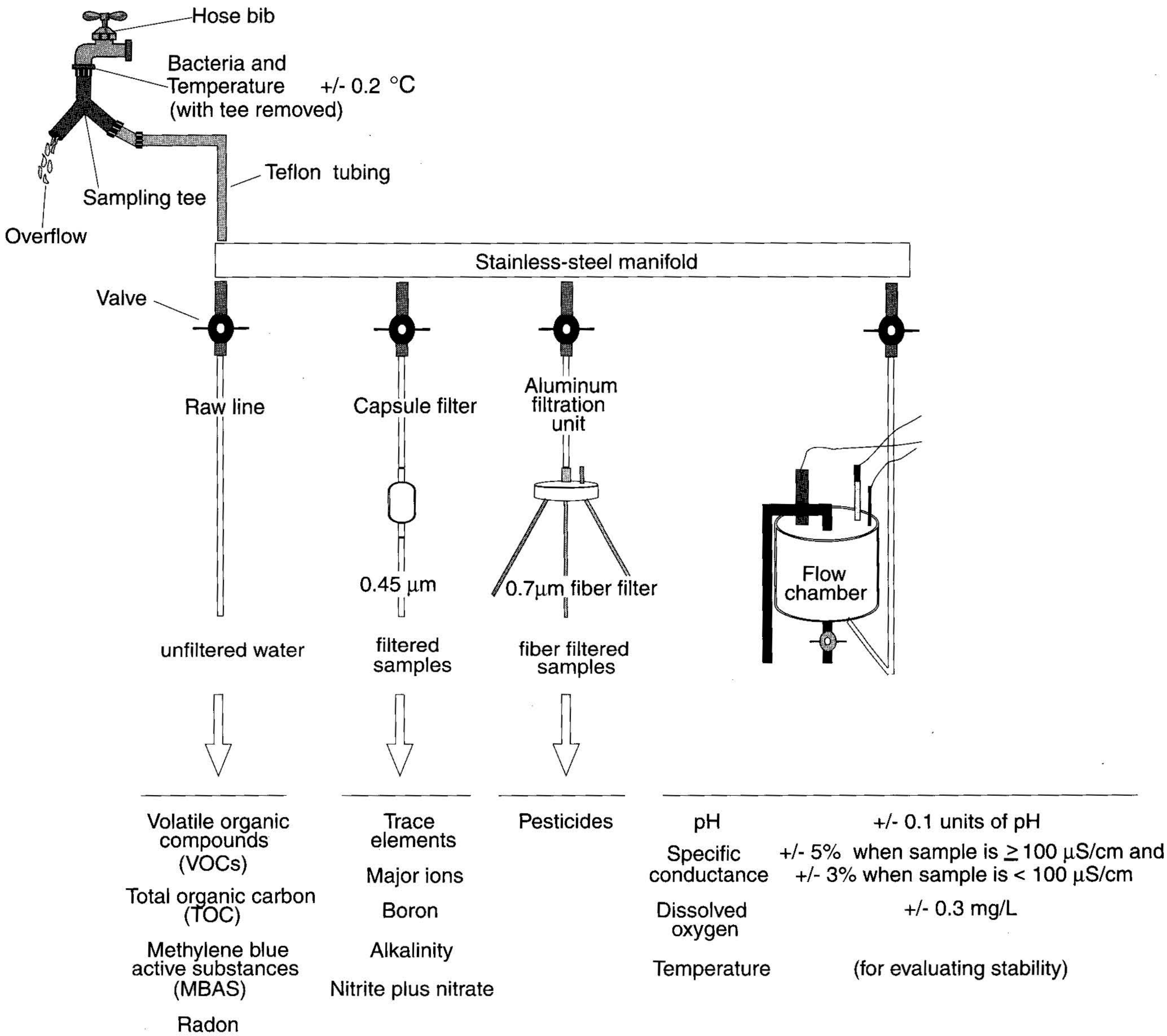


Figure 4. Ground-water sampling system and equipment precision. (°C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µm, micrometer)

techniques assisted in all stages of the reviews. The results of the water-quality analyses were stored in the USGS ground-water data base in Tacoma and uploaded into STORET (Storage and Retrieval of U.S. Waterways Parametric Data), the computerized water-quality data base of the EPA. Additional details of laboratory quality-assurance procedures and data review are discussed in the project quality-assurance plan (M. A. Jones, U.S. Geological Survey, written commun., July 25, 1995) and in the analytical methods outlined by Fishman and Friedman (1989) and in the organic analytical methods outlined by Wershaw and others (1987).

HYDROGEOLOGIC FRAMEWORK

This section describes the hydrogeologic framework, which defines the physical, lithologic, and hydrologic characteristics of the hydrogeologic units that compose the ground-water system in the study area. An understanding of these characteristics is important in determining the occurrence and availability of ground water.

The principal hydrogeologic units in the study area are composed of the unconsolidated Quaternary deposits. The lateral extent of these units was governed by the extent of the four glacial advances and retreats during the Pleistocene and by the younger alluvial and mudflow deposits of the Holocene (Crandell and others, 1958; and Walters and Kimmel, 1968). These deposits tend to be heterogenous and may be discontinuous in places. The thickness of the unconsolidated Quaternary deposits within the study area ranges from less than 600 ft in the southeast corner to more than 1,800 ft in the central part (fig. 5). Most of the available thickness data are from drillers' well logs and some oil-and-gas exploration wells (Buchanan-Banks and Collins, 1994). The median depth of wells within the study area is 160 ft below the land surface, with only a few wells at depths greater than 700 ft below the land surface. Most of the inventoried wells tap ground-water aquifers between 200 ft above sea level and 200 ft below sea level. A few wells tap aquifers at depths greater than 500 ft below sea level. The maximum thickness of the unconsolidated deposits within the study area is probably greater than shown on figure 5 because of the scarcity of wells that penetrate to bedrock and the lack of available marine-seismic data (Jones, 1996).

A knowledge of the geologic structure in the study area may also assist in mapping the unconsolidated hydrogeologic units. The structural setting may help explain the depositional sequences, thickness variations, and segmentation of the ground-water movement systems or anomalous water-level distributions within the area. For example, a predominantly clay unit could be vertically offset and juxtaposed with a sand unit, thereby truncating lateral ground-water movement along a fault and also offsetting the water-level distribution on either side of the fault. Although these types of questions may not be answered in this study, the structural history provided information for mapping the hydrogeologic units.

The study area lies within the Tacoma Basin just south of an east-west trending gravity and magnetic high. This structure is inferred as a fault or a steep monoclinal fold (Gower and others, 1985), referred to as the Narrows Structure (fig. 5) (Jones, 1996). Recent marine-seismic work near the Seattle fault zone (Gower and others, 1985) in the Puget Sound has identified two north-south trending faults within the Puget Sound. The inferred projection of these faults southward could extend south to Tacoma or beyond. Thus, the exposures of older geologic units along the Puyallup River Valley on the east side of the study area and much younger exposures along the west side may be in part due to the inferred north-south trending faults. At present the quality of the exposures along the coastline are insufficient to test for the continuation of the faults (Samuel Y. Johnson, U.S. Geological Survey, written commun., March, 1998).

The hydrogeologic units identified in this report do not necessarily correspond to geologic time-stratigraphic deposits identified in previous reports (Crandell and others, 1958; Walters and Kimmel, 1968; and Brown and Caldwell, 1985). In general, units in this report were grouped based on their continuity and lithologic type. In some parts of the study area, fine-grained glacial deposits directly overlie fine-grained interglacial deposits, and differentiating between them is difficult. Thus, these fine-grained deposits are grouped into a single semiconfining unit. Similarly, where coarse-grained glacial and interglacial deposits are vertically adjacent, they also are grouped into a single aquifer.

The surficial geologic units and lithologic units in drillers' logs from 255 inventoried wells were differentiated into hydrogeologic units (fig 6). The altitudes of the top and extent of the five uppermost hydrogeologic units were mapped. They consist of three aquifers and two semiconfining units. The aquifers consist mostly of coarse-grained sand and gravel deposits of both glacial (advance and recessional outwash) and interglacial (proglacial and coarse-grained fluvial) deposits. The semiconfining units consist mostly of fine-grained silt and clay of both glacial (till) and interglacial (lacustrine and fine-grained fluvial) deposits. Due to the heterogeneity of

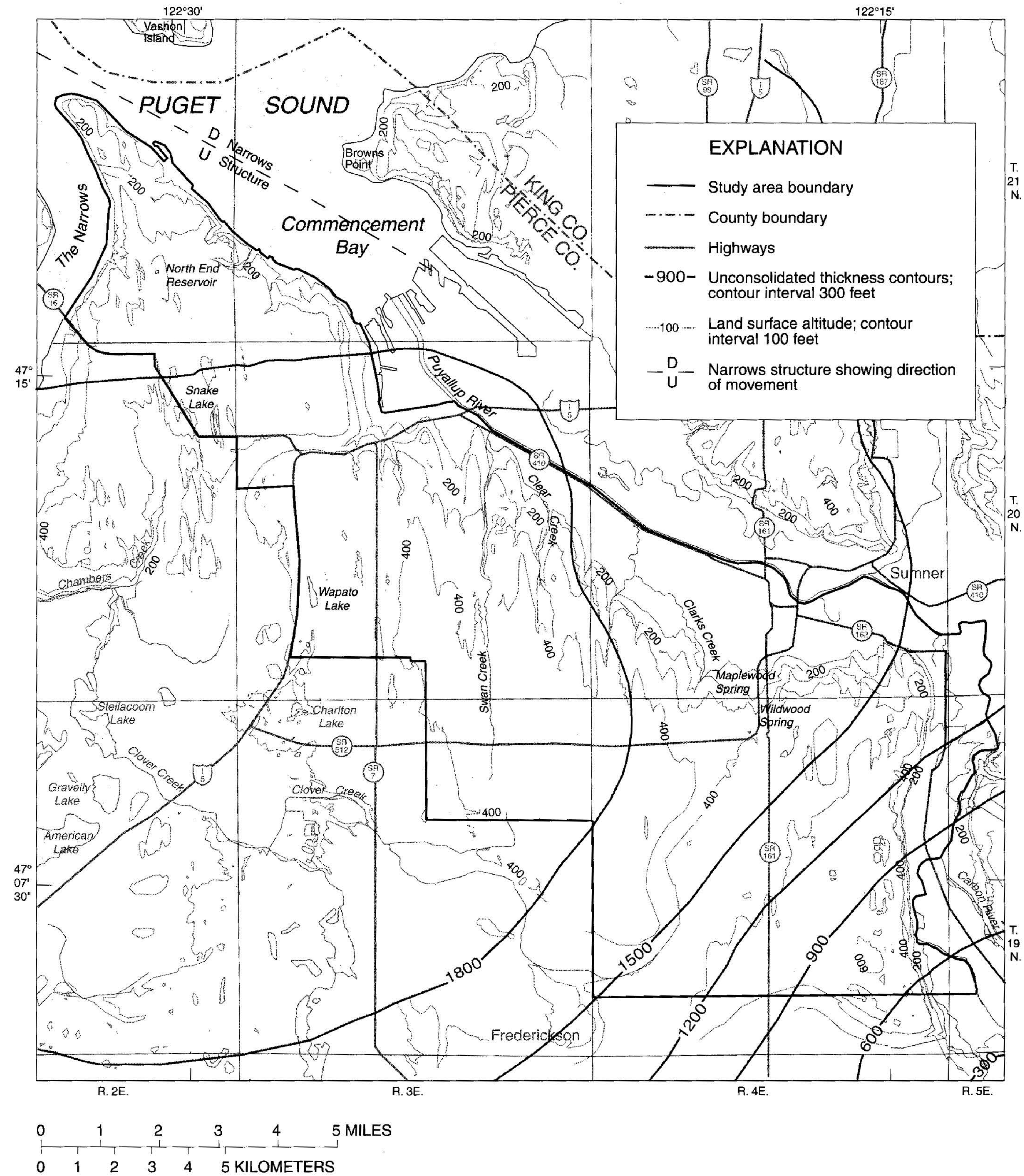
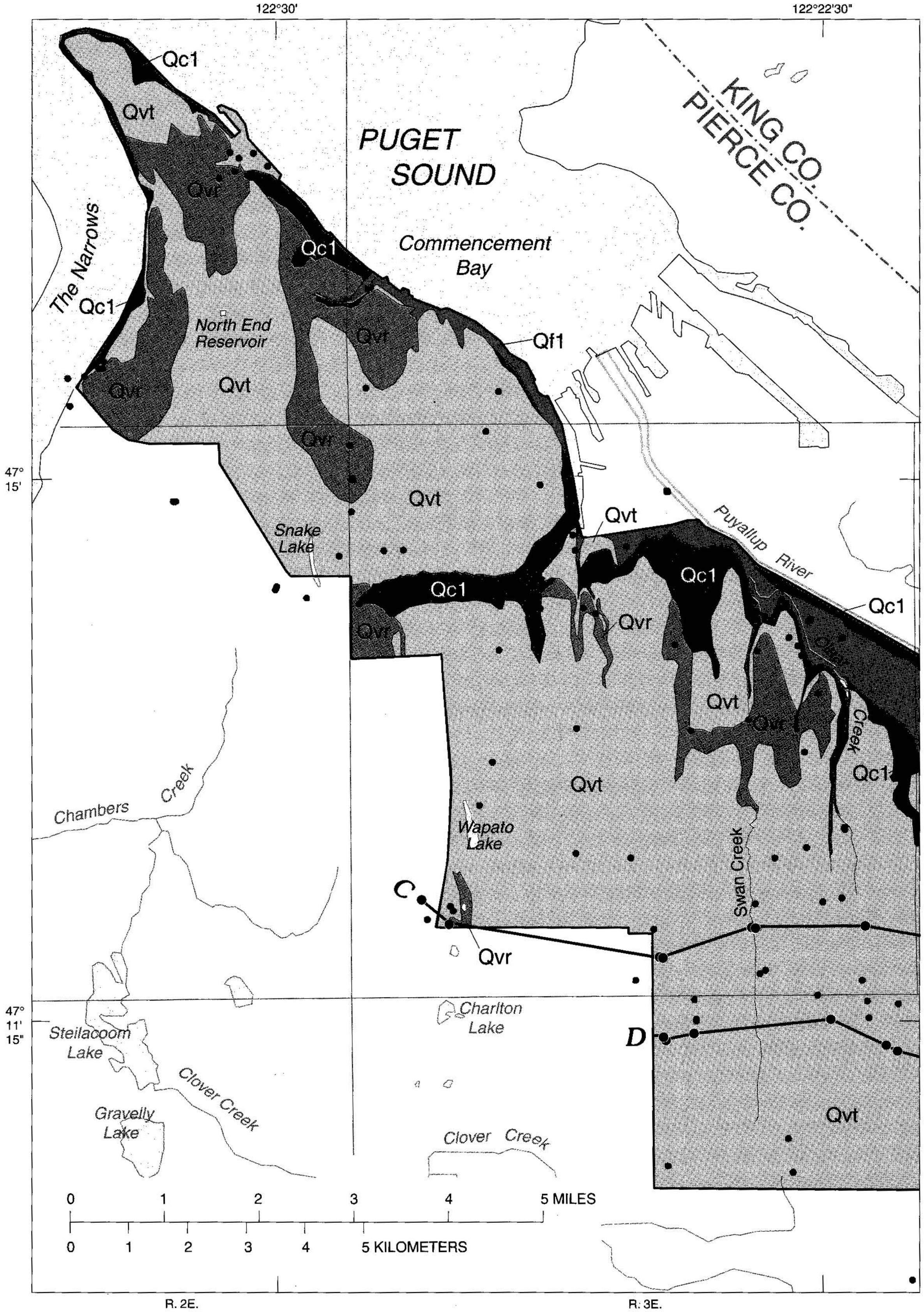


Figure 5. Thickness of unconsolidated deposits in the Tacoma-Puyallup area, Washington. (from Jones, 1996)



122°30'
122°22'30"
PUGET SOUND
KING CO.
PIERCE CO.
Commencement Bay
The Narrows
North End Reservoir
Snake Lake
Wapato Lake
Puyallup River
Swan Creek
Chambers Creek
Clover Creek
Charlton Lake
Steilacoom Lake
Gravelly Lake
Qc1
Qvt
Qvr
Qf1
C
D
T. 21 N.
T. 20 N.
T. 19 N.
47° 15'
47° 11' 15"
R. 2E.
R. 3E.
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

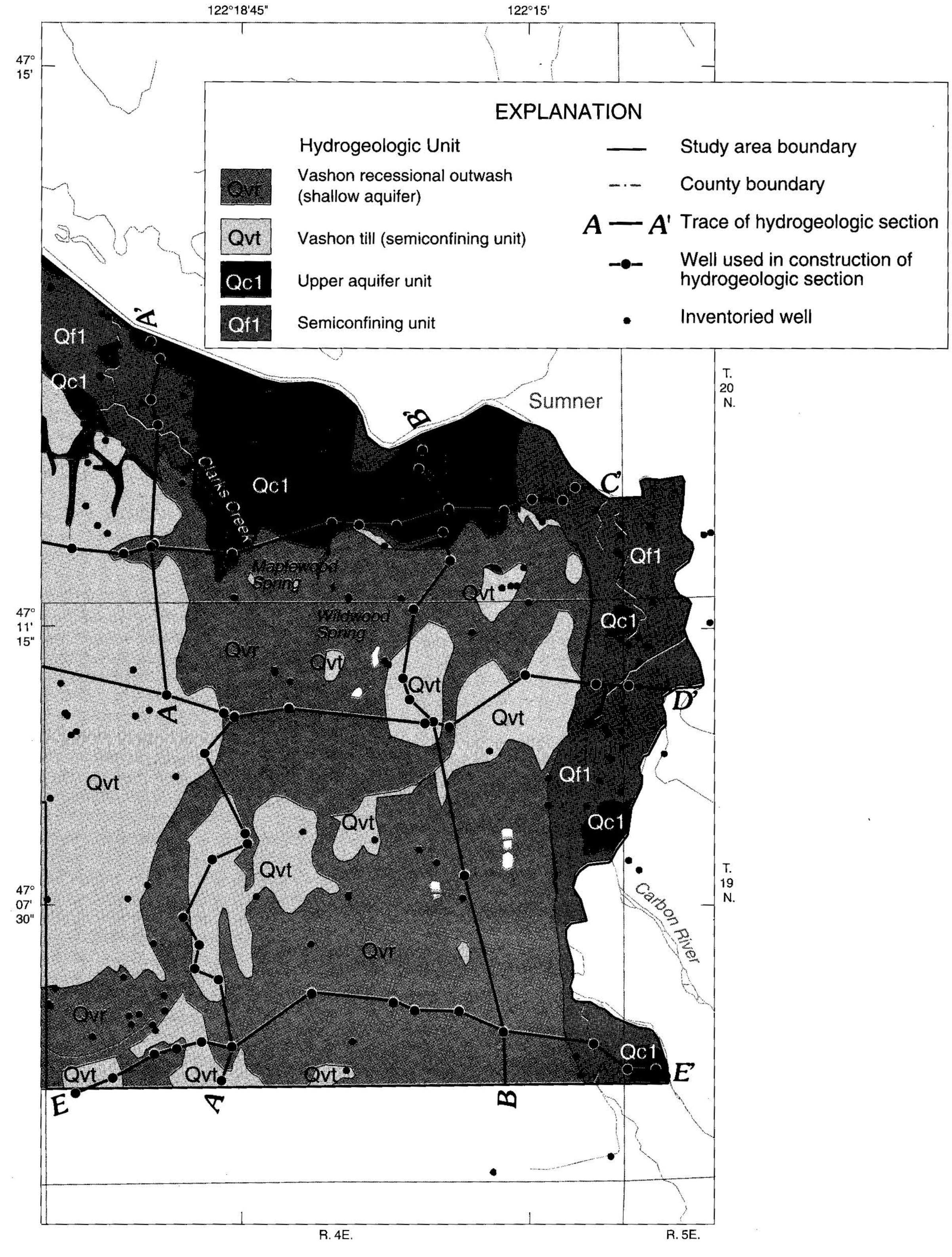


Figure 6. Distribution of hydrogeologic units at land surface, inventoried wells, and traces of the hydrogeologic sections *A - A' to E - E'* in the Tacoma-Puyallup area, Washington.

these deposits, the hydrogeologic units as differentiated are not uniformly coarse-grained or fine-grained. For example, an aquifer may be composed predominantly of sand or gravel, but it may also contain relatively thin and discontinuous lenses of clay or silt. Conversely, a semi-confining unit composed predominantly of silt or clay may also contain local lenses of sand or gravel (fig. 7). These variations may also locally influence the occurrence and movement of ground water.

The 10 hydrogeologic units identified include aquifers Qvr and Qc1 through Qc4 and semiconfining units Qvt and Qf1 through Qf4. The undifferentiated unit Qdu identifies areas where there was not sufficient information to designate a hydrogeologic unit. Units Qvr, Qvt, Qc1, and Qf1 are exposed at the surface within the study area (fig. 6). The other hydrogeologic units present at depth are shown in the hydrogeologic sections (fig. 7). The hydrogeologic sections *A-A'* to *E-E'* indicate that there is considerable variation in the thickness of individual units and that all units are not necessarily continuous throughout the study area.

Unit Qvr is present at land surface (fig. 6) and generally represents the Vashon recessional outwash deposits of the Fraser Glaciation. In most places where this unit is saturated, it is a water-table aquifer. In the southeast part of the study area, Qvr generally consists of coarse deposits of gravel, cobbles, and boulders identified as the Steilacoom Gravel by Walters and Kimmel (1968). Where this unit is present in other parts of the area, it consists of sand and gravel deposits and locally may contain lenses of silt and clay. The altitude of the top and the extent of Qvr are shown in figure 8. The altitude ranges from more than 600 ft to about 50 ft (table 15, end of text), with a median of 360 ft. The thickness of this unit ranges from a thin veneer to 100 ft, with a median thickness of 22 ft, based on information from 58 inventoried wells. There were no specific-capacity data available for the wells tapping this unit; therefore, no hydraulic conductivities were calculated.

Unit Qvt occurs at land surface throughout most of the north and north-central parts of the study area and generally represents the Vashon till (fig. 6). The unit, which varies in consistency, consists primarily of unstratified clay, silt, cobbles, and boulders and can also contain lenses of sand and gravel (fig. 7). Some shallow wells completed in this unit supply water for domestic use. The altitude of the top of this unit (fig. 9) ranges from 23 ft to 597 ft above sea level, with a median altitude of 398 ft, based on information from 148 inventoried wells (table 15, end of text). The unit is generally present in the uplands and absent in the valleys (fig. 9). It ranges in thickness from a thin veneer to 258 ft and has a median thickness of 71 ft. It is thickest in the uplands where it is present at the surface and generally thins in areas where it is beneath unit Qvr (fig. 7) and where it is exposed in cliff faces along the Puyallup River Valley and along the coast. From the specific-capacity data available for two wells tapping this unit, their hydraulic conductivities are calculated to be 200 and 23 ft/d (table 4). These two wells probably tap coarser lenses and are not representative of most of the unit.

Aquifer Qc1 generally lies beneath unit Qvt throughout the study area. It is exposed at the surface along the cliff faces of the coast, in incised channels, and in the

Table 4.--*Summary of hydraulic conductivity values estimated from specific capacity of wells, by hydrogeologic unit in the Tacoma-Puyallup area, Washington*
[--, not determined]

Hydro-geologic unit	Number of wells	Horizontal hydraulic conductivity (feet per day): Maximum	75th Percentile	Median	25th Percentile	Minimum
Qvr	--	--	--	--	--	--
Qvt	2	200	--	--	--	23
Qc1	32	4,200	320	110	46	10
Qf1	1	10	--	--	--	10
Qc2	83	12,000	850	170	33	3.7
Qf2	2	120	--	--	--	58
Qc3	24	620	280	100	27	4.1
Qc4	3	110	--	--	--	9.7

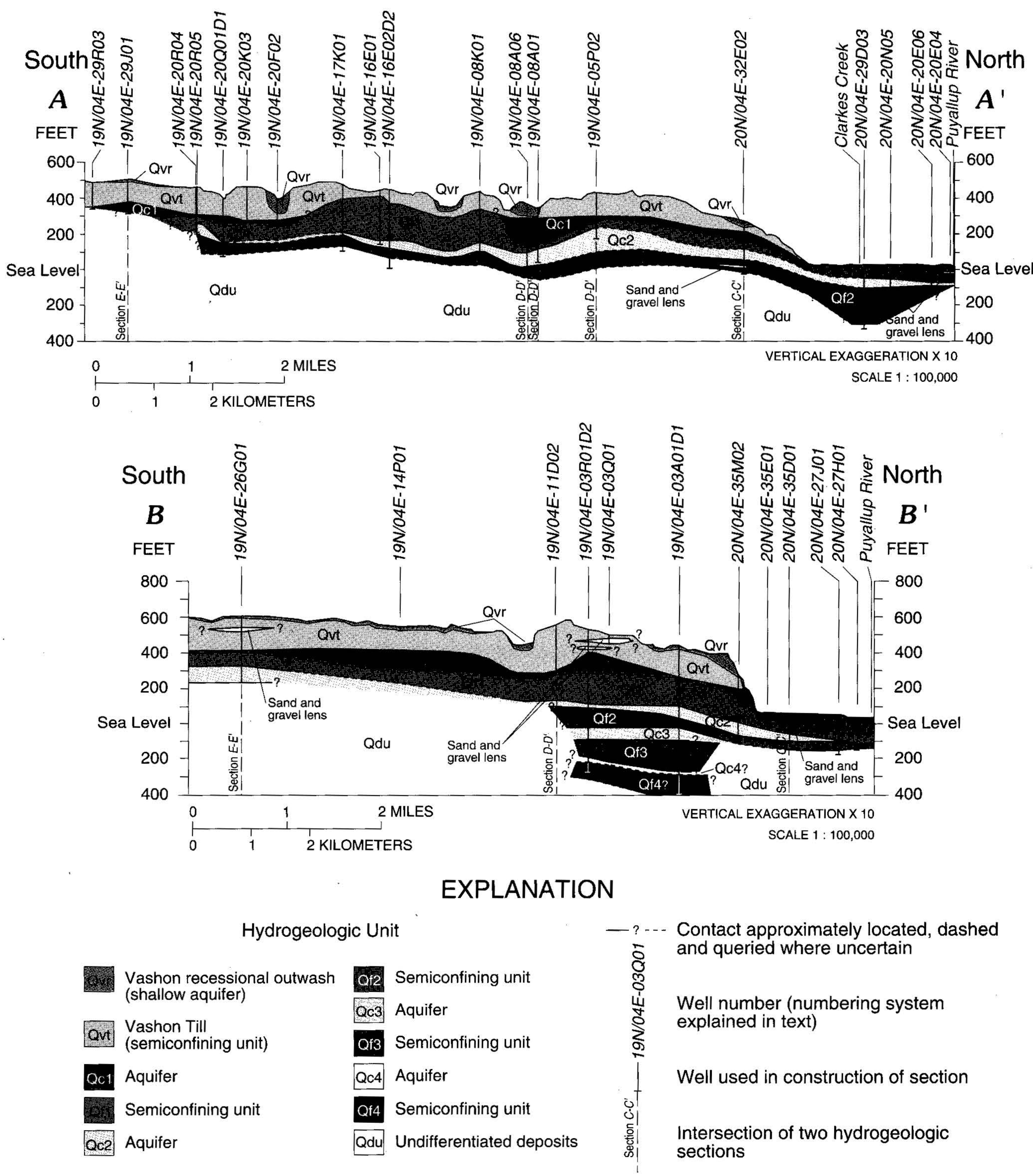


Figure 7. Hydrogeologic sections *A-A'* to *E-E'*, showing locations of hydrogeologic units in the Tacoma-Puyallup area, Washington. Traces of sections are shown on figure 6.

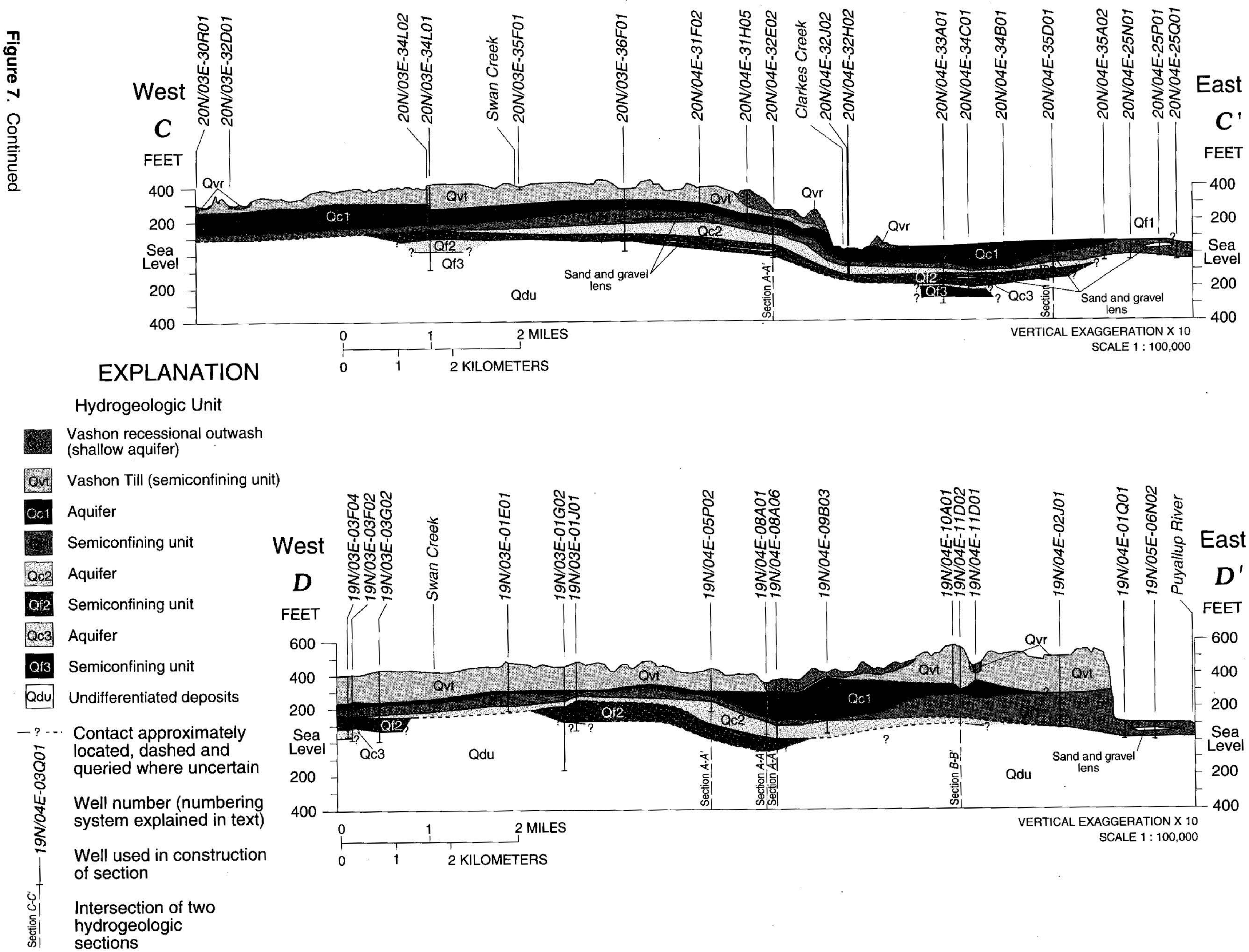


Figure 7. Continued

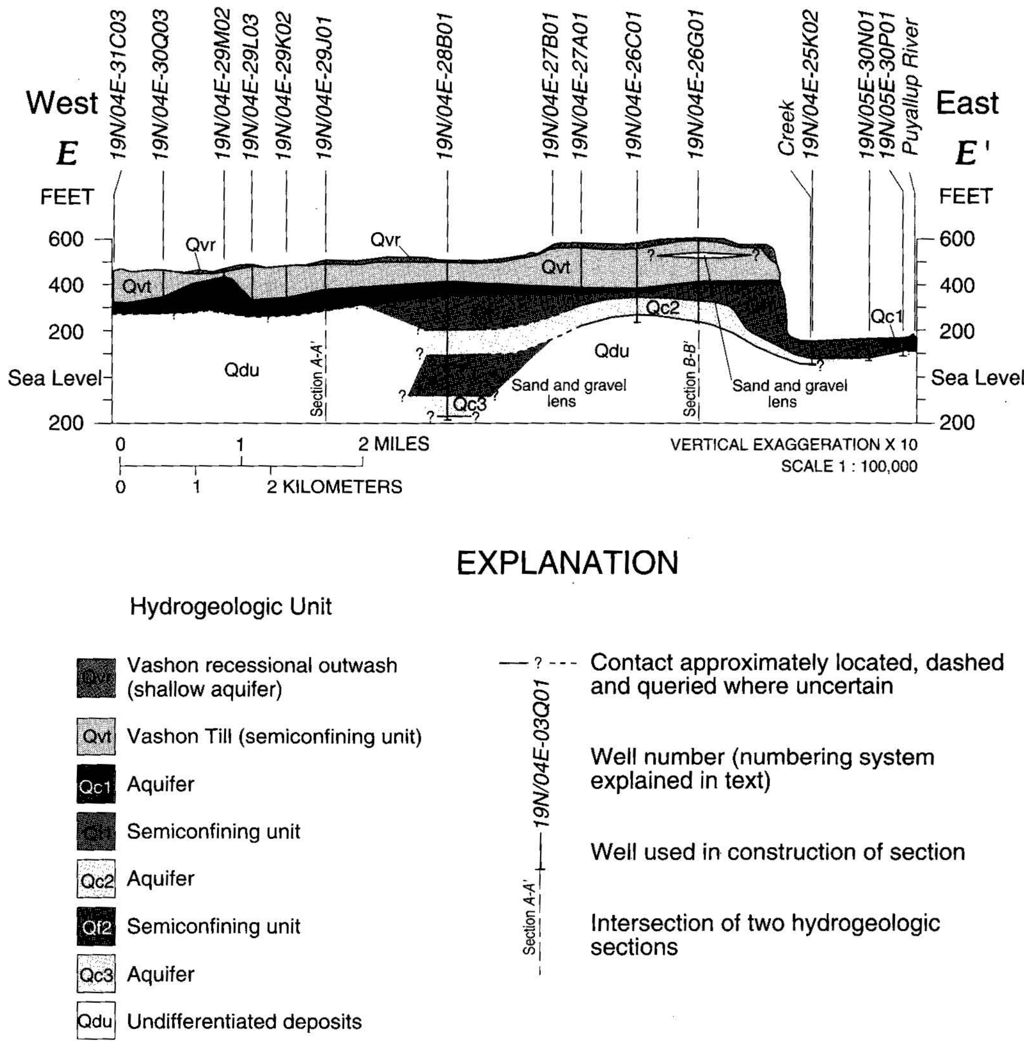


Figure 7. Continued

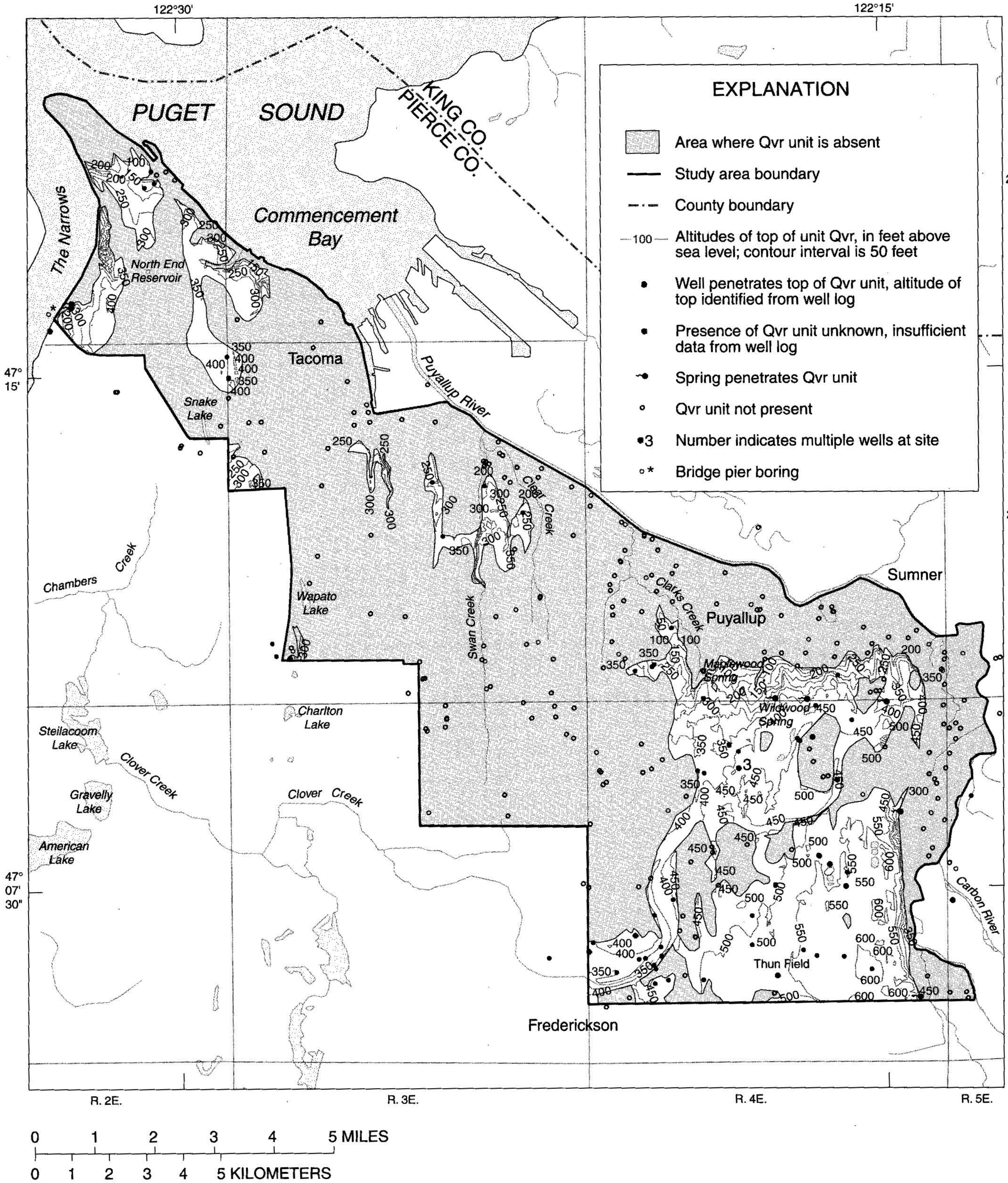


Figure 8. Altitude of the top and extent of hydrogeologic unit Qvr in the Tacoma-Puyallup area, Washington.

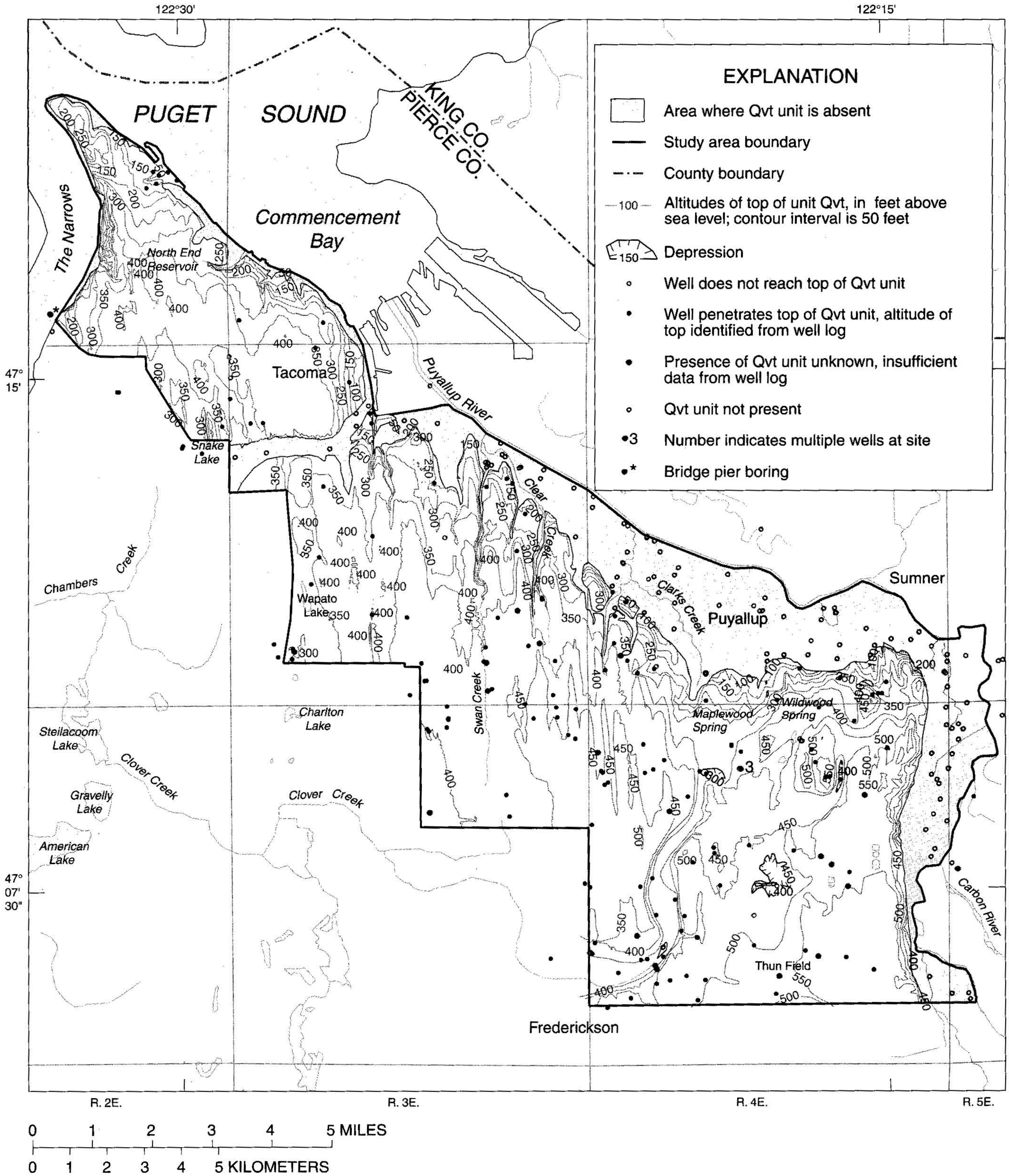


Figure 9. Altitude of the top and extent of hydrogeologic unit Qvt in the Tacoma-Puyallup area, Washington.

Puyallup River Valley (fig. 6). Aquifer Qc1 is generally a confined aquifer except where it is exposed at the surface, where it is unconfined, or not completely saturated beneath Qvt. It consists largely of sand and gravel deposits but does contain clay and silt within the sand and gravel matrix. This aquifer is tapped as a source of water by domestic and public-supply wells within the study area, and spring water from this unit is also used as a source of domestic and public supply. The altitude of the top of this aquifer ranges from 50 ft below sea level to 509 ft above sea level (fig. 10). The median altitude is 238 ft, based on information from 162 inventoried wells (table 15, end of text). The thickness of Qc1 ranges from a few feet to 297 ft, with a median thickness of 41 ft. Aquifer Qc1 is generally thinnest in the uplands and thickest in valleys and topographically low areas (fig. 7). Specific-capacity data were available for 32 wells tapping this aquifer. Calculated hydraulic conductivities range from 10 to 4,200 ft/d. The median is 110 ft/d, and the 75th and 25th percentiles are 320 and 46 ft/d, respectively (table 4). There were insufficient data to map the aerial distribution of hydraulic conductivity for this aquifer.

Unit Qf1 generally lies beneath aquifer Qc1. It is exposed at the surface near sea level along the cliff faces of the coast and in the Puyallup River Valley (fig. 6). The unit consists largely of clay but contains some volcanic, mudflow, and alluvial deposits. It also contains lenses of sand and gravel (fig. 7). Some of the small lenses of sand and gravel are tapped by wells within the study area and supply small quantities of water for domestic use. The altitude of the top of this unit (fig. 11) ranges from 150 ft below sea level to 413 ft above sea level (table 15, end of text). The median altitude is 120 ft, based on data from 161 inventoried wells. This unit ranges in thickness from a thin veneer to 248 ft, with a median of 56 ft. It is generally thickest in the upland and thin in areas of topographic lows. Few water wells tap this unit. Specific-capacity data were available for only one well in this unit. The calculated hydraulic conductivity is 10 ft/d (table 4).

Aquifer Qc2 generally lies beneath unit Qf1 and is a confined aquifer. It consists largely of gravel or sand and gravel deposits, but does contain thin beds of silt and clay. This unit also contains some mudflow and volcanic deposits. Most of the wells inventoried in the study area are completed in this aquifer (table 15, end of text). The altitude of the top of this aquifer (fig. 12) ranges from 226 ft below sea level to 345 ft above sea level. The median altitude of this aquifer is 55 ft, based on information from 145 inventoried wells. Although most wells completed in this aquifer do not fully penetrate it, its median thickness, based on the depth of the wells that penetrate it, is 27 ft. Specific-capacity data were available for 83 wells tapping this aquifer and calculated hydraulic conductivities range from 3.7 to 12,000 ft/d. The median is 170 ft/d, and the 75th and 25th percentiles are 850 and 33 ft/d, respectively (table 4). There were insufficient data to map the aerial distribution of hydraulic conductivity in this aquifer.

Unit Qf2 generally lies beneath aquifer Qc2. It consists largely of compact clay and silt, but also contains lenses of sand and gravel and mudflow deposits. It may also contain minor amounts of peat and volcanic deposits (Walters and Kimmel, 1968; and Dragovich and others, 1994). Wells tapping sand and gravel units within this unit generally yield small quantities of water to wells. The altitude of this unit ranges from 395 ft below sea level to 269 ft above sea level. Its median altitude is 15 ft above sea level, based on information from 69 inventoried wells (table 15, end of text). Its extent and top are not mapped because few wells penetrate to this depth, but it is shown where it is known to be present in figure 7. This unit ranges in thickness from a thin veneer to 177 ft, with a median of 55 ft. Only two water wells are known to tap this unit. Specific-capacity data were available for these two wells which tap sand and gravel deposits within this unit; their calculated hydraulic conductivities are 120 and 58 ft/d (table 4).

Aquifer Qc3 generally lies beneath unit Qf2. It is largely sand and gravel, but there is clay and silt within the sand and gravel matrix. It is tapped by public-supply and domestic wells within the study area. The altitude of this aquifer ranges from 432 ft below sea level to 135 ft above sea level, with a median altitude of 128 ft below sea level, based on information from 44 inventoried wells (table 15). The extent and top of this aquifer are not mapped because few wells penetrate to this depth, but they are shown where present in figure 7. In thickness, this aquifer ranges from 5 ft to 276 ft, with a median of 59 ft. Specific-capacity data were available for 24 wells tapping this aquifer, and calculated hydraulic conductivities range from 4.1 to 620 ft/d. The median value is 100 ft/d, and the 75th and 25th percentiles are 280 and 27 ft/d, respectively (table 4).

The alternating sequence of fine-grained and coarse-grained deposits appears to continue at depth below Qc3, but the information is sparse. Based on available information, these deep deposits were delineated into units Qf3, Qc4, and Qf4, which are shown on figure 7 and included in table 15 (end of text) and appendix 1. The data are based on 21 wells for Qf3, 11 wells for Qc4, and 5 wells for Qf4. Specific-capacity data were available for three wells for aquifer Qc4. The calculated hydraulic

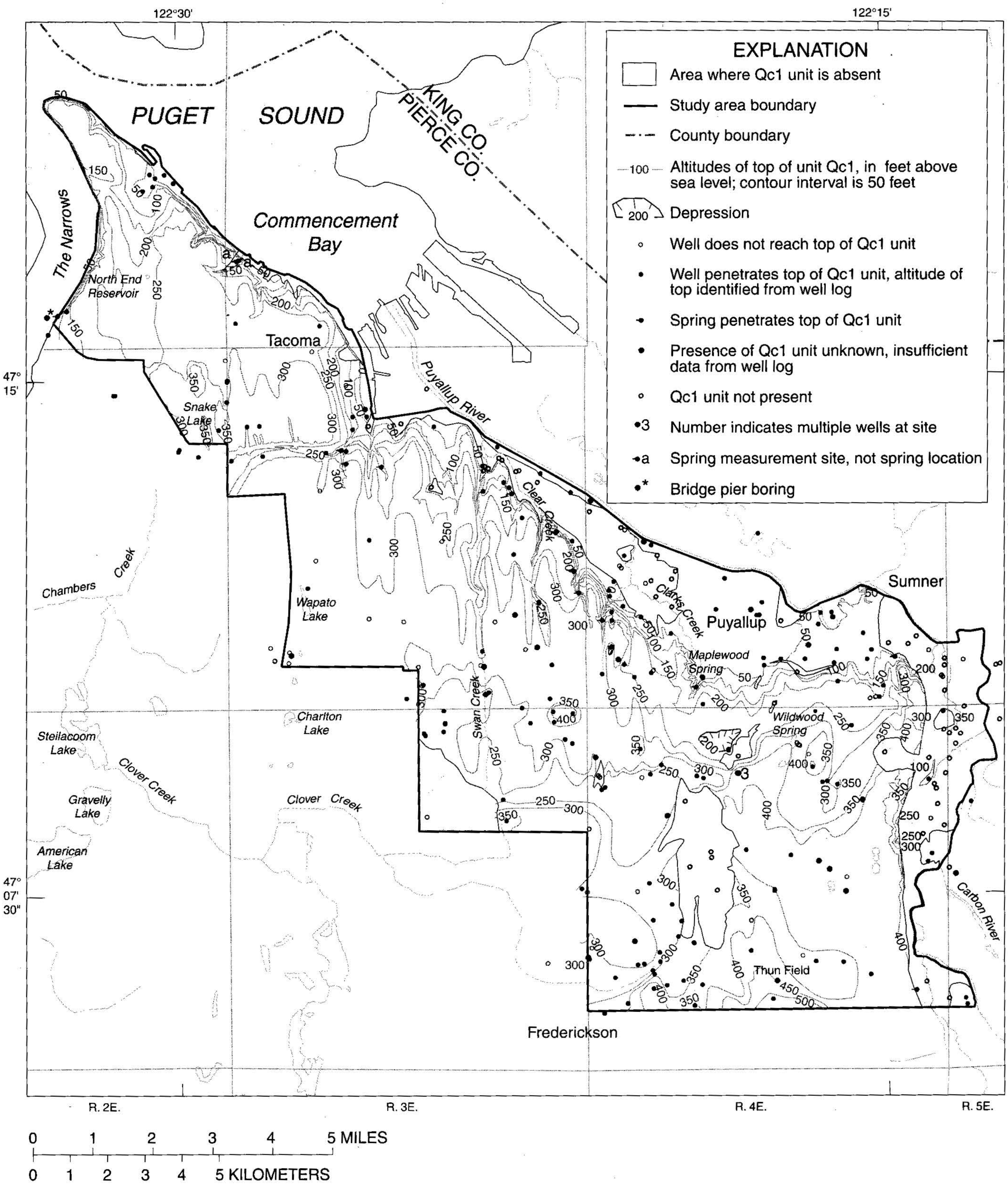


Figure 10. Altitude of the top and extent of hydrogeologic unit Qc1 in the Tacoma-Puyallup area, Washington.

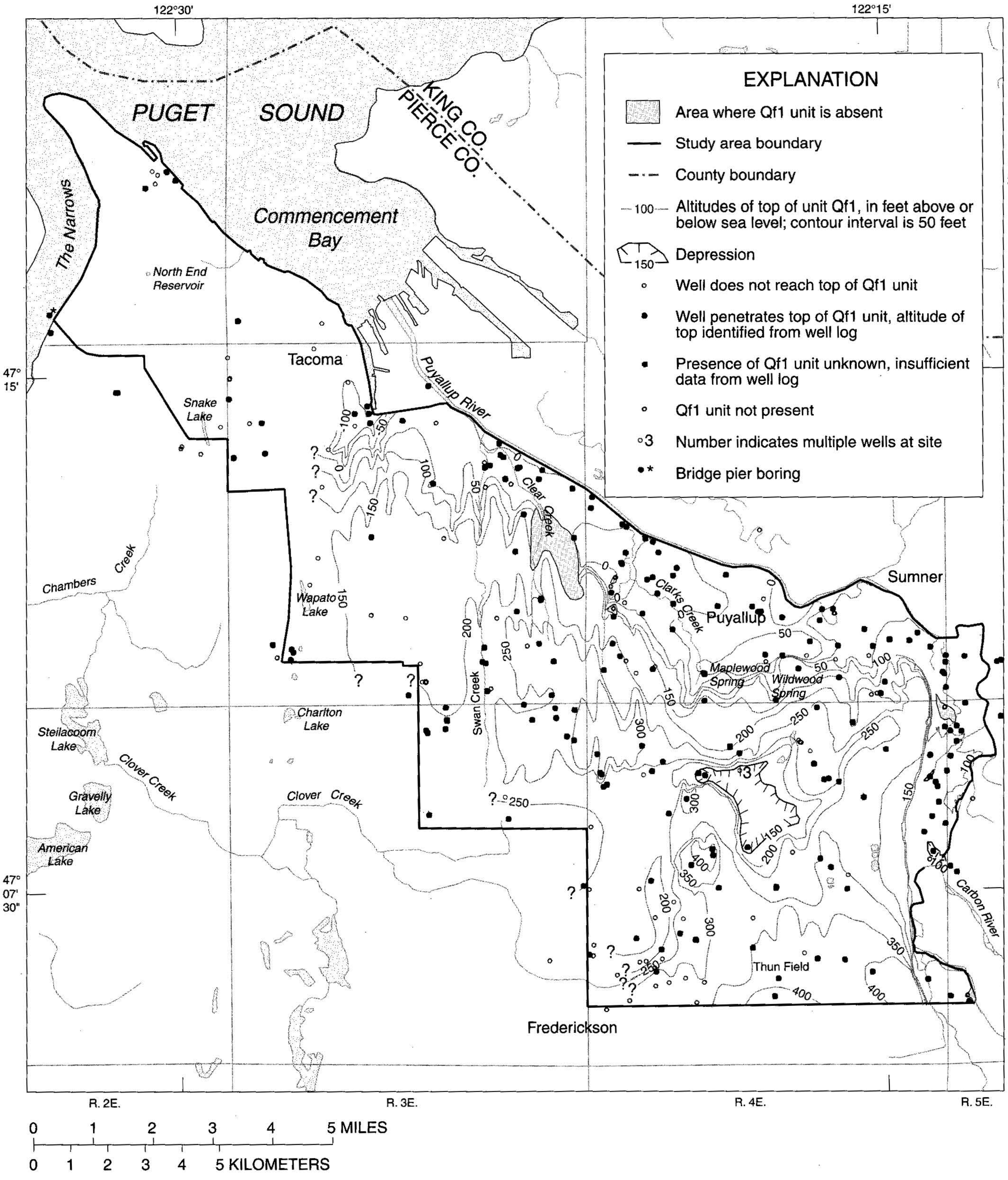


Figure 11. Altitude of the top and extent of hydrogeologic unit Qf1 in the Tacoma-Puyallup area, Washington.

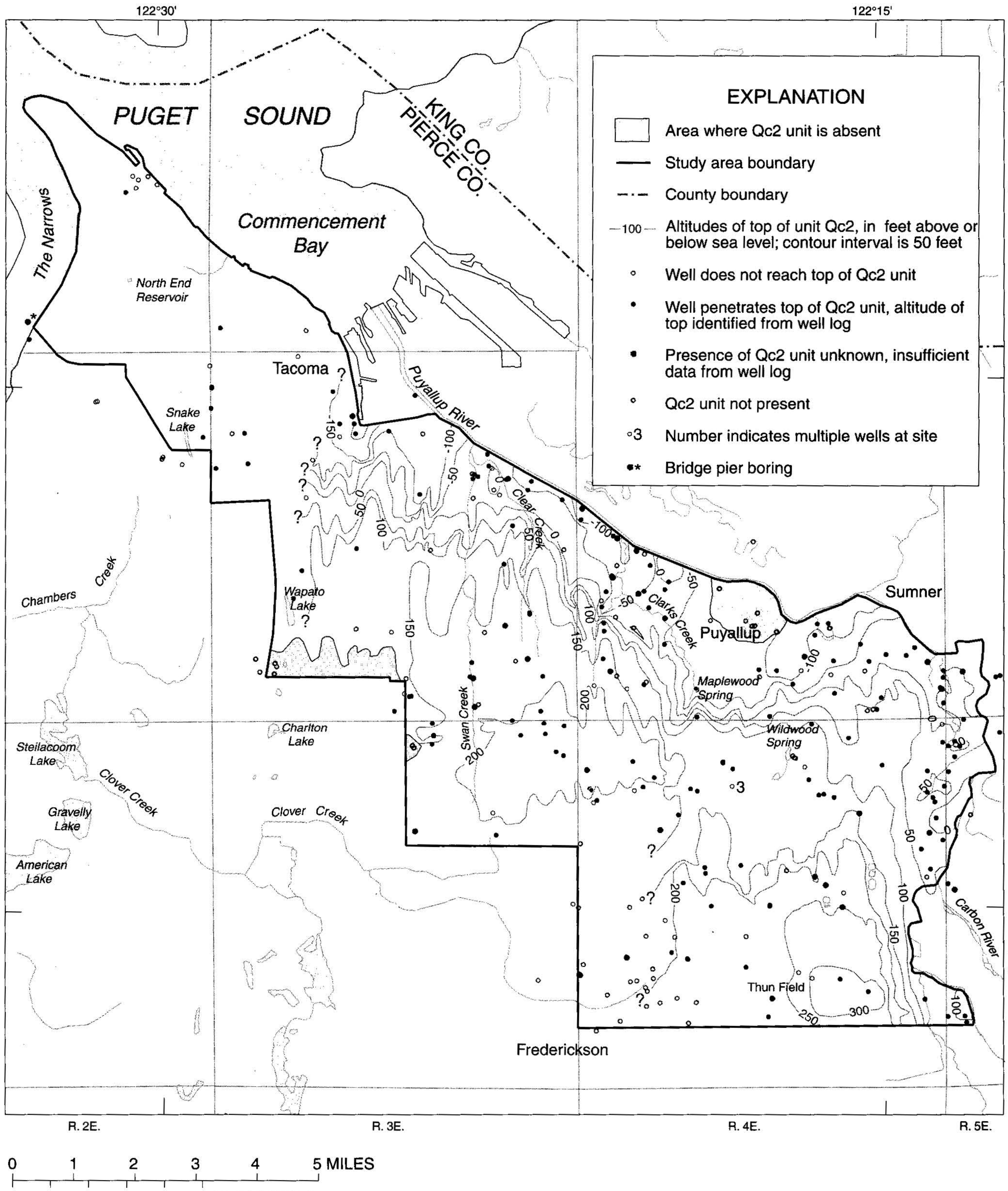


Figure 12. Altitude of the top and extent of hydrogeologic unit Qc2 in the Tacoma-Puyallup area, Washington.

conductivities are 110 and 9.7 ft/d (table 4). All remaining undifferentiated deposits are grouped into a hydrogeologic unit designated Qdu (fig 7). This unit also includes all deposits at depth where there is no information available to delineate the shallower hydrogeologic units, for example, Qf2 and Qc3. Because of the lack of data, no geologic or hydrogeologic properties were assigned to this unit. In the future, aquifers within this unit may be utilized as a source of water, but cost, lack of information, and water availability at shallower depths preclude it from being considered at present.

GROUND-WATER SYSTEM

The basic elements of ground-water systems are described in this section. This is followed by a description of the ground-water movement system of the study area, which includes recharge, ground-water movement, discharge, water-budget calculations, and water-level fluctuations.

The hydrologic cycle describes the ways in which water moves through the earth. During its continual circulation from ocean to atmosphere, to land, and then back to the ocean, water becomes temporarily stored in streams, lakes, wetlands, soils, and the ground.

Water in the atmosphere condenses to form clouds and eventually falls to the earth's surface as precipitation in the form of rain or snow, which is the source of all fresh water. Part of this precipitation runs off to roadside drainage ditches, storm drains, streams, lakes, wetlands, or directly back to the ocean. A portion of the precipitation is evaporated directly back to the atmosphere from the ocean, lakes, streams, bare soil, and plant surfaces, and part infiltrates into the ground. Of the precipitation that enters the ground, some is drawn up by plant-roots and returned to the atmosphere by transpiration from the leaves, and some continues to percolate downward, recharging the ground-water system. Some of the ground water may discharge to the land surface by seepage to lakes, wetlands, streams, and springs, which then makes its way back to the ocean. A small quantity of the ground water is also withdrawn by wells. The rest of the ground water discharges back to the ocean in the form of springs and seeps along the ocean floor.

On a long-term basis, many ground-water systems are usually in a state of dynamic equilibrium; that is, inflow to the system is equal to the outflow from the system, and there is little or no change in the quantity of water stored in the system. Precipitation falling to the earth can be intercepted by vegetation, run off the surface, or infiltrate into the ground. The water that infiltrates into the ground can be transpired by plants, evaporate from bare soil, become part of the shallow subsurface flow, or percolate downward to the water table and recharge the ground water.

Ground water is found throughout the study area under confined and unconfined conditions. Parts of some of the hydrogeologic units may be unsaturated where they are truncated along the coastal bluffs, but most of the units contain at least some ground water.

The ground-water system in northwestern Pierce County consists of multiple aquifer and semiconfining units contained in the thick sequence of unconsolidated Quaternary deposits within the study area (fig. 5). The aquifers and semiconfining units have variable boundaries and hydraulic properties. The defined aquifers are generally composed of coarse-grained deposits, but local lenses of fine-grained silt and clay may affect their permeability and flow characteristics. Conversely, the semiconfining units are generally composed of fine-grained silt and clay deposits, but local lenses of coarse-grained sand and gravel deposits may also affect their permeability and flow characteristics.

The boundaries of the ground-water system within the study area are the water table at the top, the bedrock at the bottom, the Puyallup River and Commencement Bay on the east, Puget Sound on the north, and The Narrows on the northwest. The south and southwest boundary is approximately the northeast divide of the Clover-Chambers Creek Basin.

The upper boundary is the water table, which can be an inflow, outflow, or no-flow boundary, based on its proximity to land surface, the season of the year, and the local directions of ground-water movement. The water table is not a static boundary, but rises and falls with the seasons throughout the year. During the winter months, when precipitation is at its highest, water recharges the ground-water system and the water table rises. During the summer months, with less precipitation, the water table declines. In areas where the water table is close to the land surface, the water can move upward by capillary action and evaporate back to the atmosphere at land surface, or if within the root zone, it may be transpired back to the atmosphere by plants. The bedrock is assumed to be relatively impermeable in comparison to the thick sequence of unconsolidated Quaternary deposits and is considered the lower flow boundary in the study area.

There is no geographic or physiographic feature to delineate the regional southwest boundary of the study area. On a local scale, the northeast divide of the Clover-Chambers Creek Basin (fig. 1) does act as a boundary for the shallow ground-water system. On the northeast side of the divide, shallow ground water generally flows north and northeast to the Puget Sound, Commencement Bay, and the Puyallup River. On the southwest side of the divide, the water flows southwest to Clover and Chambers Creeks (fig. 1). The source of ground water flowing north into the study area at depths below unit Qc1 extends south below the study-area boundary.

Ground-Water Recharge

Recharge to the ground-water system is primarily by percolation of precipitation. Other minor sources of recharge are seepage from streams, lakes, and wetlands, septic field leachate, irrigation, and leakage from water lines. Recharge from precipitation occurs everywhere, except in areas where ground water is discharging at land surface, for example at seeps and springs and in areas covered by impervious materials such as asphalt and concrete. But these impervious materials may only delay and redistribute the precipitation that runs off into storm drains or dry-hole catchment or encounters permeable deposits.

The area-weighted estimated long-term average ground-water recharge calculated for the Tacoma-Puyallup study area is 14.1 inches per year. The estimates were obtained from computations based on precipitation and area types that included surficial geology, land use, and information about whether the area was sewered or on a septic system. Geographic information system (GIS) techniques were employed to combine a precipitation-distribution map; a simplified surficial geology map that identifies areas of coarse- and fine-grained deposits; a simplified land-use map divided into grass, which includes all agricultural land and low-density urban areas, forest, saturated land, and high-density urban areas; and a map separating sewered areas from nonsewered areas. In addition the GIS techniques were used to generate a map of the distribution and quantity of recharge for the study area (fig. 13).

Recharge estimates were based on the relation between mean annual precipitation and surficial geology developed for east King County (Turney and others, 1995). In that study, regression equations were developed and used to estimate recharge in areas of fine-grained (till) and coarse-grained (outwash) deposits, and, based on the amount of annual precipitation, ground-water recharge through the till ranged from 10 to 25 inches per year and through the outwash from 15 to 42 inches per year (Turney and others, 1995). More recent studies in areas mantled by till (Bauer and Mastin, 1997; Mastin, 1996) reported annual area-weighted average recharge values for a 2- to 3-year period in three nearby basins--Clover, Beaver, and Vaughn Basins, located in central and northwestern Pierce County. It was assumed that the average of the average recharge from the three basins is representative of the variability of the till within the study area. The ratio of the average recharge to precipitation derived from these three basins (Bauer and Mastin, 1997) was applied directly to the mean annual precipitation value (National Oceanic and Atmospheric Administration, 1995 and 1996). Thus, for fine-grained grass covered areas, the ratio 0.178 was used, and for fine-grained forested areas, the ratio 0.115 was used. For areas underlain by coarse-grained deposits, the regression equation, shown below, developed for east King County (Turney and others, 1995) was used to compute recharge.

$$RCHG = -38.23 + 26.3\,[ln\,(PRECIP)]\ , \qquad (5)$$

where

RCHG = recharge, as a percent of precipitation, and

ln(PRECIP) = the natural logarithm of precipitation, in inches per year.

To convert *RCHG* to recharge, in inches per year, multiply *RCHG* by 0.01(*PRECIP*).

Recharge in areas defined as saturated land was assumed equal to zero. These areas included lakes, ponds, and wetlands.

Recharge estimates were adjusted for those areas where waste water was disposed of on site (septic systems). Sapik and others (1988) estimated that about 71 percent of the waste water discharged by a septic system is available for recharge through the drain field. No adjustment was made to recharge values for areas where waste water is carried by sewers to a centrally located treatment plant. Sapik and others (1988) assumed that the amount of ground water that sewers intercept and carry away is about the same amount as they leak to the ground-water system.

Lastly, the recharge estimates were adjusted to account for leakage from water-supply distribution systems in areas where the water is imported from outside

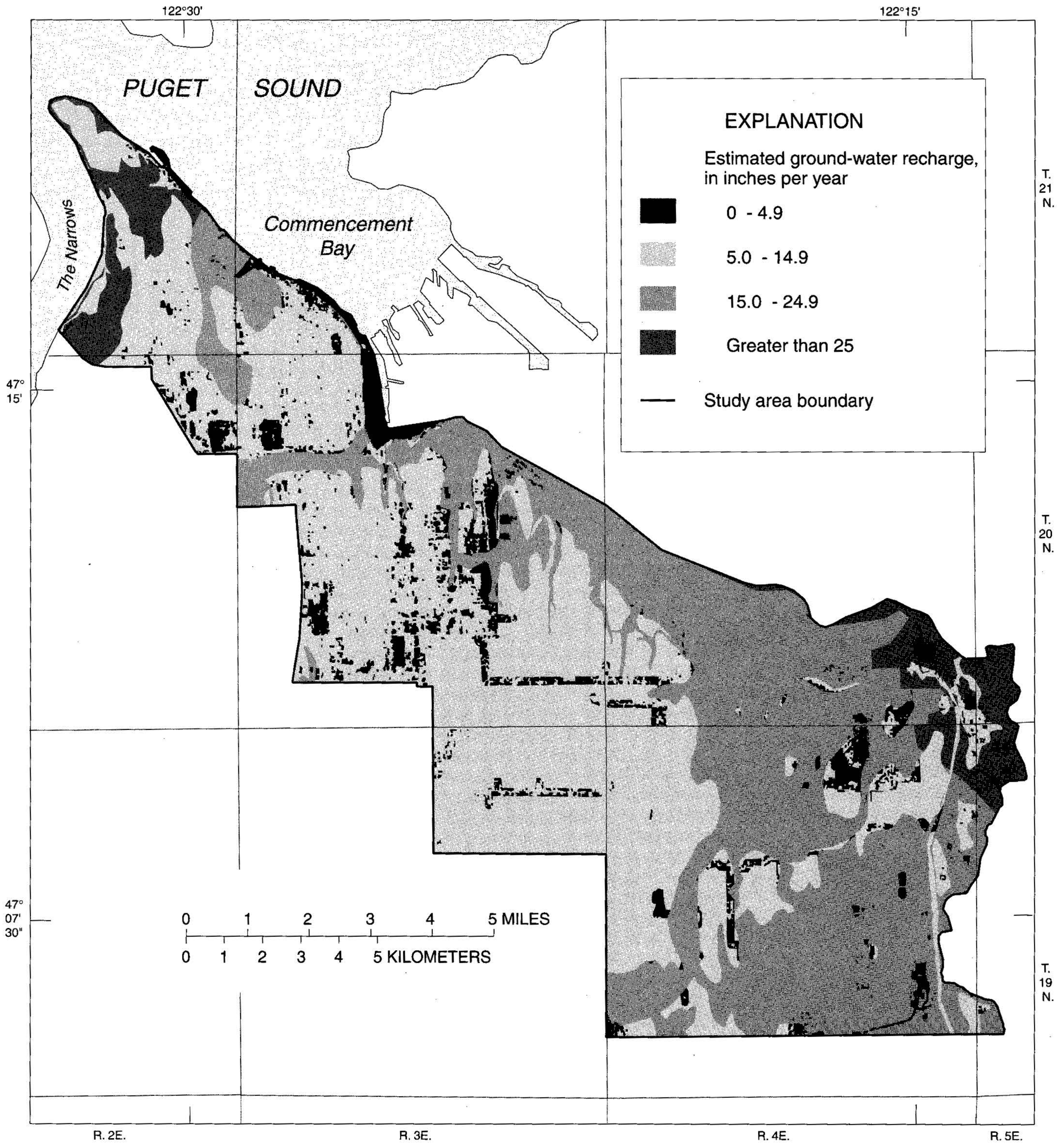


Figure 13. Distribution of estimated ground-water recharge in the study area, in inches per year in the Tacoma-Puyallup area, Washington.

the study area. This adjustment, which was applied only in high-density urban areas, was a value of 7 percent. This value is based on estimates of water losses reported from water systems inventoried in the study area.

The distribution of the long-term average annual recharge based on the previously described equations within the study area (fig. 13) reflects the combined effects of precipitation, surficial geology, land use, and type of sewage disposal. The resulting map shows recharge highest in the northwest and southeast parts of the study area. In general, the areas of lowest recharge are in areas where till is present at the surface and where precipitation is low. But the recharge through the till may be greater if the degree of compaction is less and composition is coarser than in the average for the three basins studied by Bauer and Mastin (1997). The estimated recharge is also within the possible range given by chloride mass balance calculations. This recharge map represents the distribution of the estimated amount of water that reaches the water table for recharge to the ground-water system. The unusual patterns of low recharge (0 to 4.9 inches) are largely due to the distribution of land use and sewered areas. No attempt was made to determine the fate of this recharge in quantitative terms once it becomes a part of the ground-water system. In areas with steep hillsides, some of the recently recharged ground water may move only short distances and quickly discharge into nearby streams, seeps, or springs. It may also only travel short distances in discharge areas such as the Puyallup River Valley. However, in other areas, the ground water may move vertically downward and enter the regional flow system, where it may not discharge for many years.

Ground-Water Movement

The direction of ground-water movement can be inferred from maps of water-level altitude contours. Ground-water movement generally is from areas of recharge to areas of discharge in the direction of decreasing water-level altitudes and perpendicular to the water-level altitude contours. Normally the predominant direction of ground-water movement in aquifers is lateral; however, there can be a vertical component to the direction of motion that is downward in recharge areas and upward in areas of discharge. In discharge areas, water levels in aquifers may be at or above land surface, and water levels in the deeper aquifers may be higher than those in the aquifer at or near land surface.

After the hydrogeologic units were delineated and wells were assigned to one or more of the aquifers, water-level altitude maps were constructed, based on available data, for aquifers Qc1 and Qc2 (figs. 14 and 15). These two maps were used to assist in describing and interpreting the general direction of ground-water movement in the study area. Where water levels were unavailable from inventoried wells, some historical water levels were used (appendix 1).

Ground water within the study area generally moves from the areas with high land surface altitudes in the south and southwest, to Puget Sound, The Narrows, and Commencement Bay to the north and to the Puyallup River on the east and northeast. Locally the ground water discharges toward the streams and creeks and some of the glacial outwash channels in the study area (fig. 1).

Ground-water movement in the unconfined Qvr aquifer generally follows the land surface gradient, with water moving from high-altitude areas in the southeast to the north toward Swan, Clear, and Clarks Creeks, to the northeast and east to the Puyallup River, and to the southwest to Clover and Chambers Creeks. Qvr is often truncated along the steep bluffs of the study area, and water within this unit is discharged at the surface in the form of seeps and springs, which then discharge into one of the creeks, the Puyallup River, Commencement Bay, The Narrows, or Puget Sound. Due to the discontinuous nature of this aquifer and the lack of data, no water-level altitude map was constructed.

Ground-water movement in aquifer Qc1 is shown in figure 14. Water-level altitude contours were drawn where data were available. However, the distribution of inventoried wells in this unit made contouring the water-level altitudes difficult. In general, ground water in this unit moves north, east, and northeast to the Puyallup River, Commencement Bay, The Narrows, and Puget Sound. It also appears to move southwest to the Clover Creek Channel, and some ground water probably discharges to the South Tacoma Channel. But less data are available for the Tacoma Channel area, and direction of movement may be dependent on the amount of nearby ground-water pumpage. Based on the water-level altitude contours in the southeast portion of the study area, the lateral ground-water gradient is about 100 ft/mi (feet per mile). Unit Qc1 is also truncated in areas along the steep bluffs within the study area, and the ground water within this unit is also discharged as seeps or springs. Ground water that is not captured for domestic and public-supply use generally discharges into one of the creeks, the Puyallup River, Commencement Bay, The Narrows, and Puget Sound.

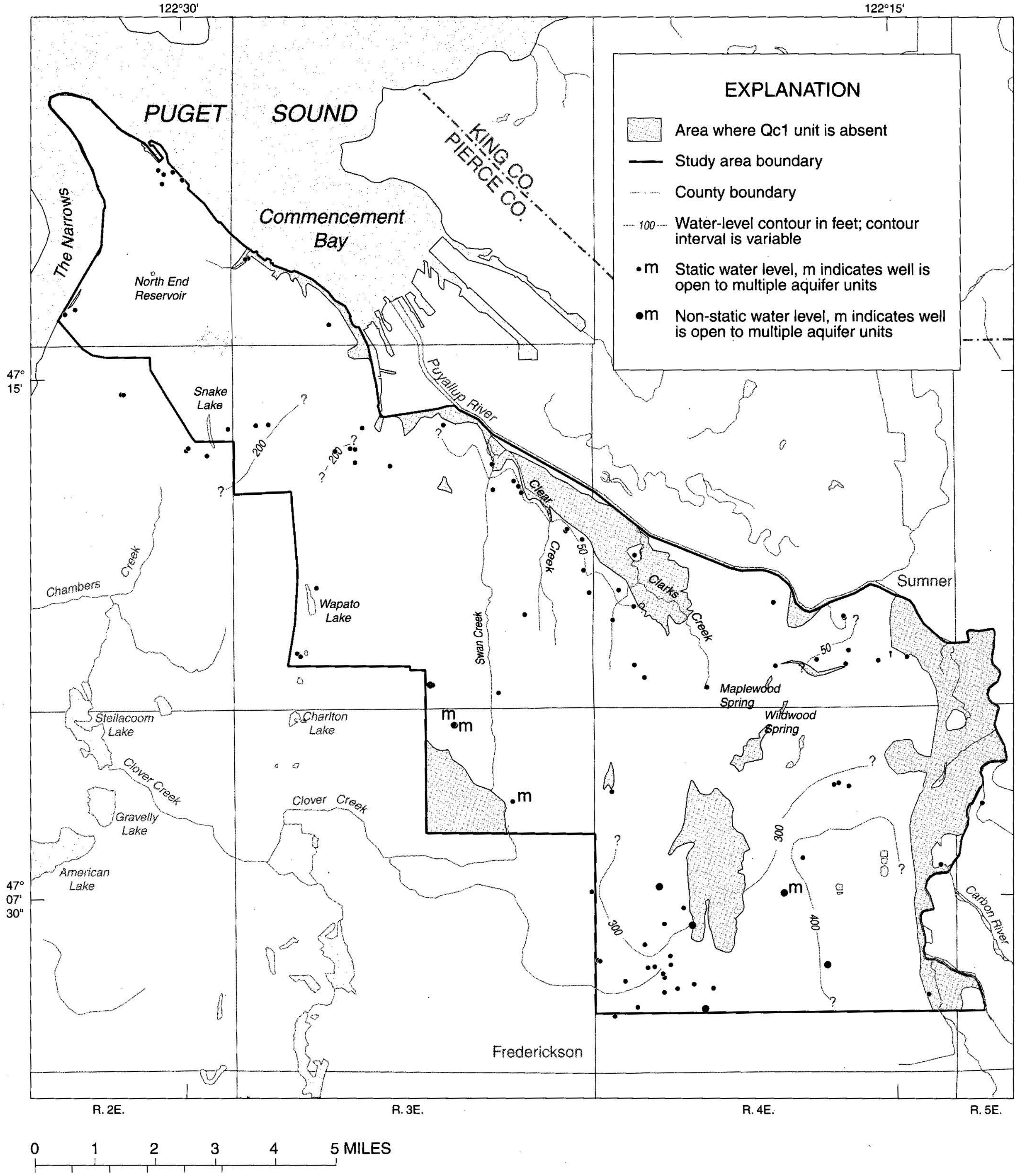


Figure 14. Water-level altitude in aquifer Qc1. Water levels were compiled from current and historical data in the Tacoma-Puyallup area, Washington.

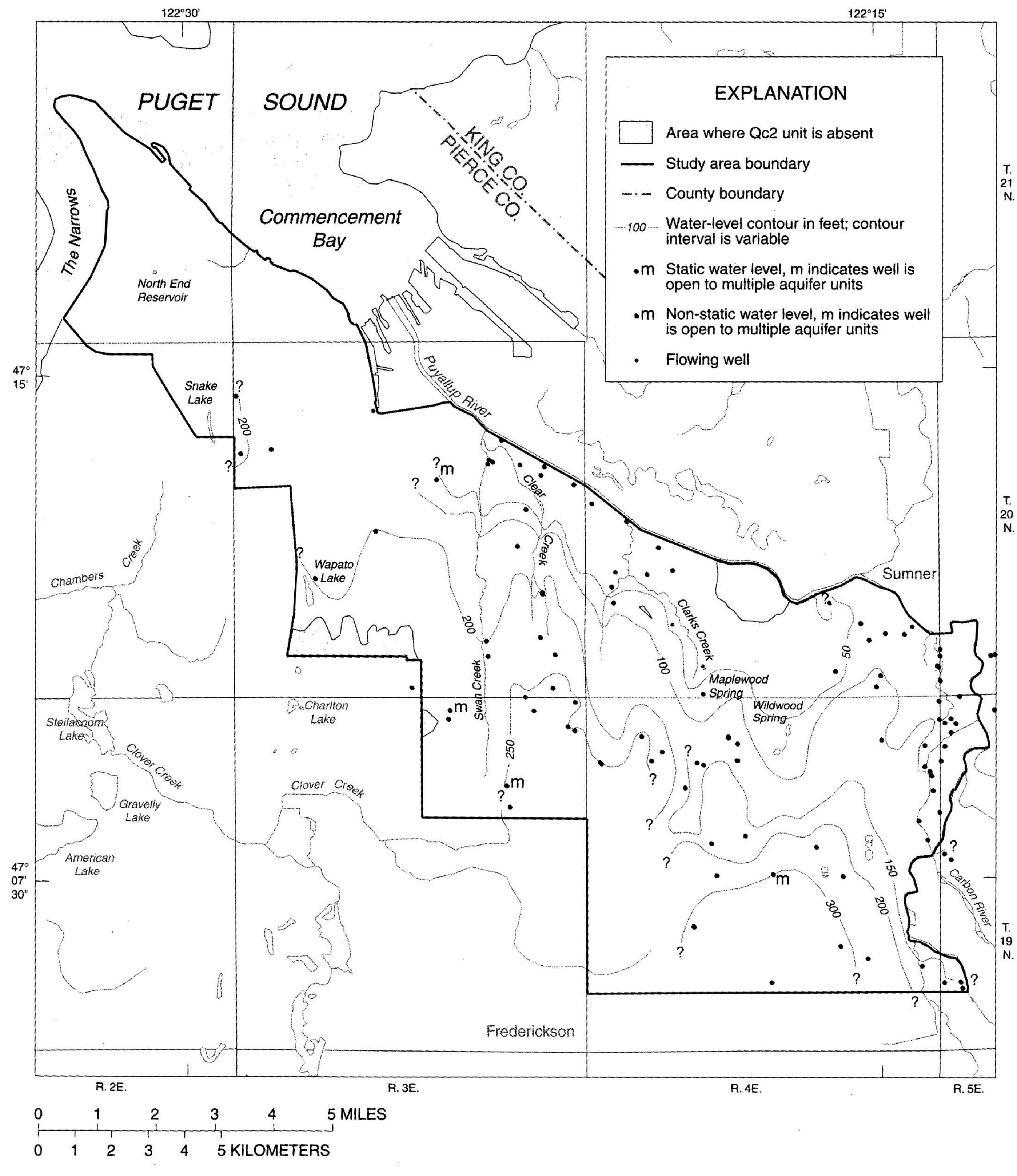


Figure 15. Water-level altitude in aquifer Qc2. Water levels were compiled from current and historical data in the Tacoma-Puyallup area, Washington.

The distribution of the data for unit Qc2 was adequate for contouring water-level altitudes in the central and eastern parts of the study area, but not for the northwest part of the study area (fig. 15). The predominant directions of ground-water movement in this unit are north and east to the Puyallup River, Commencement Bay, The Narrows, and Puget Sound, but the direction of the ground-water movement near the southwest border of the study area is unknown. The lateral ground-water gradients are variable throughout the area and are greatest in the southeast corner of the study area. Gradients in this area are 150 ft/mi to the north and east toward the Puyallup River (fig. 15). In the central part of the study area, ground-water gradients are about 100 ft/mi. Ground-water movement was not determined for units below Qc2 due to the sparse amount of data, although individual water-level altitudes for the deeper units, where available, are listed in appendix 1.

Vertical flow directions are difficult to determine because extents and thicknesses of hydrogeologic units vary, a semiconfining unit may or may not be present, and data are sparse. In general the vertical flow is downward in the upland areas and upward in areas along the coast and the Puyallup River Valley. The vertical water-level altitude difference was determined by comparing water-level altitude contours of the two water-level maps (figs. 14 and 15). Water-level altitude differences between aquifers Qc1 and Qc2 in the southeast part of the study area where sufficient contoured data were available to make a comparison ranged from 50 to 250 ft. In the central part of the study area near Wapato Lake, two closely spaced wells, 20N/03E-20P01 and 20P02 (fig. 3) between aquifers Qc1 and Qc2 (appendix 1), indicate a difference of 30 ft. The downward vertical water-level difference decreases between the two aquifers in areas within the Puyallup River Valley and in the lowland areas along the coast. In these areas upward movement is indicated by the presence of flowing wells in aquifers Qc2 and deeper (fig. 15 and appendix 1).

Water-Level Fluctuations

Ground-water levels fluctuate over time, both seasonally and long term, in response to changes in recharge to and discharge from the ground-water system. When recharge exceeds discharge, water levels will rise, and where discharge exceeds recharge, water levels will decline.

Ground-water levels fluctuate seasonally mostly because of the variations in recharge during the year. In general, water levels in shallow wells in western Washington rise from October through March, when precipitation is high, and decline from April through September, when precipitation is low. Water levels in deep wells generally respond more slowly, and usually with less change, than water levels in the shallow wells. The magnitude and timing of the seasonal water-level fluctuations in an aquifer in response to precipitation are related to the variation in ground-water recharge, the depth to the water table, the depth of the aquifer, the kind of aquifer, confined or unconfined, and the hydraulic characteristics of both the aquifer and the hydrogeologic units that may overlie it. Water-level fluctuations caused by fluctuations in precipitation are also influenced by river or lake changes due to the proximity of the well to the surface-water bodies. Other factors affecting the magnitude of water-level fluctuations in a well are pumping of the well or pumping from nearby wells.

Water levels and specific conductance, where possible, were measured bimonthly in 36 wells for a period of 2 years (fig. 16, and 17a through 17e, and table 5). These wells were completed in hydrogeologic units Qvr, Qvt, Qc1, Qc2, and Qc3, and their depths range from 11.1 ft to 573 ft. They were grouped by well depth in 100-ft intervals, except the last group, which is 200 ft, for the purpose of discussion.

The number of wells, the range of well depths, the range and median values of the individual water-level fluctuations and specific conductance, and the hydrogeologic units in which wells in each group are completed, are shown in table 5 for the 1996 water year. This water year was chosen because the aquifer testing in 1995 in the Tacoma well field just outside the study area near the South Tacoma Channel (fig. 16) may have partially affected nearby observation wells. During the period of June 14, 1995, until September 18, 1995, approximately 17.4 Mgal/d (million gallons per day) were pumped continuously from five wells located in the Tacoma well field (AGI Technologies, 1998).

In general, the water levels in all the observation wells reflect the seasonal variation in precipitation. But the expected decrease in the amount of water-level change in individual wells with increasing depth is not seen in the water-level data collected from this group of observation wells (table 5). In fact several water-level fluctuations appeared to increase with depth. This is probably because most of the wells that are completed at depth (figs. 17b, c, d, and e) were being pumped. Conversely, most of the shallow wells (fig. 17a) are unused, and the water-levels in them are unaffected by pumping.

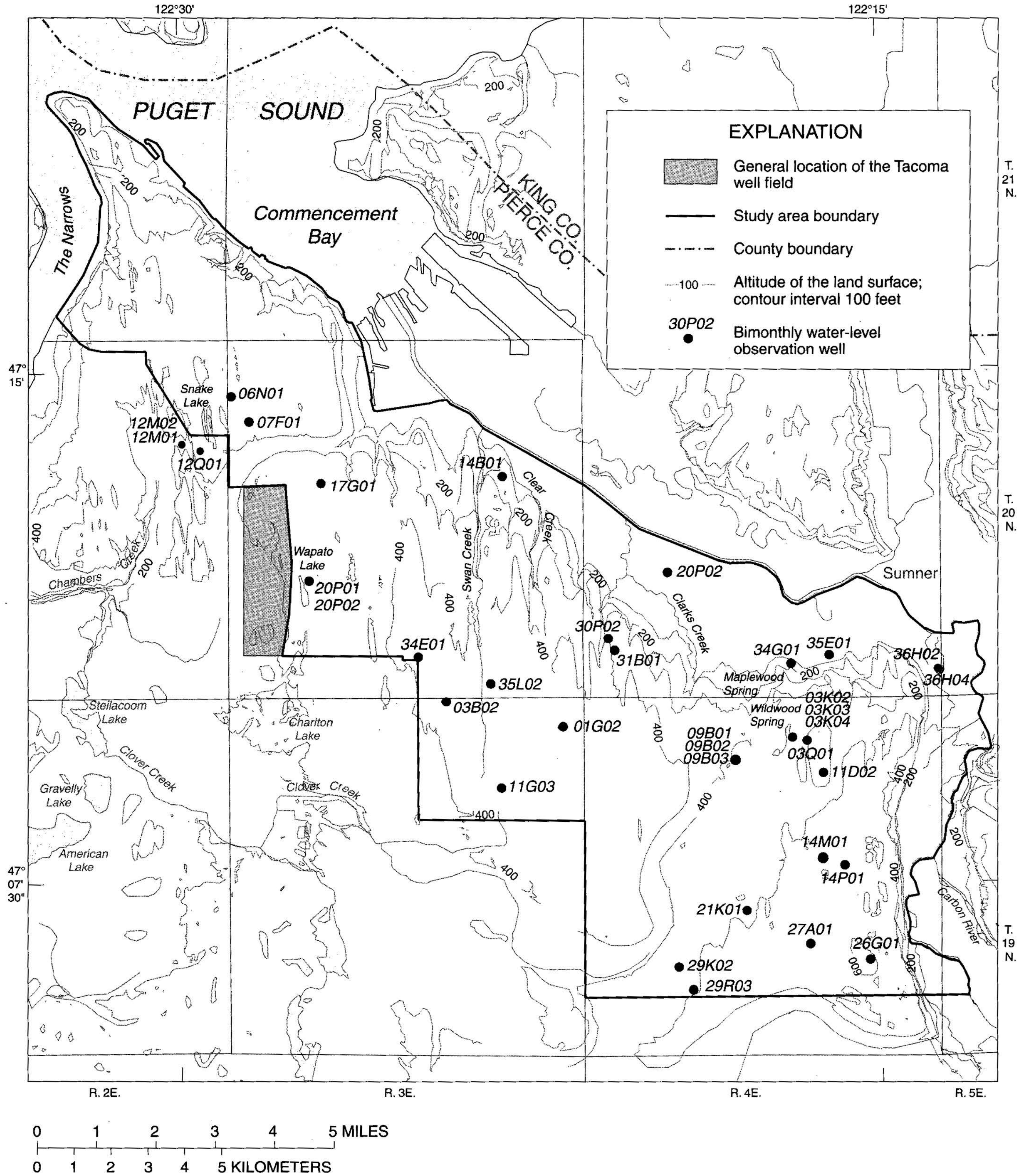


Figure 16. Locations of bimonthly water-level observation wells in the Tacoma-Puyallup area, Washington.

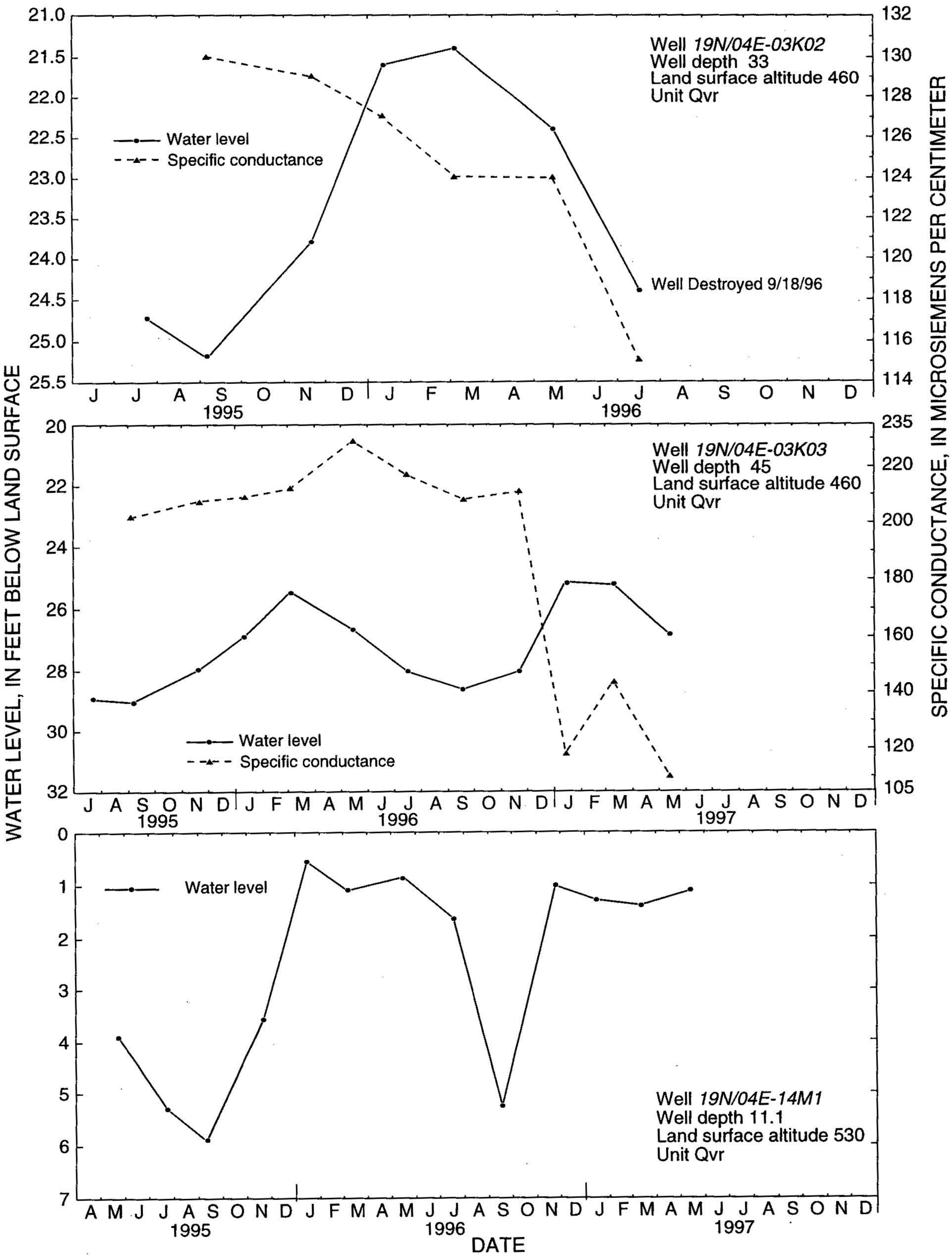


Figure 17a. Water levels and where available, specific-conductance measurements for the bimonthly observation wells 0 - 100 feet deep in the Tacoma-Puyallup area, Washington. See figure 16 for well locations.

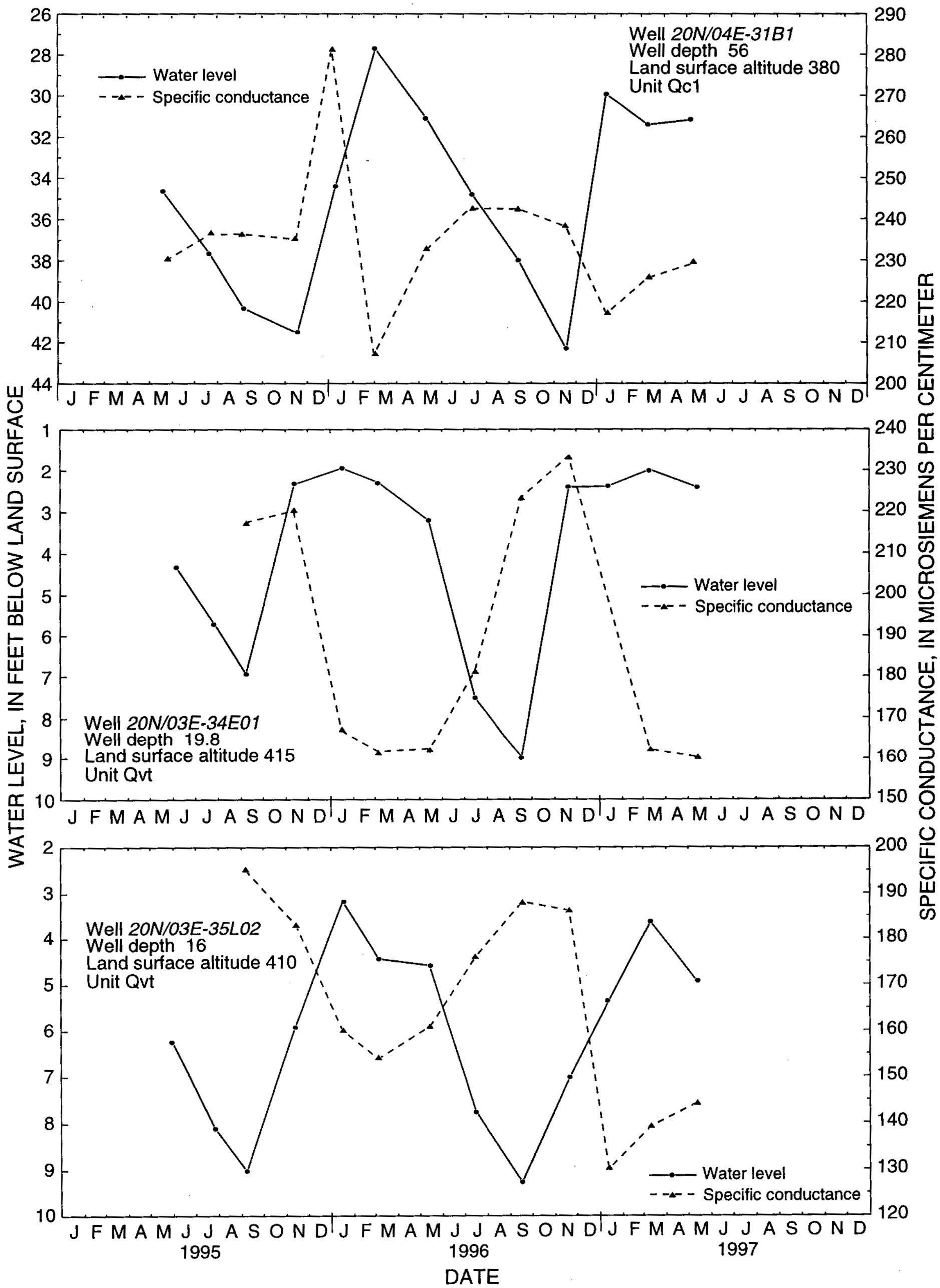


Figure 17a. Continued

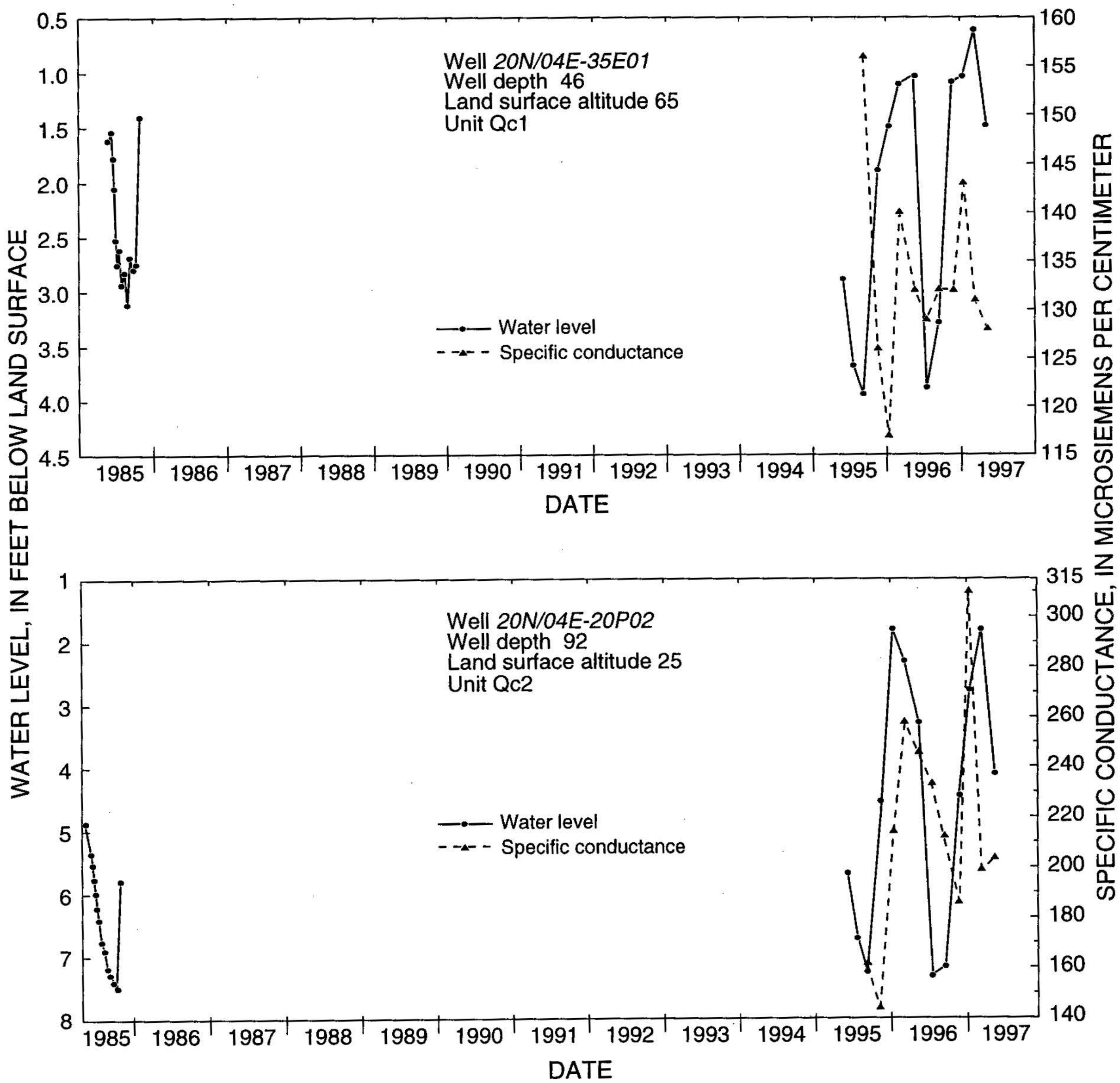


Figure 17a. Continued

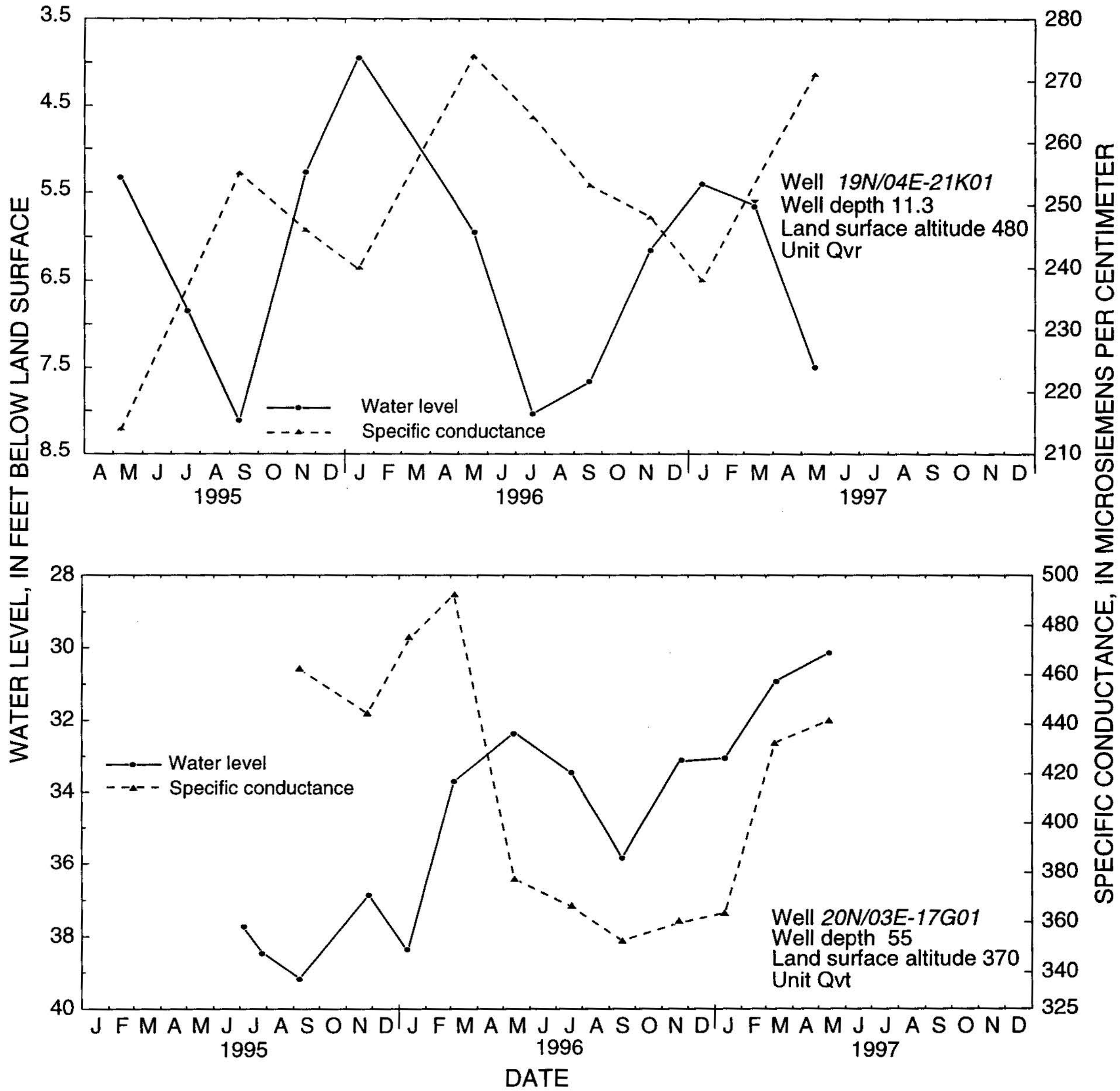


Figure 17a. Continued

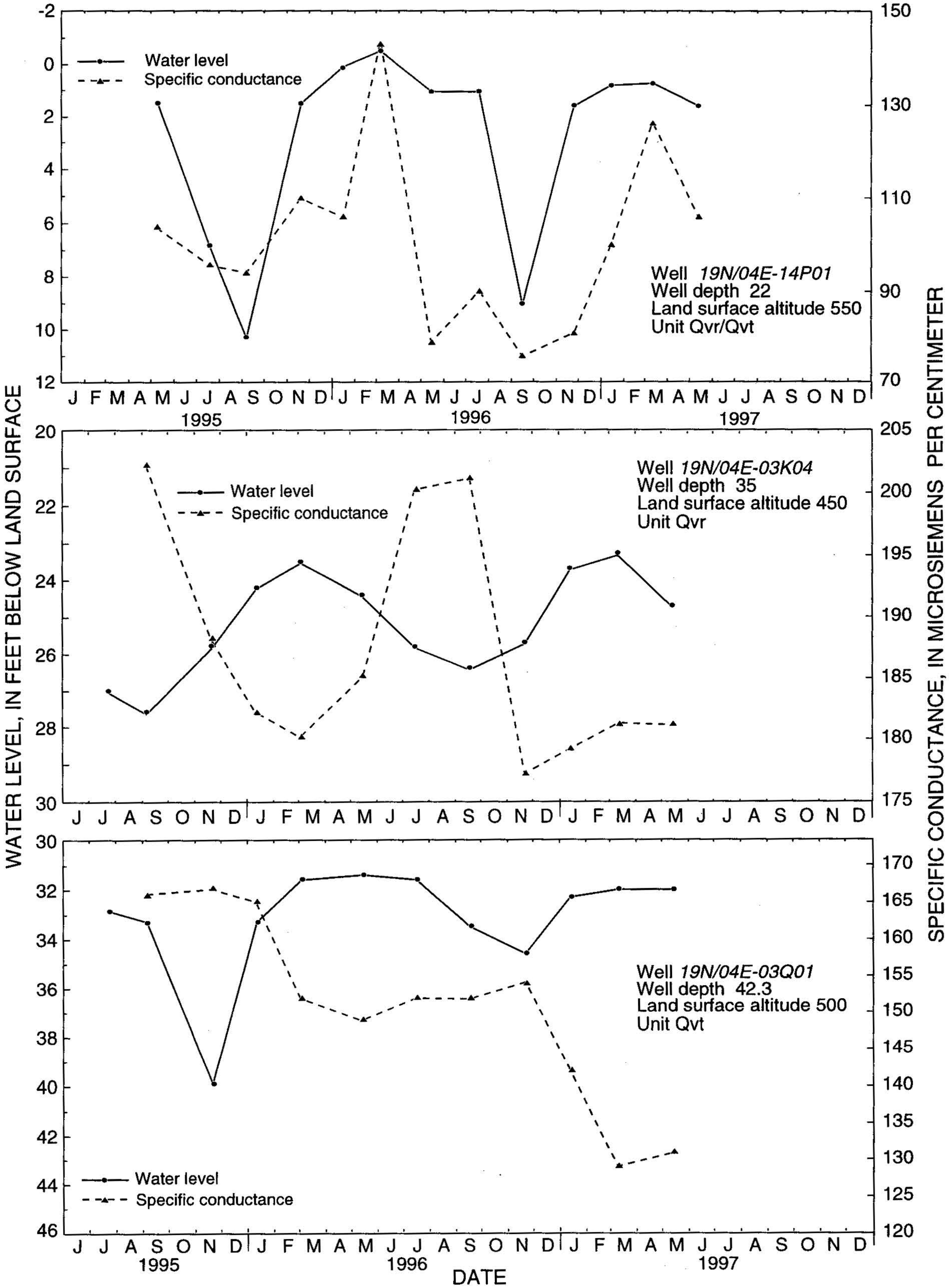


Figure 17a. Continued

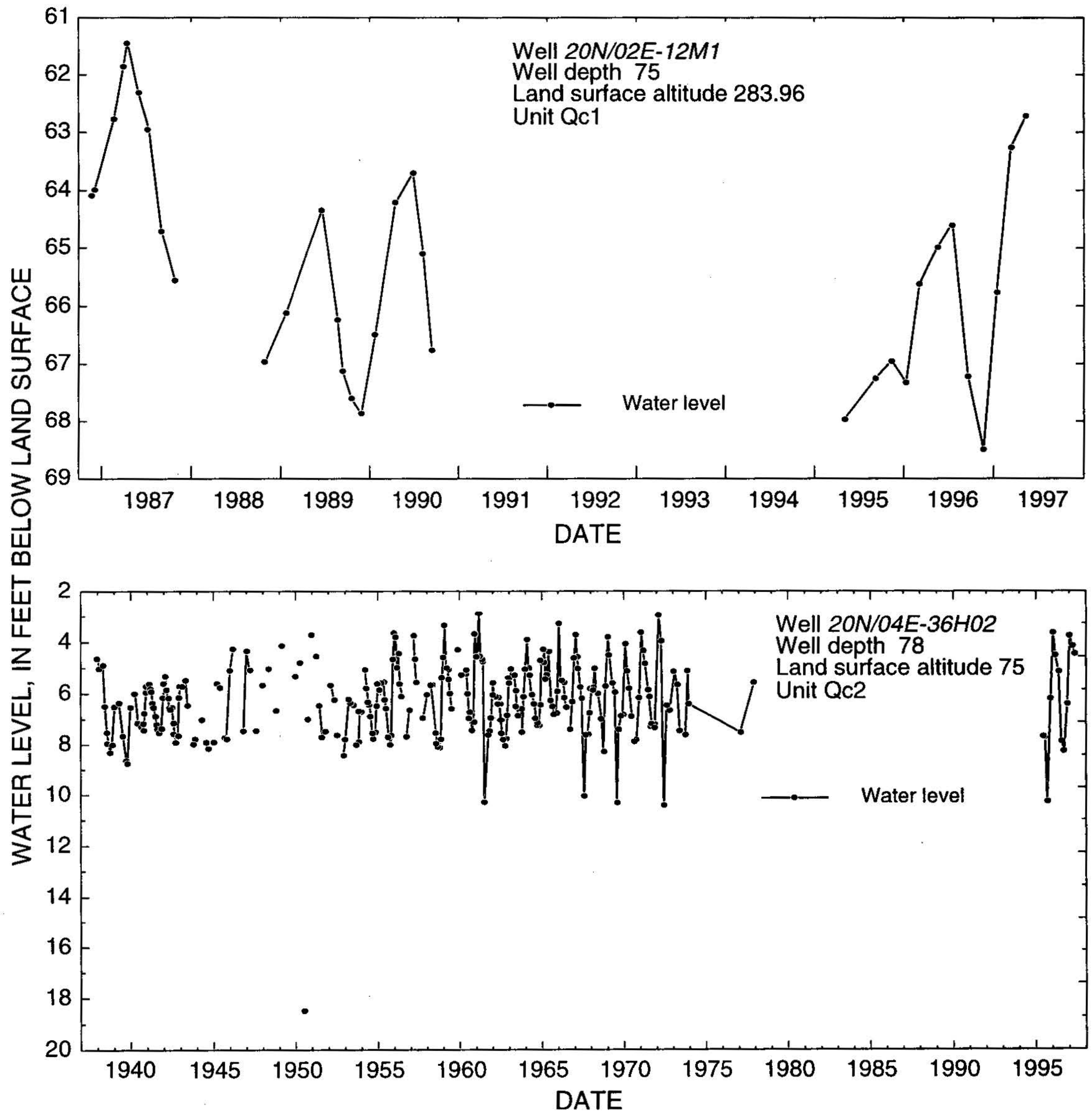


Figure 17a. Continued

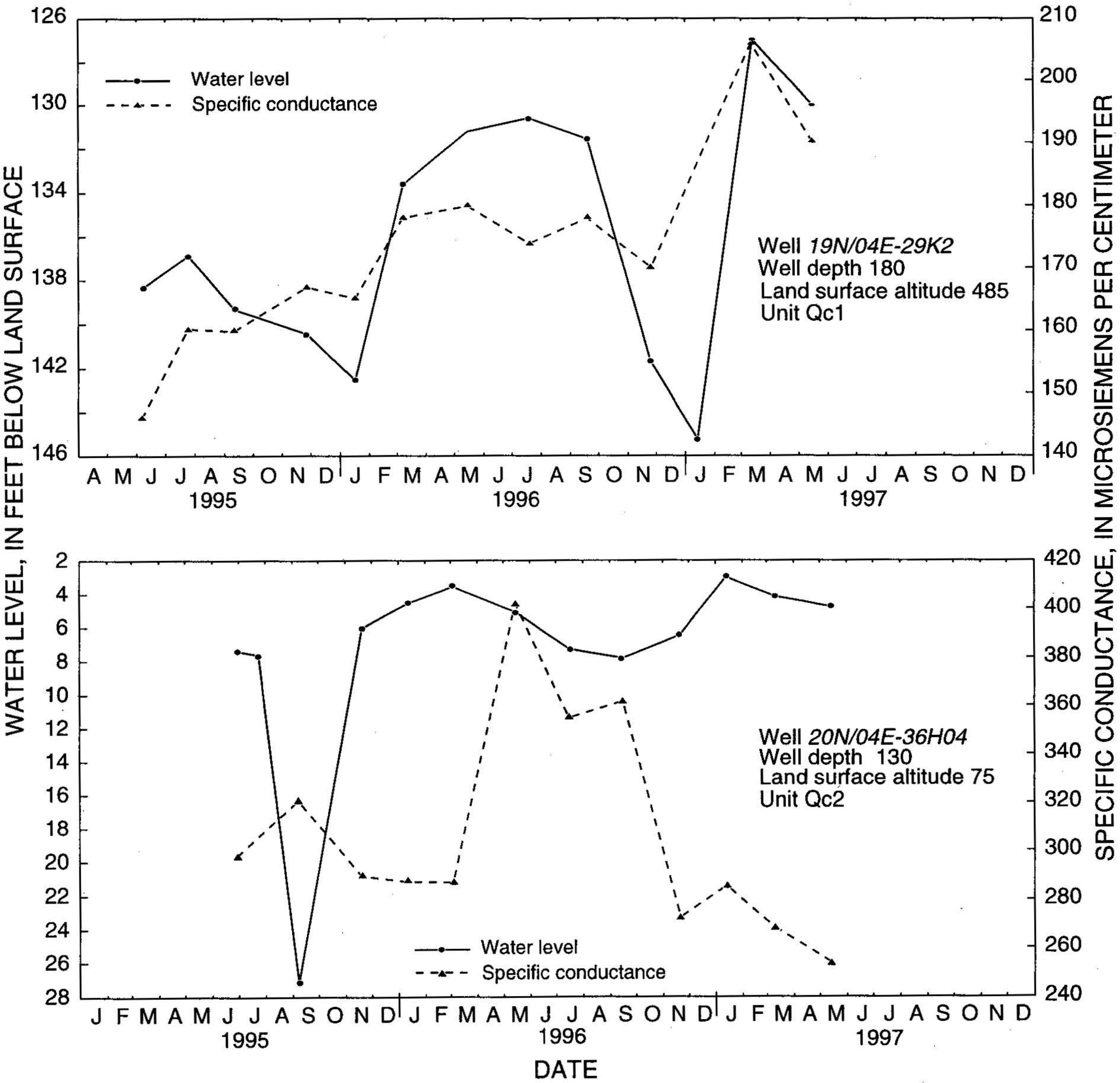


Figure 17b. Water-levels and where available, specific-conductance measurements for the bimonthly observation wells 101 - 200 feet deep in the Tacoma-Puyallup area, Washington. See figure 16 for well locations.

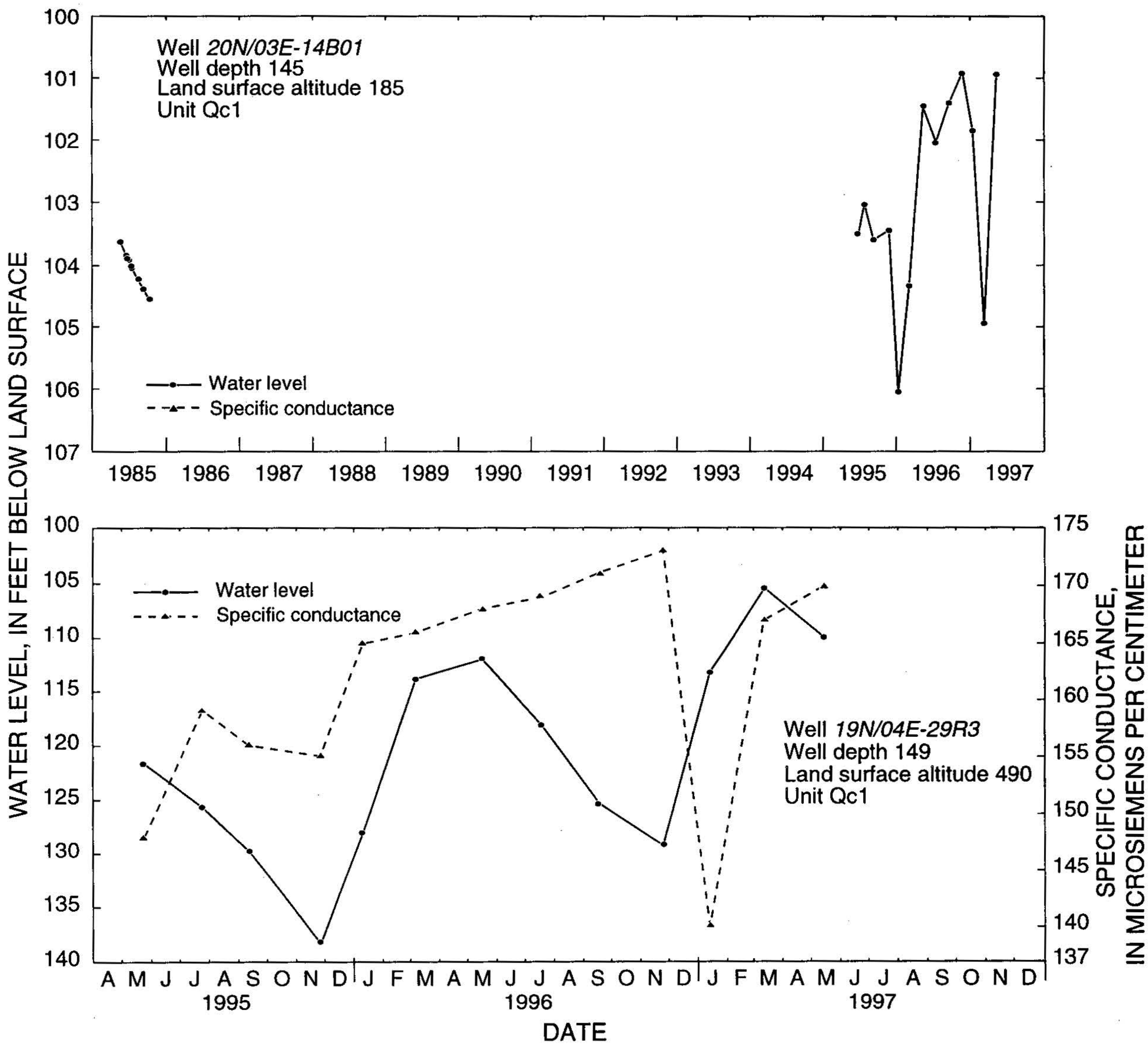


Figure 17b. Continued

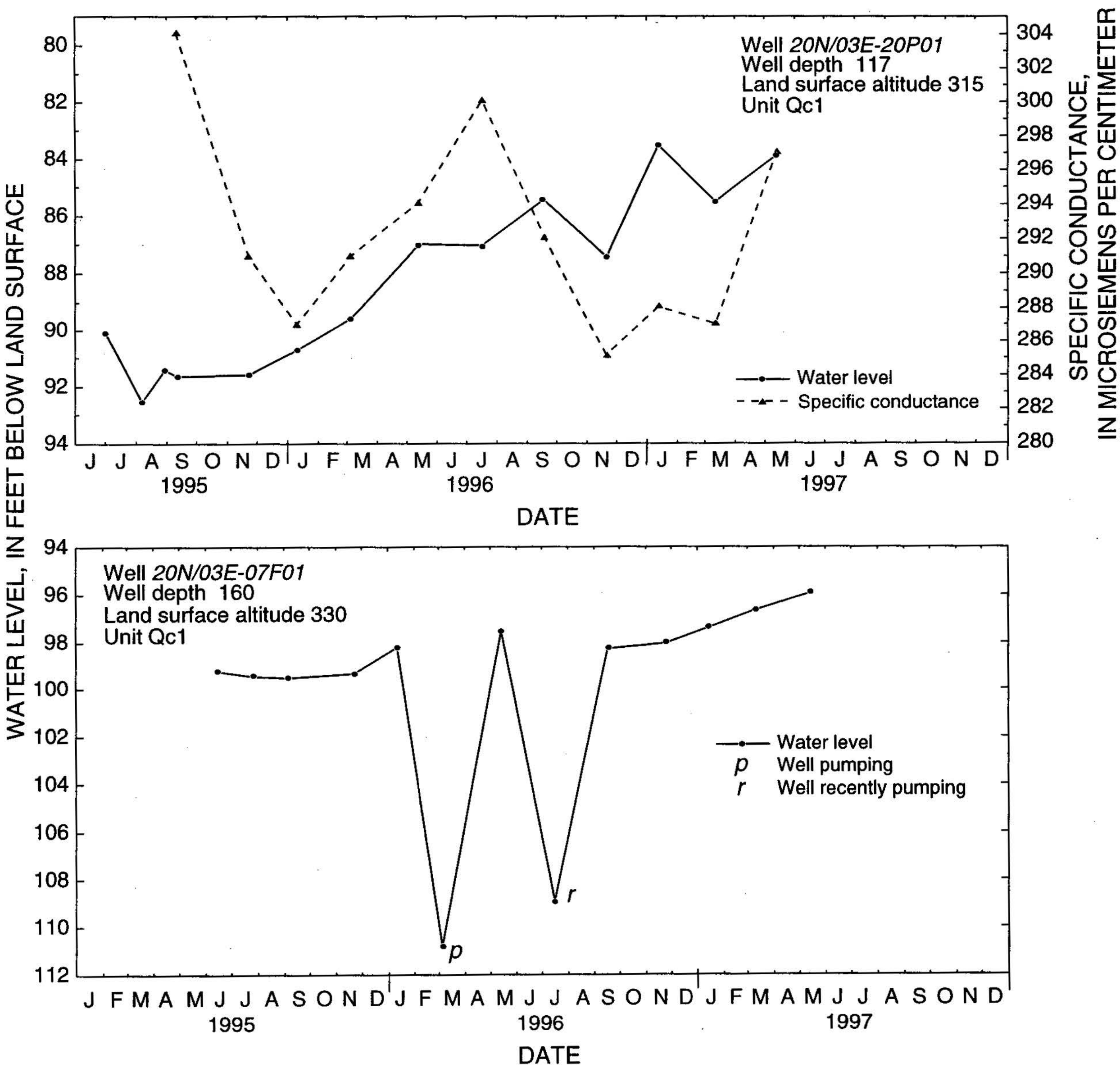


Figure 17b. Continued

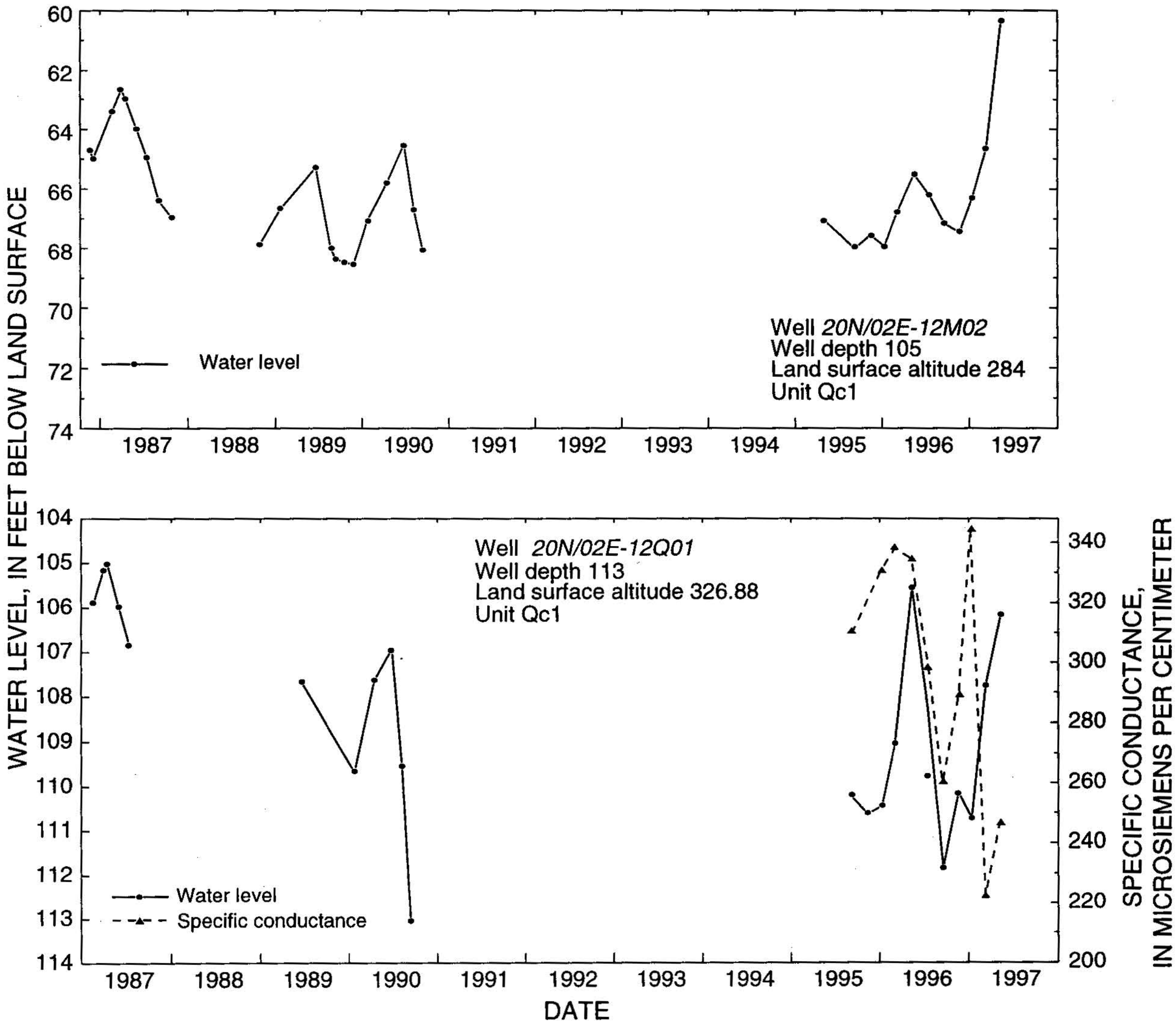


Figure 17b. Continued

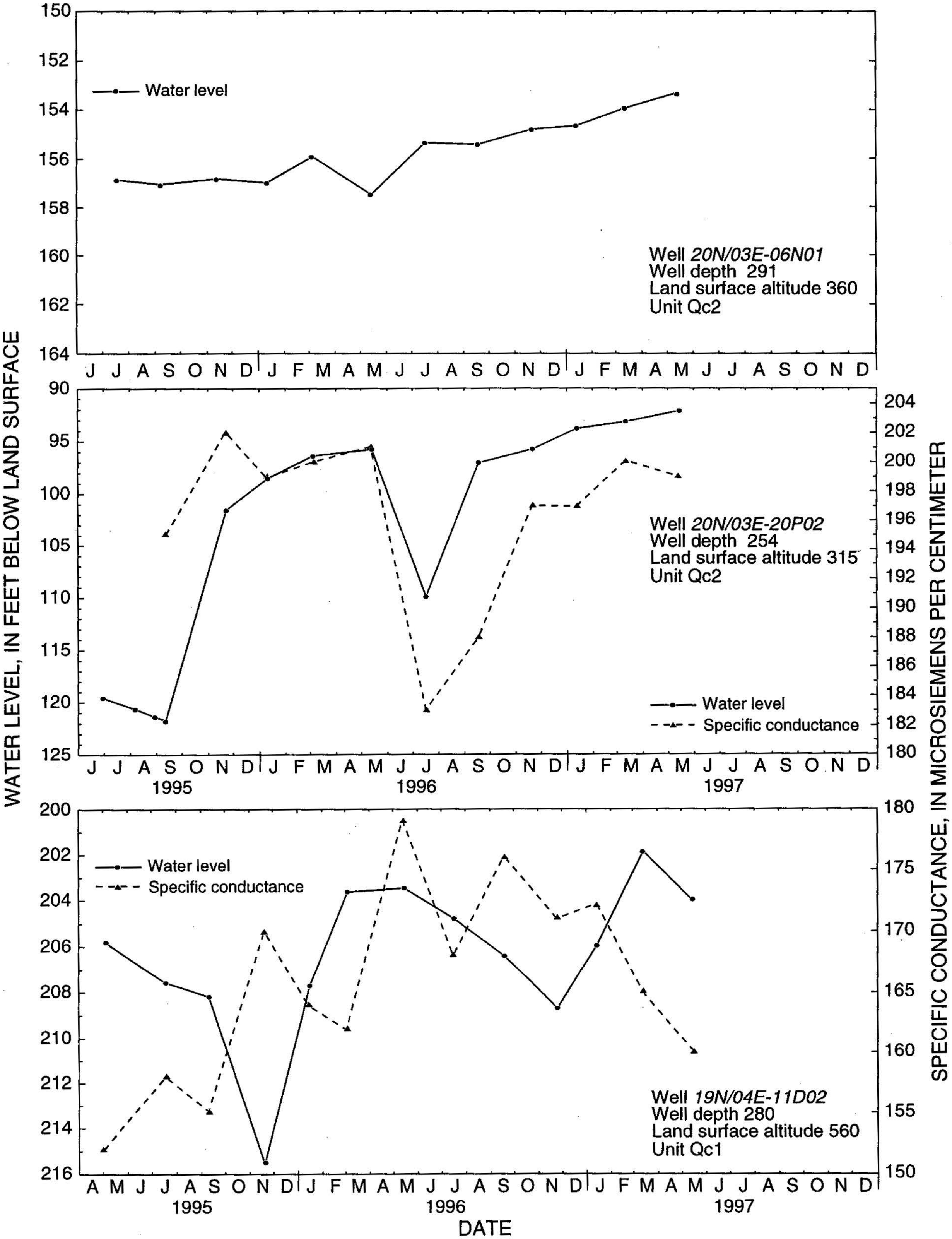


Figure 17c. Water levels and where available, specific-conductance measurements for the bimonthly observation wells 201 - 300 feet deep in the Tacoma-Puyallup area, Washington. See figure 16 for well locations.

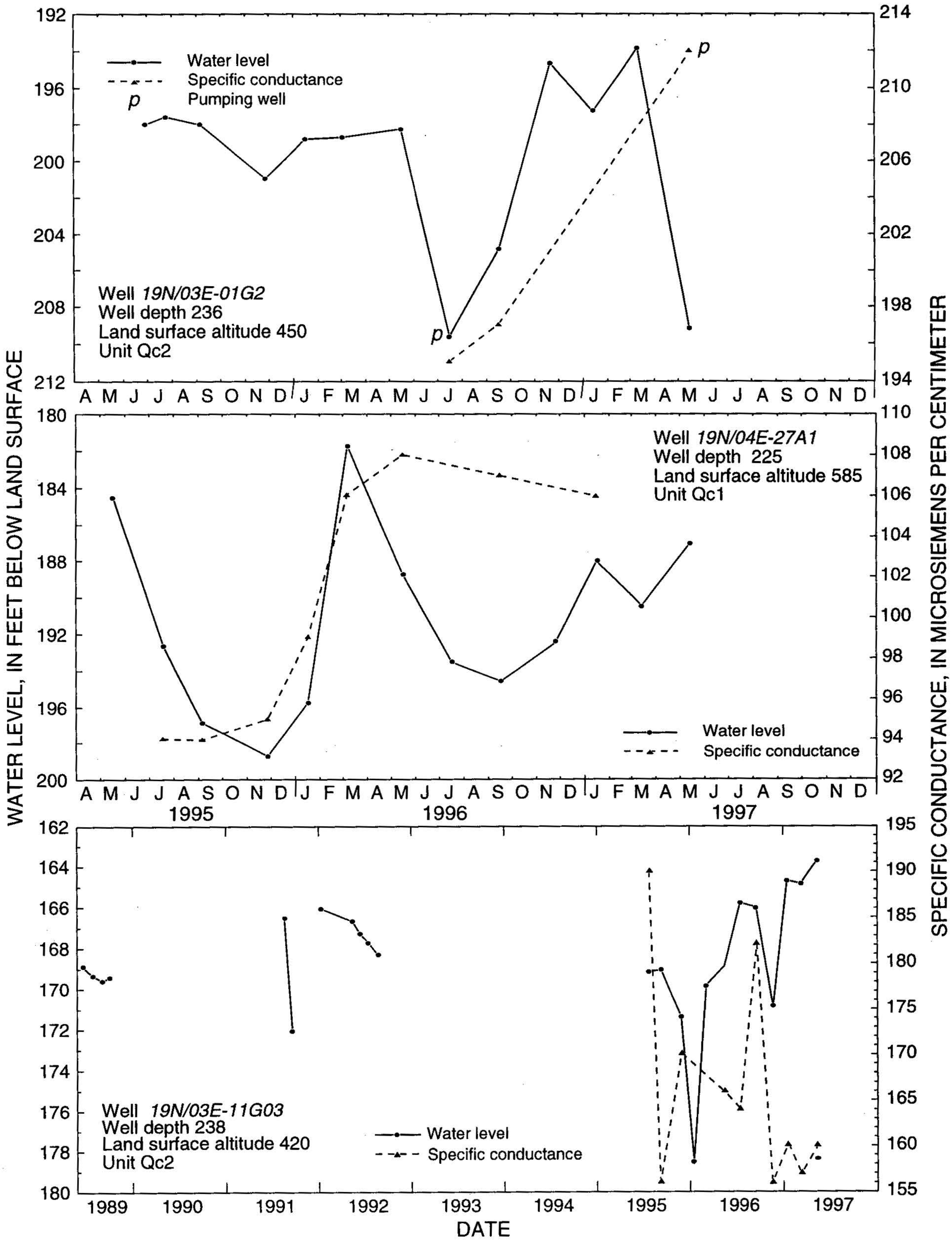


Figure 17c. Continued

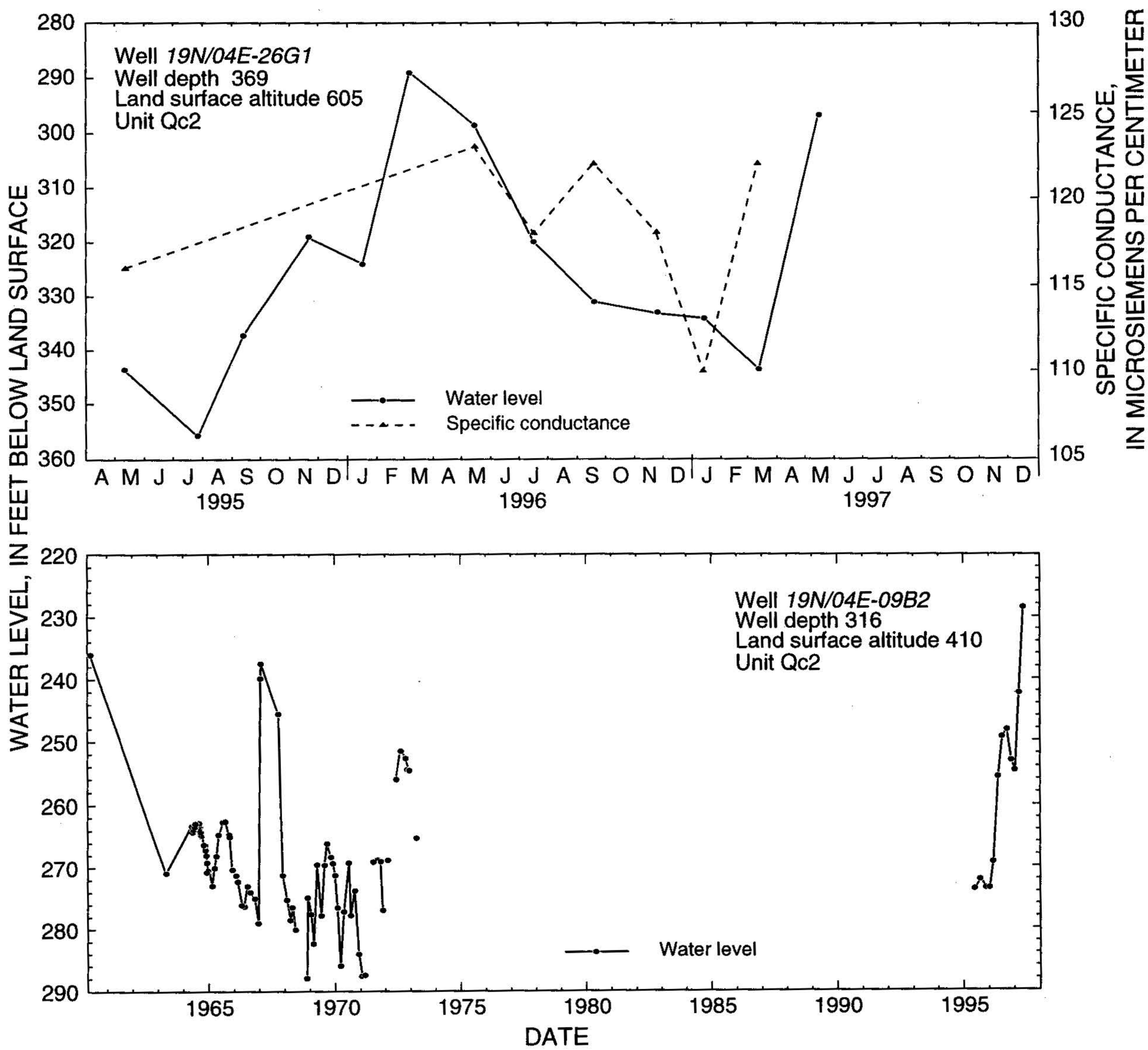


Figure 17d. Water levels and where available, specific-conductance measurements for the bimonthly observation wells 301 - 400 feet deep in the Tacoma-Puyallup area, Washington. See figure 16 for well locations.

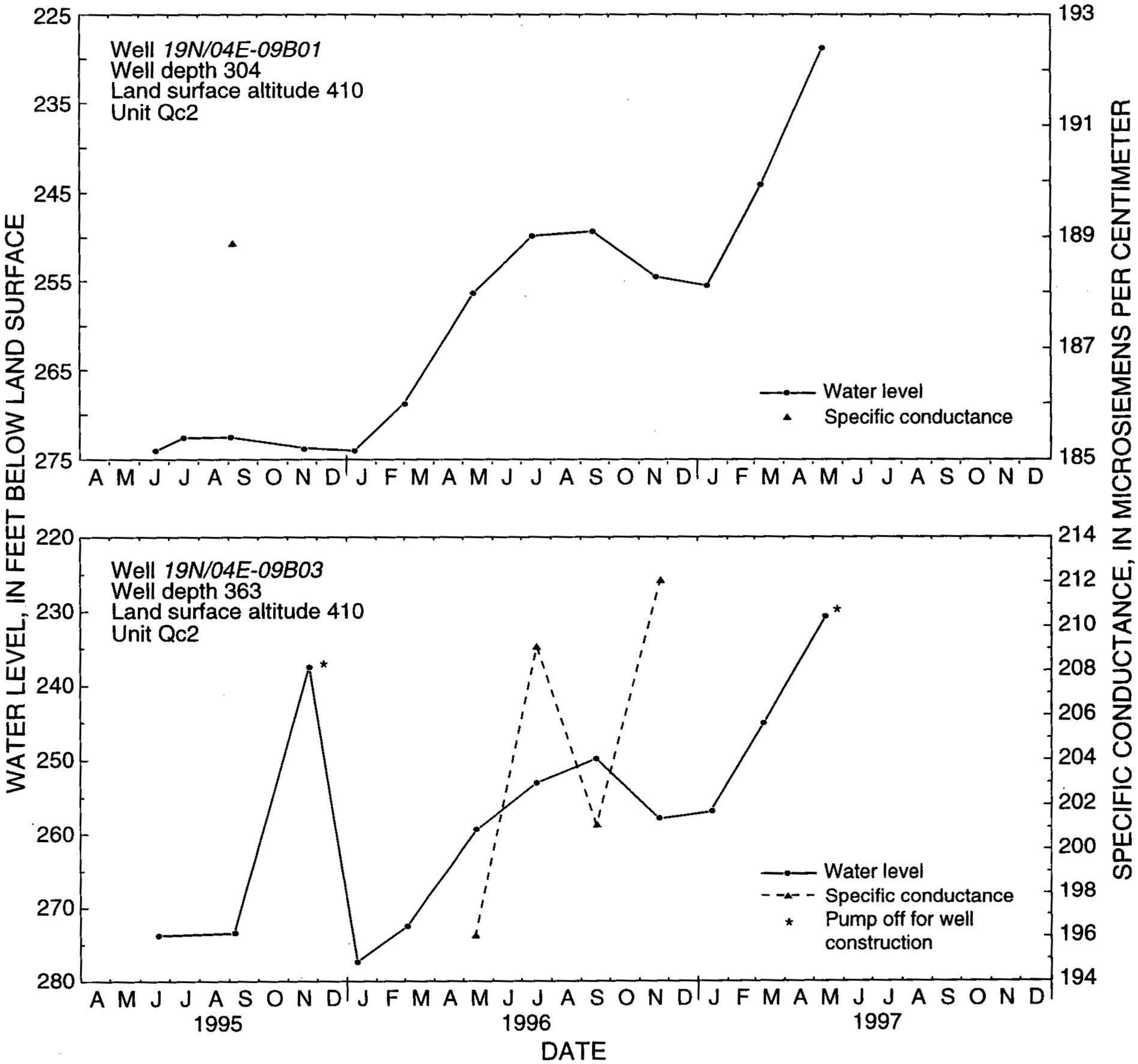


Figure 17d. Continued

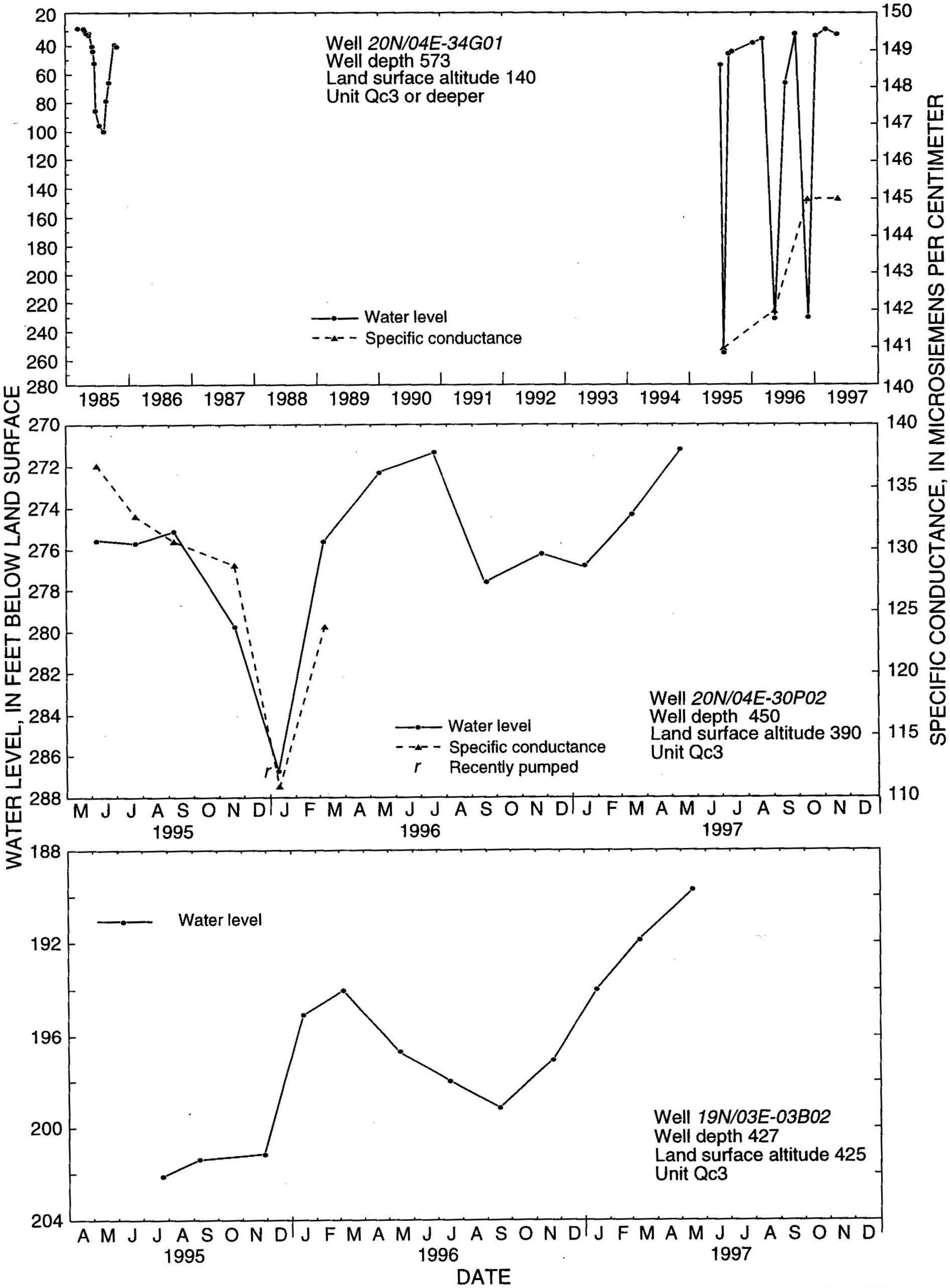


Figure 17e. Water levels and where available, specific-conductance measurements for the bimonthly observation wells 401 - 600 feet deep in the Tacoma-Puyallup area, Washington. See figure 16 for well locations.

Table 5.--*Summary of water-level and specific conductance data for the 1996 water year in the Tacoma-Puyallup area, Washington*
[--, no data; µS/cm, microsiemens per centimeter]

Number of wells	Range of well depth (feet)	Water-level change, in feet			Specific conductance change, µS/cm			Hydrogeologic units	Figure number
		Minimum	Median	Maximum	Minimum	Median	Maximum		
15	11.1-92	2.77	5.12	13.82	18	34	114	Qvr, Qvt, Qc1, Qc2	17a
8	105-180	2.41	6.23	26.32	13	16	115	Qc1 and Qc2	17b
6	225-291	1.54	12.4	17.03	6	16	17	Qc1 and Qc2	17c
4	304-369	24.68	33.44	42.19	13	--	--	Qc2	17d
3	427-573	7.12	15.38	199.61p	13	--	--	Qc3	17e

p Water-level difference is based on a pumping water level.

Seasonal changes in specific conductance values are generally greatest in the shallow wells and decrease with increasing well depth (table 5). Because the specific conductance of the newly recharging precipitation is less than that of the older ground water that has been in contact with minerals in the aquifer, as the precipitation increases and water levels in shallow wells rise, specific conductance values will decrease. In shallow wells the specific conductance value generally decreases at the same time as the water level increases (fig. 17a). As the depth of the wells increases, so does the time between the increase in the water-level and the decrease in the specific conductance (figs. 17b, c, d, and e).

Data from four wells, 20N/03E-17G01, 20N/03E-06N01, 20N/03E-20P01, and 20N/03E-20P02 show a net increase in water levels from 1995 to 1996 (fig. 17a, b, and c). This may be due to an increase in precipitation from 1995 to 1996, or it could be a recovery of water levels following the 1995 aquifer tests in the Tacoma well field.

Ground-water levels may fluctuate over time due to long-term changes in recharge or discharge. These changes may be natural, such as a long-term drought, or due to changes in land-use practices or increased withdrawals from wells. Whatever the cause, over the long term the ground-water system will establish a new equilibrium by adjusting its water levels to balance the changes in the recharge and discharge. When USGS personnel inspected and compared the historical water levels with the water levels measured during this study, no long-term trends were evident in the ground-water system.

Historical data were available for 10 wells, 20N/04E-20P2, 35E1, 36H2, and 20N/02E-12M1 (fig. 17a); 20N/03E-14B01, 20N/02E-12M02 and 12Q01 (17b); 19N/03E-11G03 (17c); 19N/04E-09B02 (17d); and 20N/04E-34G01 (17e). There appears to be no long-term trend in the water levels in wells 19N/04E-9B02, 20N/04E-36H2 or 20N/04E-20P2. However, two of these wells are located near surface-water bodies. Water levels in well 36H02, located in the Puyallup River Valley, are probably affected by the stage of the river, and water levels in well 20P2, located near Wapato Lake (fig. 16), may be influenced by changes in the lake stage. Insufficient data and the large variation in the data for wells 35E01, 11G03, and 34G01 make it difficult to determine if the data indicate any long-term trends. Wells 12M1, 12M2, and 12Q1 indicate a water-level decline of about 2 ft between 1987 and 1989, but do not indicate any long-term trend in the ground-water levels.

Ground-Water Discharge

Ground water in the study area discharges naturally as seepage to streams, lakes, cliff faces, wetlands, and springs, and as ground-water movement out of the area. It is also discharged to man-made systems such as sanitary and stormwater systems and by withdrawal from water wells. Only a small part of discharge was quantified during this study. This includes estimates of the quantity of water discharged to streams and springs and the quantity of water withdrawn from wells.

Natural Discharge

Ground-water discharge sustains the late summer flow, baseflow, of creeks within the study area. Estimates of baseflow were made on three gaged creeks--Swan, Clear, and Clarks Creeks--whose basin boundaries are contained within the study area, and the estimated baseflows were 0.5, 8, and 45 ft^3/s (cubic feet per second), respectively. The baseflow values were estimated from hydrographs of the mean daily discharge data for the 1996 water year (U.S. Geological Survey, 1996) at each of the three continuous gaging stations (locations shown on fig. 1). The ground-water discharge from baseflow to each of the three creeks is considered a minimum discharge value, due to location of the gages and the limited ability to estimate baseflow determined solely on discharge hydrographs. Data were not collected nor were sufficient data available to make reasonable estimates of ground-water discharge to Clover and Chambers Creeks, the Puyallup River, or to ground-water inflow and outflow across the southwest study area boundaries.

Discharge and specific conductance were measured, generally during the spring and fall, at 18 springs (table 6). Discharge from many small- to moderate-size springs throughout the study area was not quantified, and the combined discharge from these springs is unknown. There were also no data available to quantify the ground-water discharge and evaporation from seepage faces along the steep cliff faces in the study area.

An attempt was made to measure discharge from all springs measured by Walters and Kimmel (1968). Some of these springs measured during this period have since been physically destroyed or could not be located, and some previously unmeasured springs were added. Spring discharge measured during this study, with the exception of Maplewood Spring, ranged from 4 to 280 gal/min (gallons per minute), with a median of 49 gal/min and a total discharge of 1,525 gal/min during the summer and fall of 1995. During the spring of 1995, discharge ranged from 12 to 1,800 gal/min, with a median of 120 gal/min and a total discharge of 5,134 gal/min (table 6). Most of this discharge is assumed to be from the shallow ground-water system because the differences between specific conductance values measured in the spring and fall are small.

Water Use

In addition to natural discharge, water from surface- and ground-water sources is withdrawn within the study area for drinking water and for commercial, industrial, agriculture, aquaculture, and irrigation uses. During the 1996 water year, 22,100 million gallons of water were withdrawn to supply the study area's needs. This quantity of water represents a gross withdrawal and does not take into account the quantity of water that is returned to the ground-water system through septic systems or deep percolation of irrigation water. It is unlikely that all water users within the study area were contacted, so all water-use totals probably represent minimum values. Of the 22,100 million gallons, 69 percent (15,200 million gallons) was imported from surface-water sources outside the study area, and 31 percent (6,890 million gallons) was from ground water withdrawn within the study area (this includes wells and springs). Of the 6,890 million gallons used, 2.6 percent (179 million gallons) was imported from ground-water sources outside the study area. A summary of water used during the 1996 water year for the study area, compiled by water use, source of water (well, spring, or surface), and hydrogeologic units, is presented in table 7.

Commercial and industrial water use accounted for 42 percent (9,320 million gallons) of the water used in the study area, making it the largest water use. Water was supplied by public-supply systems as well as by commercial and industrial owners with private wells. Most water used for commercial and industrial purposes, 89.7 percent (8,360 million gallons), came from surface-water sources. Aquifer Qc1 supplied the largest amount of ground water, 6 percent (559 million gallons), for commercial and industrial purposes.

The second largest use of water during the 1996 water year within the study area was for public supply. Both metered and estimated system totals combined, including 8 group A water systems and 12 group B water systems, accounted for 37 percent (8,160 million gallons) of all the water used within the study area. Public-supply systems provided water to about 75 percent of the population (172,000 people) within the study area. The largest part of public-supply water was imported from a surface-water source outside the study area, providing 63 percent (5,160 million gallons) of the total public supply. Ground-water sources provided the remaining 37 percent (3,000 million gallons), of which 98 percent (2,930 million gallons) was from ground-water sources within the study area, and 2 percent (66.0 million gallons) was from ground-water sources outside the study area. Aquifer Qc1 supplied 47 percent (1,410 million gallons) of the total water withdrawn from the ground-water sources.

Water withdrawn from privately owned wells or springs for domestic water use was estimated at 8.7 percent (1,920 million gallons) of the total water use. These sources supplied 25 percent of the water used by the population within the study area. Aquifer Qc2 supplied 43 percent (826 million gallons), and aquifer Qc1 supplied 34 percent (660 million gallons) of the water used for domestic purposes (table 7).

Public-supply loss includes water lost to pipe breakage, leaks, flushing of lines and water for municipal purposes, for example, fire department use. Water-loss estimates were available only from the public-supply systems. Water loss from both metered and estimated public-supply systems was estimated at 8 percent (1,690 million gallons) of the total water use.

Agricultural and aquacultural water use within the study area accounts for 2.8 percent (619 million gallons) of the total water used. Agricultural estimates were based on information from owners on the number and type of livestock maintained. Estimates were then calculated from this information by multiplying the number of animals by the average amount of water used per year for each animal type. Aquacultural estimates were calculated from the number of fish raised and the average amount of water needed to raise each fish. Although aquacultural water use is largely nonconsumptive, it is included as a withdrawal from the system because the quality and location of the water is altered. Ground-water withdrawals from aquifer Qc3 provided over 90 percent (562 million gallons) of the agricultural and aquacultural water used (table 7).

Water withdrawn for irrigation purposes accounted for less than 1 percent (104 million gallons) of the total water used in the study area during 1996. Irrigation supplies were predominately withdrawn from aquifers Qc2, supplying 78 percent (81.4 million gallons), and

Table 6.--*Records of springs inventoried for this study during 1995 and 1996 in the Tacoma-Puyallup area, Washington*

[Altitude: interpolated from topographic maps; Use: H, domestic, U, unused, P, public supply; gpm, gallons per minute; µS/cm, microsiemens per centimeter; RR, railroad; gal/day, gallons per day; --, no data]

Spring number	Owner	Altitude (feet)	Discharge (gpm)	Date inven- toried	Specific conductance (µS/cm)	Temperature (degrees C)	Use	Remarks
19N/04E-01D01S	Ziemke, Pete	320	40 105	10/24/95 03/19/96	556 318	10.5 9.0	--	Near Crystal Ridge Drive
19N/04E-12N01S	Valley Water District	300	136 1,800 [b]	10/23/95 03/19/96	345 306	9.5 9.5	U	Shutdown by Department of Health due to high fecal coliform. WSB-22[a]
19N/04E-13D01S	Valley Water District	295	--	10/23/95	--	--	U	Destroyed. Current owner has no knowledge of spring. WSB-22[a]
19N/04E-25K01S	Robinett, Roger	400	--	06/12/95	--	--	H	Supplies 1 home
19N/04E-25Q01S	Koehler, Carl	450	50	06/12/95	100	9.0	H	Supplies 2 homes
19N/04E-30H01S	Marcum Spring	340	--	10/31/95	--	--	U	Destroyed in mid-1980's. WSB-22[a]
19N/04E-35Q01S	Weyerhaeuser Timber	545	--	10/31/95	--	--	U	Destroyed. Filled, leveled, and developed
19N/04E-36R01S	Mueler	--	--	10/11/95	--	--	--	Could not locate, assumed destroyed
20N/03E-08J01S	Northern Pacific RR	180	--	10/30/95	--	--	--	Destroyed. Possibly filled in by I-5. WSB-22[a]
20N/03E-09M01S	Unknown	180	24 120	10/07/95 03/19/96	276 289	11.0 11.5	--	In ravine below Hood Street Reservoir
20N/03E-09N01S	Northern Pacific RR	175	--	10/11/95	--	--	--	Destroyed. Valley was filled. WSB-22[a]
20N/03E-09P01S	Northern Pacific RR	165	--	10/11/95	--	--	U	Destroyed. Canyon filled in 1970's. WSB-22[a]
20N/03E-09Q01S	Northern Pacific RR	225	139 [b] 268 [b]	10/07/95 03/18/96	277 433	11.5 11.2	--	Spring flows from gravel above a till deposit WSB-22[a]
20N/03E-14H01S	Cullen, Fred	90	48 60	10/30/95 03/19/96	215 219	10.2 10.2	H	Supplies 4 homes
20N/03E-23D01S	Northern Pacific RR	225	--	10/30/95	--	--	--	Destroyed. Area filled and leveled. WSB-22[a]
20N/03E-24B01S	Barker	170	10 --	10/12/95 03/19/96	232 249	15.0 13.5	H	Supplies gas station and 2 homes. Flows from recessional outwash deposits. Housing development upgradient. WSB-22[a]
20N/03E-24B03S	Unknown	170	--	10/11/95	--	--	U	Housing development upgradient. Cliff face is glacial outwash
20N/03E-24J01S	Hernall, HR	160	--	10/11/95	--	--	U	Destroyed. New construction on hillside
20N/03E-25A01S	Canyon Road Springs	160	208 140 [c]	10/12/95 03/19/96	302 310	12.0 10.3	--	Located at Miles Sand & Gravel. Flows from Vashon recessional outwash. WSB-22[a]

Table 6.--*Records of springs inventoried for this study during 1995 and 1996 in the Tacoma-Puyallup area, Washington--Continued*

Spring number	Owner	Altitude (feet)	Discharge (gpm)	Date inven-toried	Specific conductance (µS/cm)	Temperature (degrees C)	Use	Remarks
20N/04E-30L03S	Unknown	230	--	10/12/95	--	--	U	Destroyed. Gravel pit occupies area. WSB-22[a]
20N/04E-32J01S	Maplewood Springs	50	3,040 [d]	07/05/95	190	9.5	P	Estimated discharge is about 5 million gal/day. Supplies approximately 4 million gal/day for drinking water and 1 million gal/day to fish hatchery. WSB-22[a]
20N/04E-34N02S	Cooper, Marie	190	--	06/01/95	--	--	U	
20N/04E-34Q01S	City of Puyallup Wildwood Park	385	42 96	10/30/95 03/19/96	162 151	10.0 10.5	U	Located in Wildwood Park. Flows from recessional outwash above Vashon till. WSB-22[a]
20N/04E-36D03S	Unknown	110	4 12	10/23/95 03/19/96	212 167	12.0 9.0	--	Flows from sand & gravel layer along Highway 162. WSB-22[a]
21N/02E-25B01S	City of Tacoma (Public Utilities)	120	1,194	03/18/96	222	10.5	--	Spring has multiple branches. Houses above stream and sewer treatment plant down stream. WSB-22[a]
21N/02E-34E01S	Northern Pacific RR	20	15 19	10/11/95 03/18/96	193 232	12.0 10.0	--	Near Memorial Park. Flows from beneath Vashon till in the Vashon advance and proglacial deposits
21N/02E-34F01S	Unknown	175	40 17	10/11/95 03/18/96	156 182	11.0 9.5	--	Near Memorial Park. Flows from beneath Vashon till in the Vashon advance and proglacial deposits. Landslide in winter 95 has changed spring and spring discharge. WSB-22[a]
21N/02E-34F02S	Unknown	175	217 240	10/11/95 03/18/96	208 212	11.0 11.0	--	Near Memorial Park. Flows out base of recessional outwash over top of till. WSB-22[a]
21N/02E-34F03S	Unknown	175	280 100	10/11/95 03/18/96	214 156	11.0 11.0	--	Near Memorial Park. Flows out base of recessional outwash over top of till. WSB-22[a]
21N/03E-30M01S	Metropolitan Park District of Tacoma	45	120 240	10/31/95 03/18/96	250 248	10.5 11.0	-- --	Spring located in Puget Gardens Park. Confined by clay with gravel on top. Puyallup Tribal Fisheries Report provides some information. WSB-22[a]
21N/03E-30M02S	Metropolitan Park District of Tacoma	30	152 [b] 723 [b]	10/31/95 03/18/96	395 255	11.2 11.3	-- --	Springs located in Puget Gardens Park. Confined by clay with gravel on top. Puyallup Tribal Fisheries Report provides information

[a] Springs were previously inventoried. Information available in Water Supply Bulletin No. 22, Walters and Kimmel (1968).
[b] The specific conductance and temperature are averaged measurements of the spring--at several locations along the cliff face.
[c] Landslide diverted part of the spring discharge from the main spring discharge point--part of the diverted spring discharge in new spring location--not able to get all of spring discharge. The specific conductance and temperature are the average of two measurements taken from the old and new spring location.
[d] Discharge is average for the year; a fraction of spring discharge is withdrawn for public supply.

Table 7.--*Summary of estimated water use during 1996 by water-use category, source, and hydrogeologic unit in the Tacoma-Puyallup area, Washington*

		Withdrawals (million gallons per year)									
		Hydrogeologic unit								Surface water imported from outside study area	Total
		Qvr	Qvt	Qc1	Qf1	Qc2	Qf2	Qc3	Qc4 and deeper		
Metered public supply [a]											
	Wells			433		1,030	1.46	207	315		1,990
	Springs			942							942
Estimated public supply [a,b,c]											
	Wells			31.3		23.0	0.030	4.63	7.00		66.0
	Surface water									5,160	5,160
Metered public-supply loss [a,d]											
	Wells			33.2		89.5		19.0	27.5		169
	Springs			95.8							95.8
Estimated public-supply loss [a,b,c,d]											
	Wells			9.20		6.74	0.009	1.36	2.05		19.4
	Surface water									1,670	1,670
Commercial and Industrial [b]											
	Wells					260	0.006	49.7	92.3		402
	Springs			559							559
	Surface water									8,360	8,360
Domestic [b,e]											
	Wells	62.0	165	660	62.0	826	20.7	124			1,920
Estimated agriculture and aquaculture [b]	Wells	0.062	0.003	3.55		0.102		562	53.1		619
Irrigation [b]											
	Wells	1.88		20.6		81.4		0.029	0.073		104
Subtotal											
	Wells	63.9	165	1,190	62.0	2,320	22.0	968	497		5,290
	Springs			1,600							1,600
	Imported Surface Water									15,200	15,200
Total											22,100

[a] Includes Class A and Class B water systems.
[b] Amount of water withdrawn is based on suppliers' estimate or area population and represents a minimum value.
[c] Distribution of water withdrawn from specific units based on distribution of water withdrawn from metered public supply and from well logs of wells which supply the area.
[d] Loss includes water loss in leakage in suppliers' distribution system and water used for public uses such as fire hydrants, public parks, street cleaning, etc.
[e] Distribution of water used for specific hydrogeologic units based on domestic wells that were inventoried during the study.

Qc1, supplying 20 percent (20.6 million gallons). Irrigators contacted included golf courses, berry farms, tree farms, nurseries, pastures, daffodil farms, and vegetable farms. Water used for residential purposes such as lawn watering is accounted for under the public-supply category.

Ground-Water Budget

The ground-water budget for the study area was calculated from the information reported in the previous sections. Although it is an estimate based on incomplete data, the ground-water budget gives some insight into the present dynamics of the ground-water system and may indicate where more information is needed to improve the budget estimate.

Water flows into the study area's ground water from recharge from the surface and from ground water moving in across the south and southwest boundary. Recharge to the study area's ground-water system comes from precipitation, septic tank leachate, public water-supply losses, river, creek, and lake infiltration, and irrigation. Discharge from the ground-water system moves to the creeks, the Puyallup River, Puget Sound, springs, seepage faces, ground-water outflow, and is pumped from wells. The components of the ground-water budget equation can be expressed as

$$GW_{in} + R_{pt} + R_{irr} + R_{imp} + R_{inf} = D_{cr} + D_{spr} + D_p + D_{riv} + D_{ps} + GW_{out} + \Delta S \quad ,(6)$$

where

GW_{in} = ground-water movement into the study area;
R_{pt} = recharge from precipitation and septic systems;
R_{irr} = recharge from irrigation;
R_{imp} = recharge from public water-supply systems;
R_{inf} = recharge from river, creek and lake infiltration;
D_{cr} = discharge to creeks;
D_{spr} = discharge to the springs and seepage faces;
D_p = discharge from pumping wells;
D_{riv} = discharge to the Puyallup River;
D_{ps} = discharge to Puget Sound;
GW_{out} = ground-water movement out of the study area; and
ΔS = rate of change in ground-water storage.

In the shallower ground-water system, hydrogeologic units Qc1 and above, ground-water movement across the south and southwest boundary is in both directions, inflow to the north and outflow to the southwest through the Clover Creek Channel and potentially through the Kirby and South Tacoma Channels. The ground-water inflow and outflow across the south and southwest boundary of the study area were not quantified due to the complex configuration of the study-area boundary and a lack of available data. Ground-water inflow to the deeper ground-water system was also not quantified due to a lack of data.

Ground-water recharge was estimated at 92 ft^3/s, which is about 37 percent of the annual precipitation over the study area. This value includes the estimates from precipitation, irrigation, and imported water (see section on Ground-Water Recharge), but estimates for ground-water infiltration from lakes, creeks, and the Puyallup River were not available.

The total of the components of ground-water discharge from the study area that could be estimated was 96 ft^3/s. This value is the sum of estimated baseflow from the creeks of 59 ft^3/s, and the estimated discharge from pumping wells of 22 ft^3/s, plus the average of the total spring and fall discharge values, 7 ft^3/s, added to the average annual discharge for Maplewood Spring, 7 ft^3/s. Discharge estimates for the remaining components, D_{riv} and D_{ps}, and for the rate of change of ground-water storage, ΔS, were not quantified. Assuming the ground-water system is in equilibrium and there is no change in storage and substituting the values back into the equation, the ground-water budget is

$$GW_{in} + 92 + R_{inf} = 59 + 14 + 23 + D_{riv} + D_{ps} + GW_{out} + \Delta S \quad ,$$

Of the unquantified inflow and outflow components in the equation, ground-water inflow (GW_{in}) and ground-water outflow (GW_{out}) are probably the most significant. Data collected to estimate these components would be valuable in obtaining a better estimate of the total ground-water budget.

Based on the configuration of the study area and its general location in the regional ground-water system, the recharge to the ground-water system within the study area moves through the shallow ground-water system along relatively short flowpaths before being discharged to cliff faces as seeps and springs or to creeks. Assuming minimal ground-water inflow occurs from outside the study area to these upper units, a local ground-water budget was approximated for the shallow ground-water system, units Qc1 and above. The budget for the shallow ground-water system differs from the overall budget by (1) including a term for discharge to deeper units and (2) including only the pumpage from the shallow system (6 ft^3/s). This local water budget, expressed in equation 8, shows that at least 86 percent of the quantified recharge within the study area discharges through the shallow ground-water system. The remaining 14 percent or less is discharged to unmeasured springs, seeps, stormwater discharge, or recharge to the deeper ground-water system. Thus, units in the shallow ground-water system constitute a local ground-water movement system, and the hydrogeologic units below Qc1 are part of a more regional ground-water system. Since most of the public-supply wells are completed in the deeper units (table 7), information on the regional ground-water movement system is necessary to determine the ground-water budget for the deeper units. This would include more information and data collected on the ground-water inflow and outflow and discharge to the Puyallup River and Puget Sound.

$$GW_{in} + 92 + R_{inf} = 59 + D_{riv} + 14 + 6 + D_{ps} + GW_{out} + D_{gw} \quad , \quad (7)$$

where

D_{gw} = flow to the deeper units.

GROUND-WATER QUALITY

Water from 33 of the wells and springs (fig. 18) was sampled and analyzed to determine the quality of ground water in the study area. All 33 samples were analyzed for nitrite plus nitrate, major ions, arsenic, iron, manganese, and bacteria. A subset of samples was analyzed for trace elements, MBAS, boron, radon, pesticides, TOC, and VOCs (table 8). Temperature, pH, specific conductance, alkalinity, and dissolved-oxygen content were also determined for all 33 samples.

The overall quality of ground water in the study area is good; only four constituents were found at concentrations above maximum levels specified in drinking water standards or guidelines. Two of the four constituents, the pesticide dieldrin in water from one well and total coliform bacteria in water from four wells and springs, did not meet standards or guidelines related to human health (table 9). Concentrations of iron or manganese in water from eight wells and springs were above maximum concentrations specified by secondary drinking water standards, which are not health related. The occurrence of iron and manganese in ground water at concentrations not meeting secondary drinking water standards is fairly typical in the Puget Sound Region (Turney, 1986). Concentrations of other trace elements met drinking water standards or guidelines.

Dissolved solids in water are made up mostly of the dissolved ions calcium, sodium, potassium, bicarbonate, sulfate, and chloride. In some instances, other substances, like silica, or other ions, like nitrate, make up a significant part of the dissolved-solids content. Large concentrations of dissolved solids reduce the desirability of the water for drinking, but this is not a problem in the study area, where the maximum observed concentration was 261 mg/L, which is well below the secondary drinking water standard of 500 mg/L (table 9).

Ground water in the study area is predominately of the bicarbonate type, but percentages of sodium plus potassium vary with location and depth (fig. 19). Higher percentages of sodium plus potassium in shallow ground water probably indicate effects of land-use activities. Higher percentages in deep ground water are generally indicative of natural sources. Because ions compose a large part of the dissolved-solids content in water, specific conductance (a measure of electrical conductivity) is also shown in figure 19 as a good indicator of dissolved-solids concentrations.

Radon activities in ground-water samples ranged from 260 $\pm$ 25 to 810 $\pm$ 28 pCi/L (picocuries per liter); the median activity was 450 $\pm$ 28 pCi/L (table 9). The source of radon in ground water is the radioactive decay of uranium, and higher radon levels are found in areas underlain by granites or similar rocks that usually contain more uranium. Compared with other parts of the United States, the geologic radon potential of the Puget Sound Region is low (Schumann, 1993), and radon activities in ground water in the study area are indicative of that low potential.

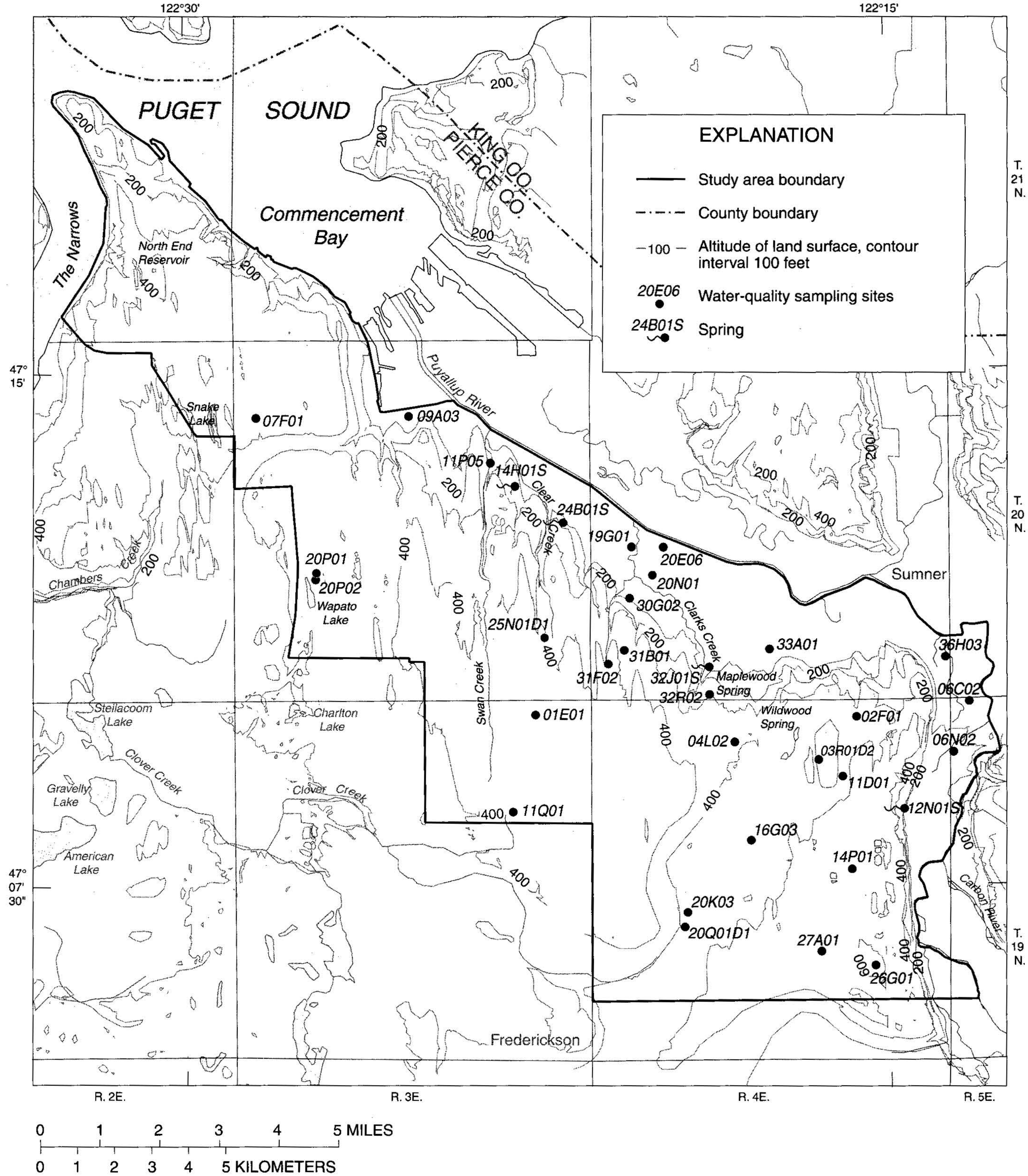


Figure 18. Locations of wells and springs sampled for water quality in 1996 in the Tacoma-Puyallup area, Washington.

Table 8.--*Matrix indicating analyses performed on sample from well or spring and hydrogeologic unit tapped by well or spring in the Tacoma-Puyallup area, Washington*

[Hydrogeologic unit: Qvr, surficial aquifer; Qvt, upper semiconfining unit; Qcl, upper confined aquifer; Qfl, semiconfining unit below Qcl; Qc2, second confined aquifer; Qc3, third confined aquifer; Qc4, fourth confined aquifer; x, analysis performed; --, analysis not performed]

Local well number	Well located in valley (v) or upland (u)	Depth to top of first opening	Hydrogeologic unit	Nitrate, major ions, and field measurements (alkalinity, dissolved oxygen, temperature, pH, and specific conductance)	Boron and MBAS (methylene blue active substances)	Arsenic	Other trace elements	Volatile organic compounds	Pesticides	Radon	Total organic carbon
19N/05E-06C02	v	212.75	Qc2[a]	x	x	x	--	--	--	x	x
19N/05E-06N02	v	99	Qc2	x	x	x	--	--	--	--	--
20N/03E-09A03	v	199	Qc3	x	--	x	--	--	--	x	x
20N/03E-11P05	v	25	Qc1	x	x	x	x	x	x	--	--
20N/04E-19G01	v	53	Qc1	x	x	x	x	x	x	--	--
20N/04E-20E06	v	105	Qc2	x	x	x	--	x	--	--	--
20N/04E-20N01	v	90	Qc2[a]	x	x	x	--	--	--	--	--
20N/04E-33A01	v	321	Qc4[a]	x	x	x	--	--	--	--	--
20N/04E-36H03	v	86.5	Qc2	x	x	x	x	x	x	--	x
19N/03E-01E01	u	256	Qc2	x	--	x	--	--	--	x	x
19N/03E-11Q01	u	237	Qc2	x	--	x	--	--	--	x	x
19N/04E-02F01	u	550	Qc3	x	--	x	--	--	--	x	x
19N/04E-03R01D2	u	552	Qc3[a]	x	x	x	x	--	--	x	x
19N/04E-04L02	u	254	Qc2	x	--	x	--	--	--	--	--
19N/04E-11D01	u	119.5	Qc1	x	x	x	--	--	x	--	--
19N/04E-12N01S	u	spring	Qvr	x	x	x	x	x	x	--	--
19N/04E-14P01	u	22	Qvr/Qvt	x	x	x	x	x	x	--	--
19N/04E-16G03	u	375	Qc2	x	--	x	--	--	--	x	x
19N/04E-20K03	u	193	Qc1	x	x	x	--	--	--	--	--
19N/04E-20Q01D1	u	315	Qc3[a]	x	x	x	--	--	--	--	--
19N/04E-26G01	u	369	Qc2	x	--	x	--	--	--	x	x
19N/04E-27A01	u	206	Qc1	x	--	x	--	--	--	--	--
20N/03E-07F01	u	87	Qc1	x	x	x	x	x	x	--	--
20N/03E-14H01S	u	spring	Qc1	x	x	x	x	x	x	--	--
20N/03E-20P01	u	103	Qc1	x	x	x	x	x	x	x	x
20N/03E-20P02	u	239	Qc2 some Qfl	x	--	x	--	--	--	x	x
20N/03E-24B01S	u	spring	Qc1	x	x	x	x	x	x	--	--
20N/03E-25N01D1	u	258	Qc2	x	--	x	--	--	--	--	--
20N/04E-30G02	u	78.5	Qc1	x	x	x	x	x	x	--	--
20N/04E-31B01	u	56[b]	Qvt	x	x	x	--	--	--	--	--
20N/04E-31F02	u	180	lens of gravel in Qfl	x	x	x	--	--	--	--	--
20N/04E-32J01S	u	spring	Qc1	x	x	x	x	x	x	x	x
20N/04E-32R02	u	271	Qc2	x	--	x	--	--	--	--	--

[a] Hydrogeologic unit of well is questionable.

[b] Approximate depth to first opening.

Table 9.--*Summary of concentrations of inorganic constituents, trace elements, and bacteria, values of other properties, concentrations of pesticides and volatile organic compounds detected, and associated drinking water standards or guidelines, in the Tacoma-Puyallup area, Washington*

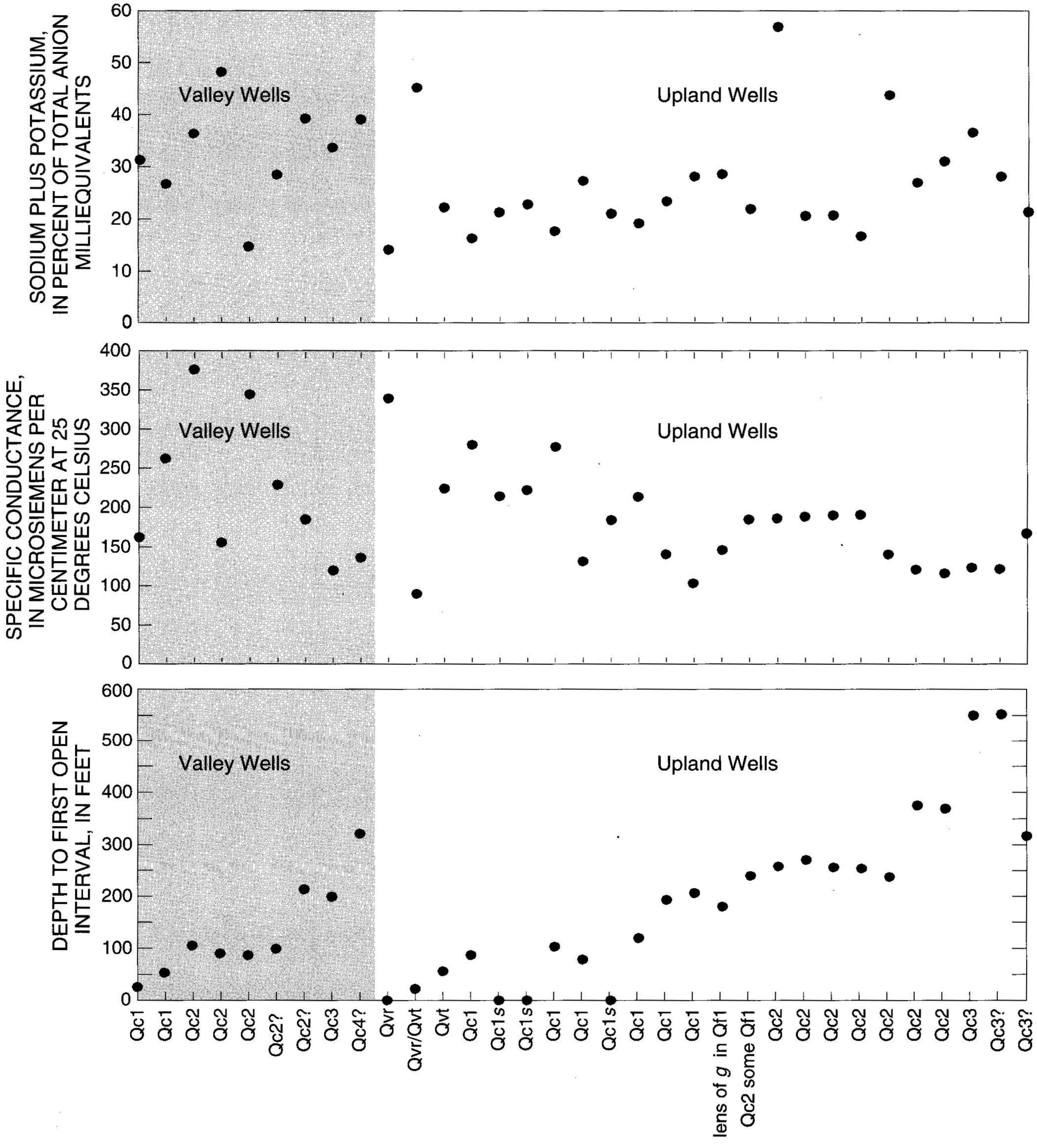
[Concentrations of constituents, standards, and guidelines are in milligrams per liter unless otherwise noted; <, less than; cols./100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; µS/cm, microsiemens per centimeter at 25° Celsius; E, estimated value; MCL, maximum contaminant level (USEPA, 1996); SMCL, secondary maximum contaminant level (USEPA, 1991); RSD, USEPA risk-specific dose health advisory associated with a cancer risk of one in a million (Nowell and Resek, 1994); HA, USEPA lifetime health advisory for a 70-kilogram adult (USEPA, 1996); AL, USEPA action level, which requires treatment if concentrations exceed action level (USEPA, 1995); na, not applicable]

Constituent or property	Number of samples	Concentration or value			Standard or guideline	Number of samples exceeding standard or guideline	Type of standard or guideline
		Minimum	Median	Maximum			
		Major Inorganic Constituents					
Alkalinity (mg/L as $CaCO_3$)	33	22	75	210	none	na	none
Calcium	33	7.4	16	39	none	na	none
Chloride	33	1.6	5.4	10	250	0	SMCL
Fluoride	33	<0.1	<0.1	0.5	4	0	MCL
Magnesium	33	2.4	7.7	21	none	na	none
Nitrite plus nitrate (as nitrogen)	33	<0.05	1.1	6.4	10	0	MCL
Potassium	33	0.5	2	6.8	none	na	none
Sodium	33	4.4	7	20	none	na	none
Sulfate	33	0.3	5.2	23	500	0	MCL
		Trace Elements					
Arsenic (µg/L)	33	<1	<1	10	50	0	MCL
Barium (µg/L)	12	<2	4	24	2,000	0	MCL
Boron (µg/L)	22	7.6	19.8	68.2	600	0	HA
Cadmium (µg/L)	12	<1	<1	<1	5	0	MCL
Chromium (µg/L)	12	<1	<1	<1	100	0	MCL
Copper (µg/L) (at tap)	12	<1	<1	3	1,300	0	AL
Iron (µg/L)	33	<3	6	12,000	300	3	SMCL
Lead (µg/L) (at tap)	12	<1	<1	<1	15	0	AL
Manganese (µg/L)	33	<1	1	1,100	50	8	SMCL
Mercury (µg/L)	12	<0.1	<0.1	0.1	2	0	MCL
Selenium (µg/L)	12	<1	<1	<1	50	0	MCL
Silver (µg/L)	12	<1	<1	<1	100	0	SMCL
Zinc (µg/L)	12	<3	3.5	88	5,000	0	SMCL

Table 9.--*Summary of concentrations of inorganic constituents, trace elements, and bacteria, values of other properties, concentrations of pesticides and volatile organic compounds detected, and associated drinking water standards or guidelines, in the Tacoma-Puyallup area, Washington--Continued*

Constituent or property	Number of samples	Concentration or value			Standard or guideline	Number of samples exceeding standard or guideline	Type of standard or guideline
		Minimum	Median	Maximum			
			Bacteria				
Coliform, Total (cols./100 mL)	33	<1	<1	90	*	4	MCL
Escherichia coli (cols./100 mL)	7	<1	2	43	none	na	none
Streptococci, Fecal (cols./100 mL)	33	<1	<1	3	none	na	none
			Other Properties and Constituents				
Dissolved oxygen	33	<0.1	3.9	10.7	none	na	none
Dissolved solids	33	61	132	261	500	0	SMCL
MBAS detergents	22	<0.02	<0.02	0.02	none	na	none
pH (standard units)	33	6.1	7	8	6.5-8.5	0	SMCL
Radon (pCi/L)	11	260	450	810	none	na	none
Silica	33	16	35	62	none	na	none
Specific conductance (µS/cm)	33	90	184	376	none	na	none
Total organic carbon	12	0.1	0.35	2.8	none	na	none
			Pesticides and Volatile Organic Compounds				
Atrazine (µg/L)	12	<0.001	<0.001	0.009E	3	0	MCL
Desethylatrazine (µg/L)	12	<0.002	<0.002	0.009E	none	na	none
Dieldrin (µg/L)	12	<0.001	<0.001	0.045	0.002	1	RSD
Diuron (µg/L)	12	<0.02	<0.02	0.04	10	0	HA
Metribuzin (µg/L)	12	<0.004	<0.004	0.024	100	0	HA
Pebulate (µg/L)	12	<0.004	<0.004	0.075	none	na	none
Tebuthiuron (µg/L)	12	<0.01	<0.01	0.078	500	0	HA
1,1,1-Trichloroethane (µg/L)	12	<0.2	<0.2	0.17	200	0	MCL

* MCL is based on presence/absence of total coliforms in a sample. If sample is total coliform positive, the culture must be analyzed to determine if fecal coliforms or *Escherichia coli* are present. If fecal coliform or *Escherichia coli* are detected, violation of MCL for total coliform has occurred (U.S. Environmental Protection Agency, 1996, Maximum contaminant levels (subpart G of 141 section 141.63 for microbiological contaminants, National primary drinking water regulations): U.S. Code of Federal Regulations Title 40, chap. I. There were a total of seven samples having total coliform colonies, four of which tested positive for *Escherichia coli.*



Qvr Shallow aquifer; *s* designates spring
Qvt Upper semiconfined unit
Qc1 Upper confined aquifer; *s* designates spring
Qf1 Semiconfined unit below Qc1; *g* designates gravel
Qc2 Second confined aquifer
Qc3 Third confined aquifer
Qc4 Fourth confined aquifer

Figure 19. Relation between hydrogeologic unit and depth to first opening, specific conductance, and percent sodium plus potassium in the Tacoma-Puyallup area, Washington.

In comparison, radon activities in ground waters collected by the USGS National Water Quality Assessment Program in 20 study units located throughout the United States ranged from 7 to 40,000 pCi/L; the median was 508 pCi/L (Sarah Ryker, U.S. Geological Survey, written commun., 1997). In 1991, EPA proposed a maximum contaminant level of 300 pCi/L for radon in drinking water, but this rule has not been put into effect (U.S. Environmental Protection Agency, 1996).

Even though the overall quality of ground water is good, land-use activities have affected quality. These effects, as well as other factors influencing water quality, are discussed in the following sections.

Conceptual Model of Factors Affecting Water Quality

Variations in the quality of ground water in the study area relate to the complex interaction between land-use activities and natural factors. An analysis of the vulnerability of ground water in the Puget Sound Basin to contamination by nitrate (Tesoriero and Voss, 1997) illustrates this interaction. The authors found that ground water most vulnerable to nitrate contamination is shallow, in coarse-grained glacial sediments, and underlies areas with high percentages of agricultural or urban land uses. Deep ground water underlying fine-grained sediments is more isolated from the effects of land-use activities than shallow ground water underlying coarse-grained sediments.

The decrease in specific conductance values with depth (fig. 19) is another indication that deep ground water is more isolated from the effects of land-use activities. Valley and upland wells are grouped in figure 19 because, as will be discussed later, different factors affect nitrate concentrations in valley and upland ground waters.

Other natural factors that can alter the quality of ground water are chemical and biological mechanisms that transform, and in some instances remove, contaminants or constituents present in the water. An example is denitrification, which is a process whereby nitrate in ground water is converted to nitrous oxide and nitrogen gas (Korm, 1992). A conceptual model of how land use and other factors affect ground-water quality in the study area is illustrated in figure 20.

Effects of Land-Use Activities on Water Quality

One objective of this study was to characterize the quality of ground water in the aquifers of the study area. As a result, the data collected were not sufficient to determine local areas of contamination or to make a detailed analysis of the spatial relation between land use and underlying ground-water quality in the study area. For example, boron, TOC, and MBAS samples, which were collected as potential indicators of contamination by septic systems, did not prove useful because the number of samples in shallow ground water were too few. The effects of land-use activities on ground-water quality are indicated, however, by elevated concentrations of nitrate in shallow ground water, increasing concentrations of nitrate and chloride over time in water discharged from Maplewood Spring, and the presence of pesticides, VOCs, and bacteria in some wells and springs.

Nitrate

Samples collected during this study were analyzed for nitrite plus nitrate, and this designation is used to identify data listed in tables and shown on figures. In most natural waters, nitrite is a short-lived intermediate species produced during the oxidation of ammonia to nitrate, and it is not usually present in significant quantities (Ebbert and others, 1995). For simplicity, the term nitrate, instead of nitrite plus nitrate, is used in the text of this report, and all concentrations are reported in units of milligrams per liter (mg/L) as nitrogen.

Concentrations of nitrate in the study area ranged from less than 0.05 to 6.4 mg/L (table 9, fig. 21). The median concentration was 1.1 mg/L, which is well below the primary maximum contaminant level for drinking water of 10 mg/L. The highest concentrations of nitrate were found in shallow ground water. However, concentrations of nitrate in shallow ground water in the Puyallup River Valley were low. Denitrification (the conversion of nitrate to nitrous oxide and nitrogen gas) is probably the primary cause of low nitrate concentrations in ground water sampled in the Puyallup River Valley, although this was not confirmed by this study. A more detailed discussion of denitrification, the relation between depth to ground water and nitrate concentrations, and differences between valley and upland wells is presented later in the section Other Factors Affecting Water Quality.

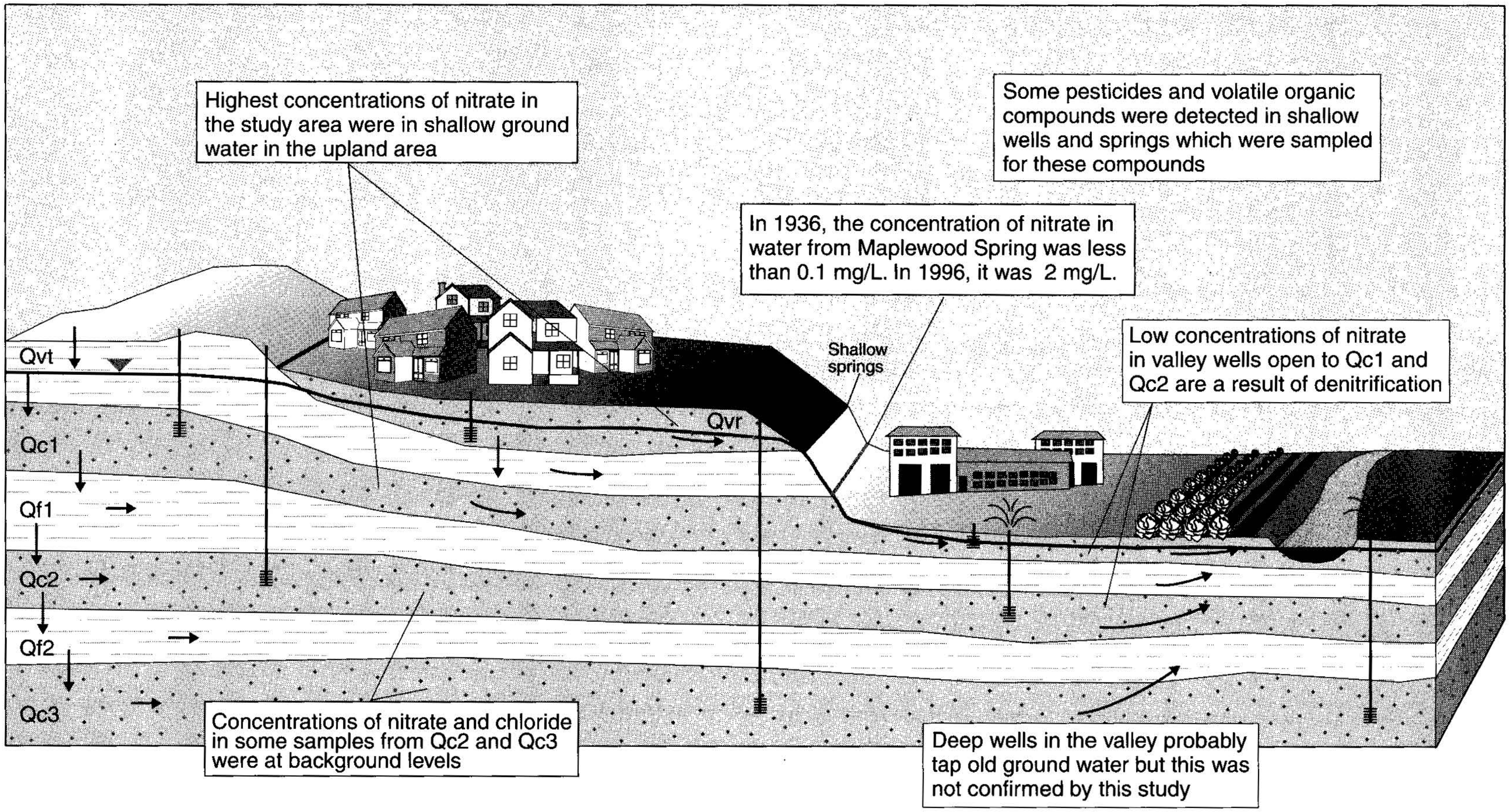


Figure 20. Overview of ground-water quality and factors affecting it.

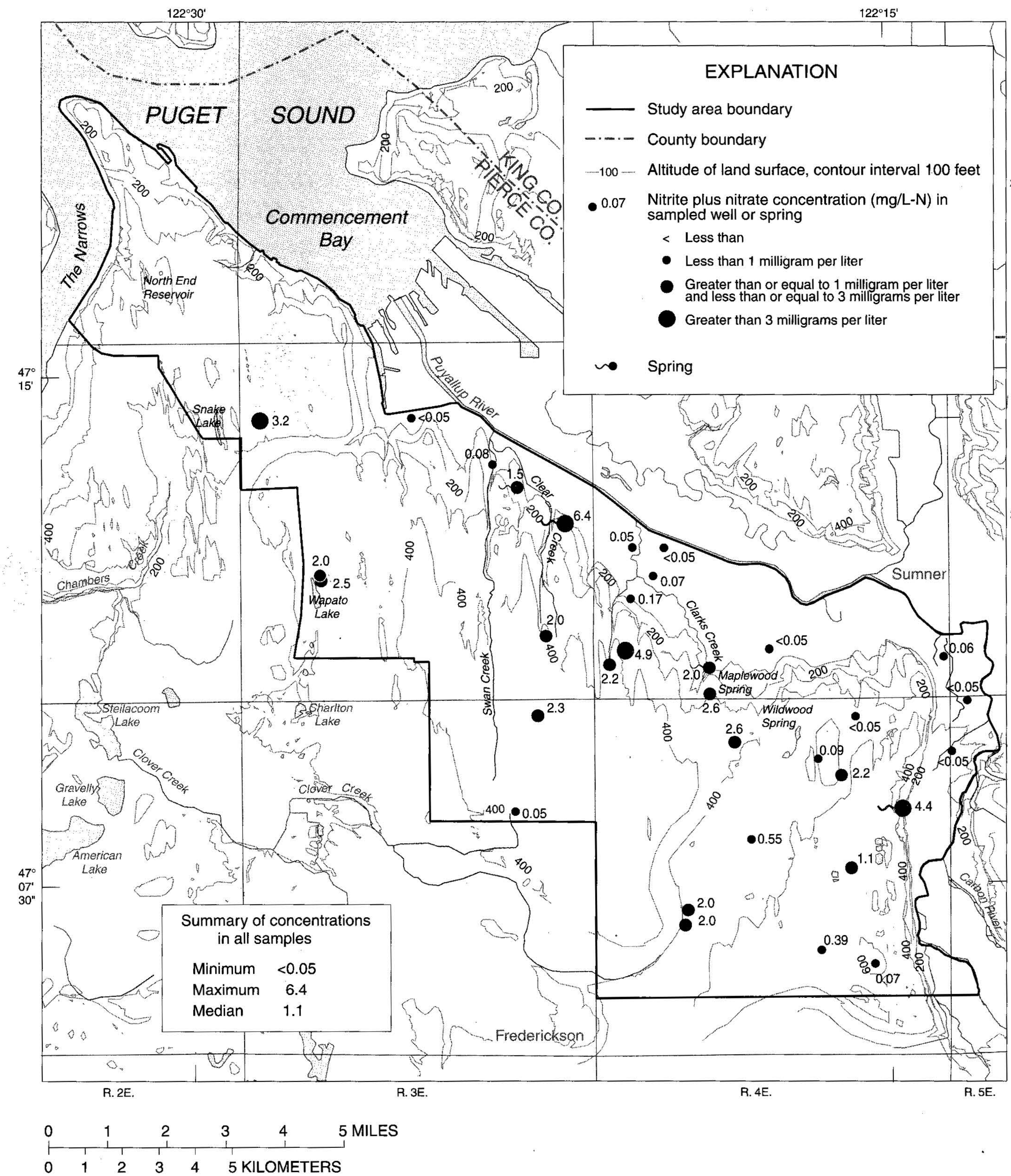


Figure 21. Concentrations of nitrite plus nitrate in water sampled from wells and springs, 1996 in the Tacoma-Puyallup area, Washington.

An increase over time in concentrations of nitrate and chloride in water discharged from Maplewood Spring (fig. 22) is an indication that land-use activities have affected ground-water quality in the study area. In 1936, the concentrations of nitrate and chloride in the spring water were 0.09 mg/L and 2.0 mg/L, respectively (table 10). When the USGS sampled the spring in 1996, the concentration of nitrate was 2 mg/L, and the concentration of chloride was 5.4 mg/L.

The years 1988-1994 were selected for a statistical test to determine if there is a trend in concentrations of nitrate in water from Maplewood Spring during recent years. These years were selected because they bracket the period over which samples were collected frequently by the City of Puyallup (Doug Maclean, City of Puyallup, written commun., 1996).

A distribution-free test, Kendall's Tau (Kendall, 1995), was used for trend testing. The null hypothesis for this test is that the random variable (concentration) is independent of time. In this test, all possible pairs of data values are compared; if the later value (in time) is higher, a plus is scored; if the later value is lower, a minus is scored. If there is no trend in the data, the odds are 50-50 that a value is higher (or lower) than one of its predecessors. In the absence of a trend, the number of pluses should be about the same as the number of minuses. Tau, the test statistic, is equal to zero if the number of pluses equals the number of minuses. If, however, there are many more pluses than minuses, the values later in the series are more frequently higher than those earlier in the series, and so an uptrend is likely. Similarly, if there are many more minuses than pluses, a downtrend is likely. If all the differences are positive, tau = 1; if they are all negative, tau = -1.

In addition, the magnitude of the trend was estimated as the median of the differences (expressed as slopes) of the ordered pairs of data values compared using Kendall's Tau test. Although the magnitude of the trend is expressed as a slope (value per unit time), it does not imply a linear trend (Hirsch and others, 1982).

Results (fig. 23) indicate an increasing trend in the concentration of nitrate in water from Maplewood Spring, with a median slope of +0.05 milligrams per liter per year. Two questionable concentrations of less than 0.2 mg/L (table 10) were not included in the trend test.

Two additional Kendall's Tau tests were performed: one for the period 1988-1994, including the two questionable concentrations; and one for the period 1975-1997, also including the two questionable concentrations. Results shown below indicate a significant upward trend for all tests.

Pesticides and Volatile Organic Compounds

Pesticides were detected in 5 of 12 ground-water samples (fig. 24). The five samples with detections represent shallow ground waters collected from a spring and from four wells with depths to first openings ranging from 22 to 86 feet below land surface. This study targeted shallow ground water for pesticide determinations. Available data suggest that deep ground water in the study area is unlikely to contain pesticides. No pesticides were detected in samples from three deeper wells in the study area that were collected during a 1994 study of pesticides in public-supply wells (Ryker and Williamson, 1996). Depths to first openings in those wells ranged from 216 to 552 feet below land surface.

Test period	Tau	p-value	Median slope NO_3-N (milligrams per liter per year)	Remarks
1988-94	0.86	0.01	0.05	Without questionable concentrations
1988-94	0.86	0.01	0.07	With questionable concentrations
1975-97	0.88	<0.01	0.06	With questionable concentrations

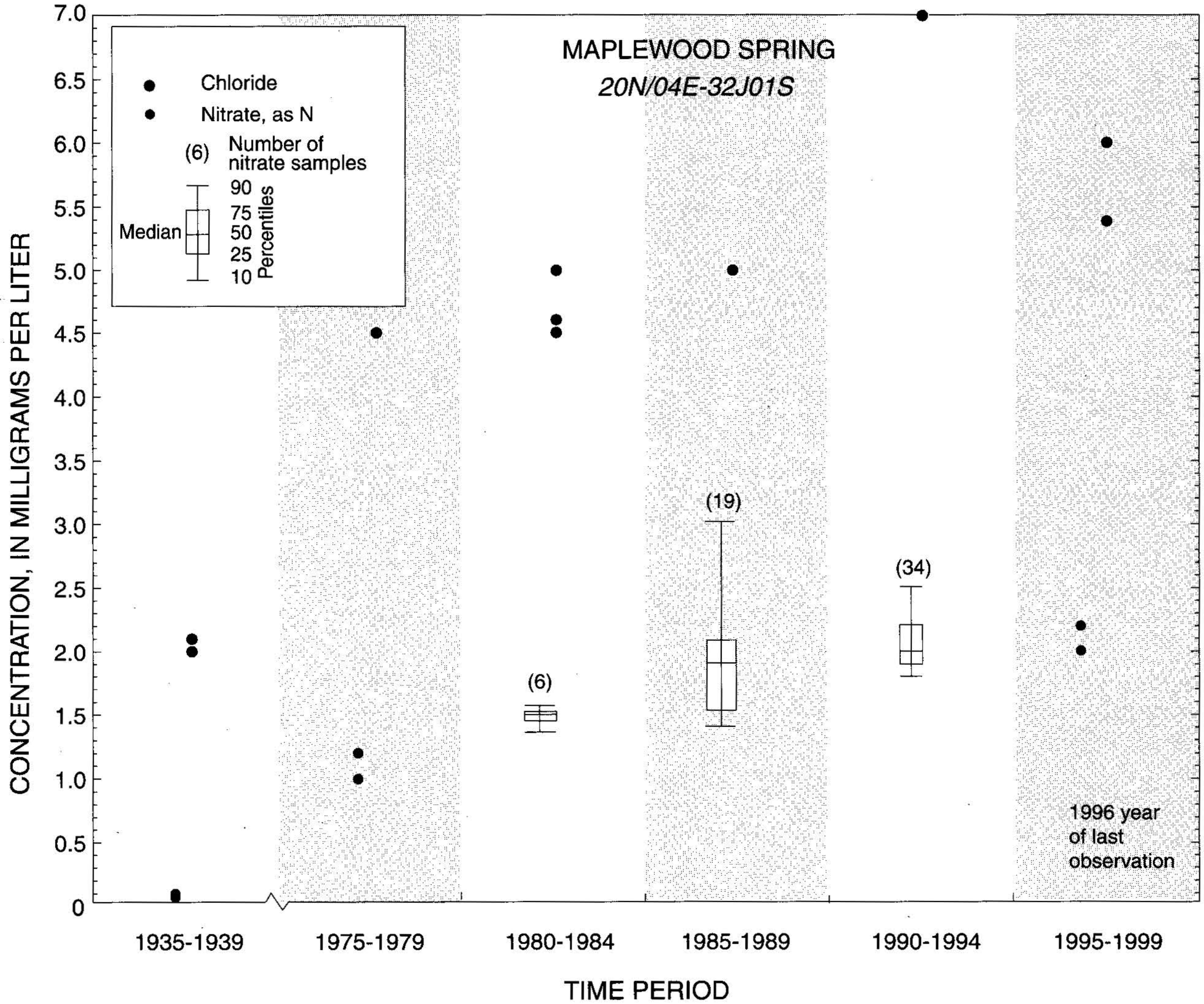


Figure 22. Trends in concentrations of nitrate and chloride in water from Maplewood Spring, 1936-96 in the Tacoma-Puyallup area, Washington.

Table 10.--*Concentrations of nitrate and chloride in water from Maplewood Spring, in the Tacoma-Puyallup area, Washington*

[U, unknown; B, before treatment; A, after treatment; <, less than; USGS, U.S. Geological Survey Laboratory; DOH, Washington State Department of Health Laboratory; LTL, Laucks Testing Laboratories, Seattle Washington; WML, Water Management Laboratories, Tacoma, Washington; Analytical methods for nitrate: I-2545-78 cadmium reduction (Skougstad and others, 1979); 418 C cadmium reduction (American Public Health Association, 1981, 1985); 418 F cadmium reduction (American Public Health Association, 1985); 4110 B ion chromatography (American Public Health Association, 1992); I-2545-85 cadmium reduction (Fishman and Friedman, 1989); Analytical methods for chloride: 407 A argentometric method (American Public Health Association, 1971, 1981, 1985); 407 B mercuric nitrate method (American Public Health Association, 1985); I-2187-78 ferric thiocyanate automated (Skougstad and others, 1979); I-2057-85 ion chromatography (Fishman and Friedman, 1989); 4110B ionchromatography (American Public Health Association, 1992)]

Sample collection date	Collection location	Laboratory	Nitrate (mg/L as N)	Analytical method for nitrate	Chloride (mg/L)	Analytical method for chloride
10/20/36	U	USGS	0.09	unknown	2.0	unknown
1/11/38	U	USGS	0.07	unknown	2.1	unknown
4/29/75	B	DOH	1.0	unknown	4.5	407 A
4/3/78	B	LTL	1.2	unknown	no sample	--
9/2/81	B	DOH	1.3	418 C	no sample	--
2/15/84	B	USGS	1.5	I-2545-78	4.6	I-2187-78
5/29/84	B	USGS	1.6	I-2545-78	4.5	I-2187-78
6/25/84	B	DOH	2.0	418 C	5.0	407 A
8/27/84	B	USGS	1.6	I-2545-78	no sample	--
3/9/87	B	DOH	1.6	418 F	5.0	407 A
4/12/88	B	WML	1.9	418 C	no sample	--
5/12/88	B	WML	<0.2	418 C	no sample	--
6/13/88	A	WML	1.5	418 C	no sample	--
7/25/88	B	WML	2.0	418 C	no sample	--
8/24/88	A	WML	1.9	418 C	no sample	--
9/19/88	B	WML	2.4	418 C	no sample	--
10/17/88	B	WML	1.6	418 C	no sample	--
11/14/88	B	WML	1.9	418 C	no sample	--
12/19/88	B	WML	1.6	418 C	no sample	--
1/23/89	B	WML	<0.2	418 C	no sample	--
2/21/89	B	WML	1.8	418 C	no sample	--
3/21/89	B	WML	4.4	418 C	no sample	--
4/17/89	B	WML	3.5	418 C	no sample	--
5/23/89	B	WML	2.1	418 C	no sample	--
6/19/89	B	WML	2.8	418 C	no sample	--
7/17/89	B	WML	2.0	418 C	no sample	--
8/22/89	B	WML	1.4	418 C	no sample	--
9/18/89	B	WML	1.5	418 C	no sample	--
10/16/89	B	WML	1.4	418 C	no sample	--
11/21/89	B	WML	1.9	418 C	no sample	--

Table 10.--*Concentrations of nitrate and chloride in water from Maplewood Spring, in the Tacoma-Puyallup area, Washington--Continued*

Sample collection date	Collection location	Laboratory	Nitrate (mg/L as N)	Analytical method for nitrate	Chloride (mg/L)	Analytical method for chloride
12/18/89	B	WML	1.1	418 C	no sample	--
1/16/90	B	WML	1.9	418 C	no sample	--
1/22/90	B	WML	2.0	418 C	no sample	--
2/20/90	B	WML	1.8	418 C	no sample	--
3/19/90	B	WML	1.8	418 C	no sample	--
4/16/90	B	WML	1.9	418 C	no sample	--
5/21/90	B	WML	2.1	418 C	no sample	--
6/18/90	B	WML	2.0	418 C	no sample	--
7/23/90	B	WML	1.9	418 C	no sample	--
8/20/90	B	WML	2.6	418 C	no sample	--
9/24/90	B	WML	2.0	418 C	no sample	--
11/20/90	B	WML	0.6	418 C	no sample	--
12/18/90	B	WML	2.0	418 C	no sample	--
1/21/91	B	WML	2.8	418 C	no sample	--
2/19/91	U	WML	2.2	418 C	no sample	--
3/18/91	B	WML	2.1	418 C	no sample	--
4/22/91	B	WML	1.9	418 C	no sample	--
5/20/91	B	WML	2.2	418 C	no sample	--
6/17/91	B	WML	1.6	418 C	no sample	--
7/22/91	B	WML	2.5	418 C	no sample	--
8/26/91	B	WML	1.9	418 C	no sample	--
9/24/91	B	WML	0.8	418 C	no sample	--
10/28/91	B	WML	2.4	418 C	no sample	--
12/16/91	B	WML	2.0	418 C	no sample	--
2/18/92	B	WML	2.1	418 C	no sample	--
4/20/92	B	WML	1.2	418 C	no sample	--
7/6/92	B	WML	2.4	418 C	no sample	--
10/12/92	B	WML	2.6	418 C	no sample	--
1/18/93	B	WML	1.8	418 C	no sample	--
4/5/93	B	WML	2.1	418 C	no sample	--
7/14/93	B	WML	2.2	418 C	7.0	407 B
11/9/93	B	WML	2.4	418 C	no sample	--
3/21/94	B	WML	1.9	418 C	no sample	--
6/27/94	B	WML	2.2	418 C	no sample	--
9/11/95	B	WML	2.2	4110 B	no sample	--
6/18/96	B	USGS	2.0	I-2545-85	5.4	I-2057-85
8/15/96	B	WML	2.5	4110 B	6.0	4110 B
10/10/97	B	WML	2.7	4110 B	no sample	--

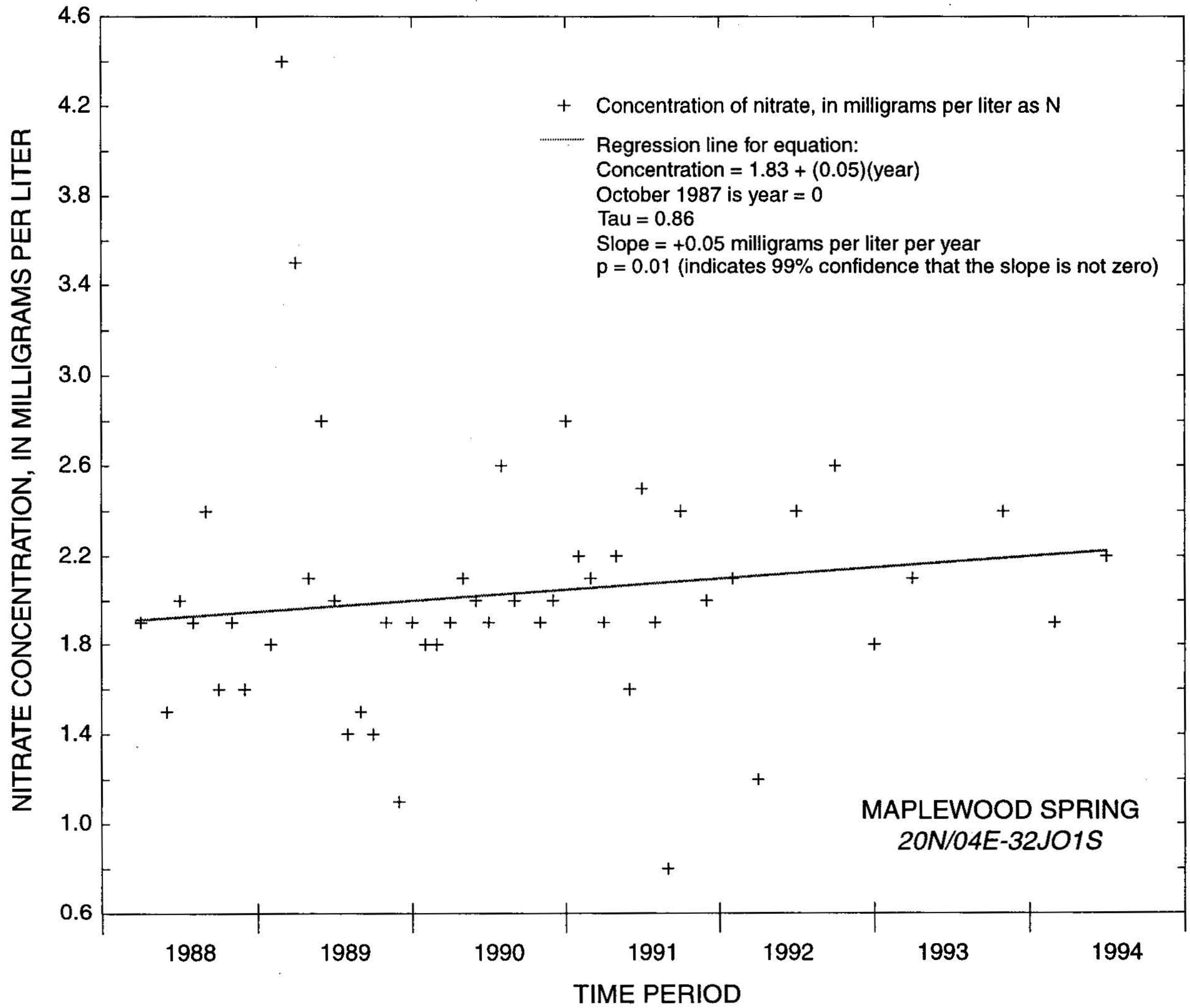
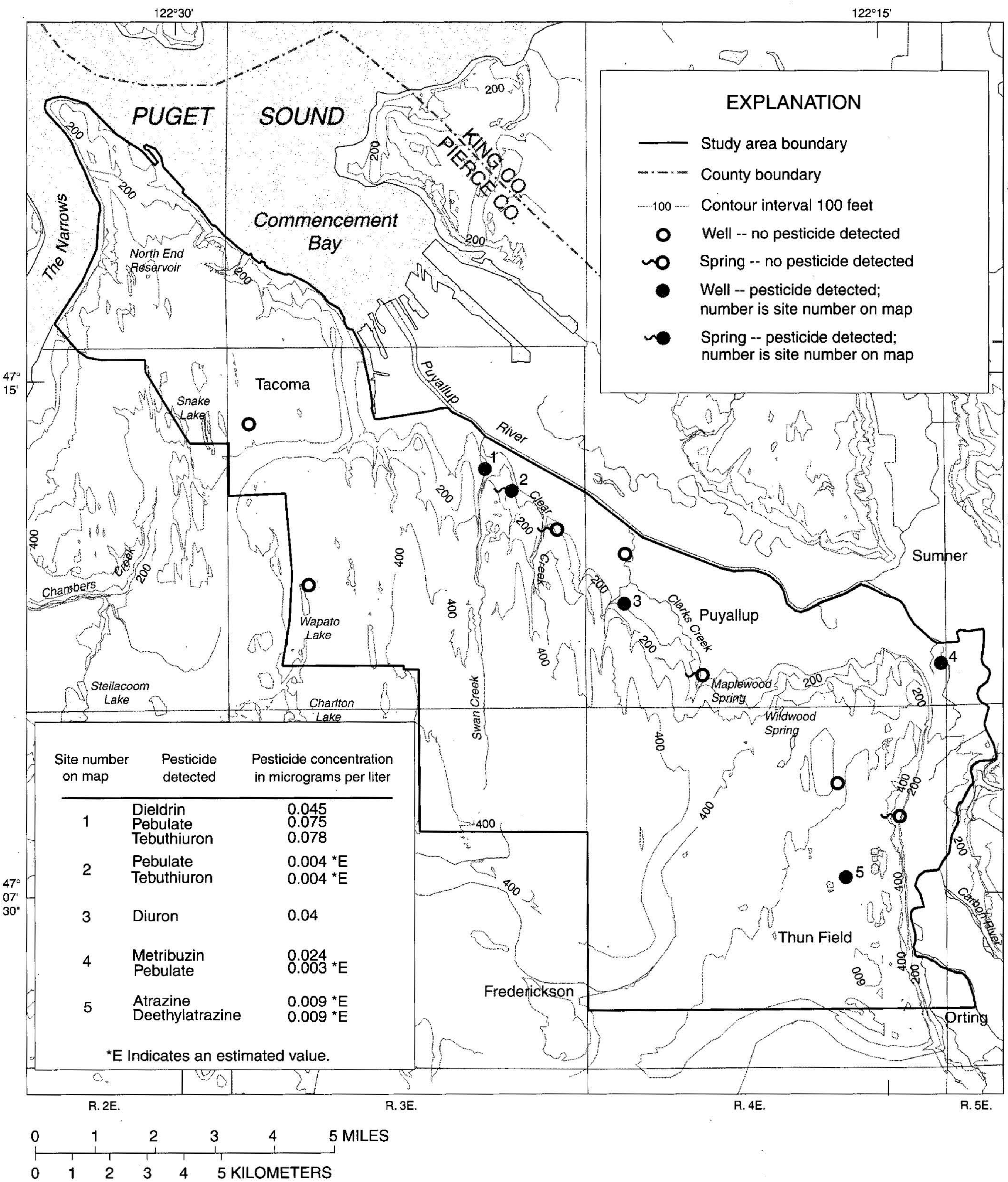


Figure 23. Trend in concentration of nitrate in water from Maplewood Spring 1988-94 in the Tacoma-Puyallup area, Washington. Sources of data are listed in table 10.



Site number on map	Pesticide detected	Pesticide concentration in micrograms per liter
1	Dieldrin Pebulate Tebuthiuron	0.045 0.075 0.078
2	Pebulate Tebuthiuron	0.004 *E 0.004 *E
3	Diuron	0.04
4	Metribuzin Pebulate	0.024 0.003 *E
5	Atrazine Deethylatrazine	0.009 *E 0.009 *E

*E Indicates an estimated value.

Figure 24. Locations of wells and springs sampled for pesticides and where pesticides were detected, 1996 in the Tacoma-Puyallup area, Washington.

Dieldrin, an organochlorine insecticide, was detected in one sample at a concentration of 0.045 µg/L (micrograms per liter), which violated the drinking water guideline (table 9). In addition to its direct use as an insecticide, dieldrin is also a break-down product of the insecticide aldrin. The EPA suspended nearly all uses of aldrin and dieldrin in 1974, so the detection of dieldrin in the study area most likely reflects historic rather than current application patterns. Organochlorine compounds, like dieldrin, have a strong affinity for natural organic matter in soils, and it has traditionally been assumed that they are unlikely to migrate to ground waters. However, frequent detections of these compounds in well waters in other areas indicate that affinity for organic matter is an unreliable indicator of whether an individual pesticide will reach ground waters (Barbash and Resek, 1996). Dieldrin was the only pesticide detected that violated drinking water guidelines (table 9).

Pebulate, a thiocarbamate herbicide, was detected at concentrations ranging from 0.003 to 0.075 µg/L in water from two wells and one spring. It is a preplant herbicide effective on grassy and broadleaf weeds. Because pebulate is not one of the most heavily used herbicides in the Puget Sound region (Bortleson and Davis, 1997), its detection in three samples may reflect local usage patterns.

Tebuthiuron, detected at a concentration of 0.078 µg/L in water from one well and at a concentration of 0.004 µg/L in water from one spring, is a broad spectrum urea herbicide used to control weeds on noncropland areas, rangelands, rights-of way, and industrial sites (Meister Publishing Company, 1994). Tebuthiuron has all the characteristics of a material with a high potential for ground-water contamination. It is highly soluble, absorbs only weakly to soil particles, and is highly persistent in soils. It has, in fact, been detected frequently in ground waters of the United States; it was the fourth most detected pesticide in ground-water samples collected by the USGS in 10 urban areas during 1993-1995 (Kolpin and others, 1998). It is one of the most heavily used herbicides in the Puget Sound region (Bortleson and Davis, 1997).

The herbicides atrazine, diuron, and metribuzin were each detected once, and desethylatrazine, a break-down product of atrazine, was also detected once (fig. 24). Atrazine and metribuzin are triazine herbicides, which are often found in ground water, especially in the agricultural areas where corn is grown (Barbash and Resek, 1996). Neither is used heavily in the Puget Sound region. Diuron, a urea herbicide used to control weeds on both crop and noncrop areas, is heavily used in the Puget Sound region and has been detected in surface waters of the region (Bortleson and Davis, 1997).

The same 12 wells and springs that were sampled for pesticides were sampled for VOCs. The only compound detected was 1,1,1-trichloroethane, and it was detected at low concentrations in water from one well and one spring (fig. 25). Trichloroethane, a cleaning solvent, is ubiquitous in the environment and is often one of the more frequently detected VOCs in ground water underlying urban areas (Daly and Lindsey, 1996; Fenelon and Moore, 1996).

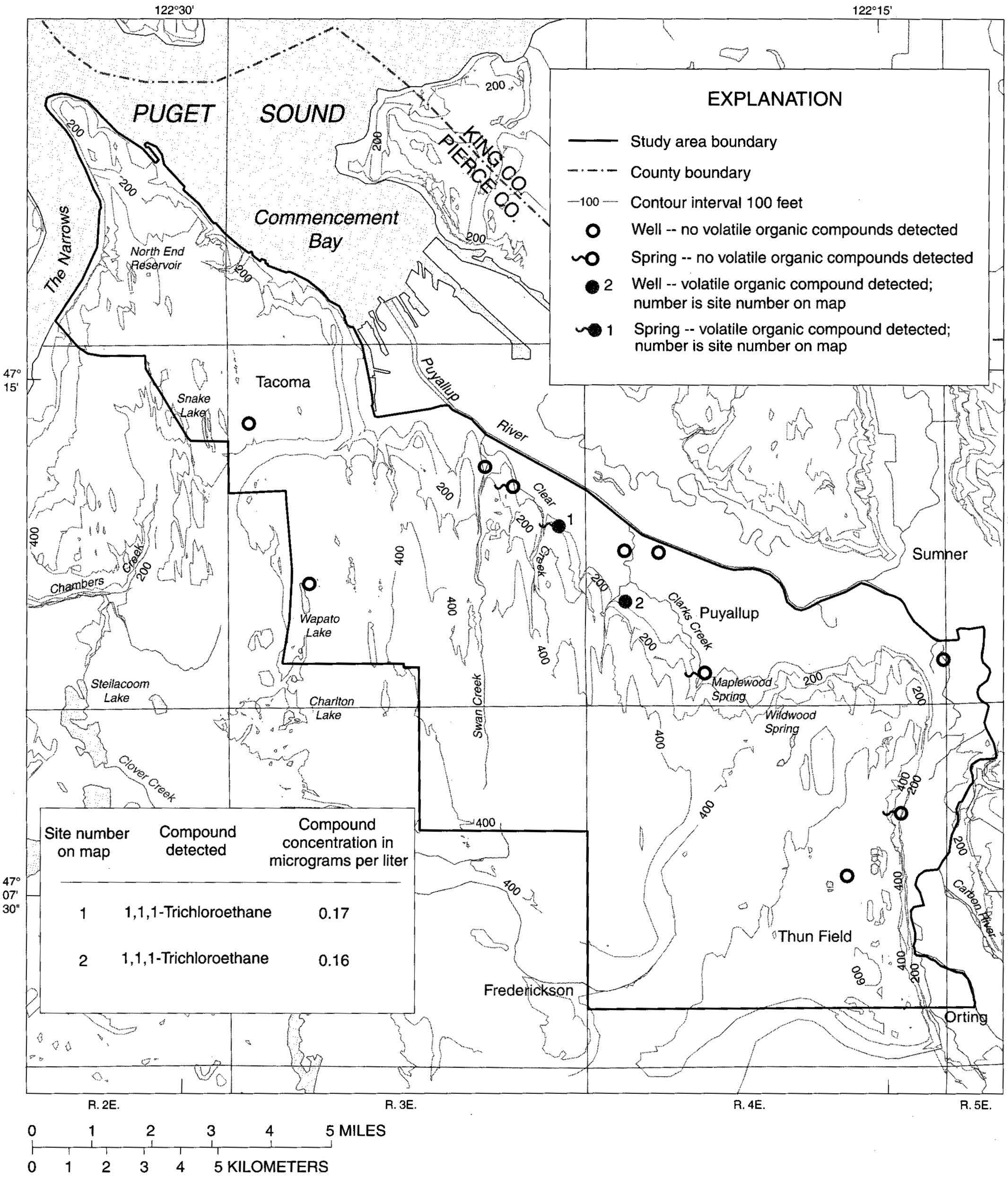
Bacteria

Samples from 33 wells and springs were analyzed to determine the presence of total-coliform, *Escherichia coli (E. coli)*, and fecal-*streptococci* bacteria. Although some strains of *E. coli* are pathogenic, these bacteria are not typically disease-causing and are used as indicators of water-borne pathogens. Although all three groups of bacteria are found in the intestinal tract of humans and warm-blooded animals, total-coliform and fecal-*streptococci* bacteria are not restricted to this habitat. The presence of *E. coli* in water, however, is direct evidence of fecal contamination from warm-blooded animals.

Bacteria were detected in water from 9 of 33 sampled wells and springs, and *E. coli* were found in four samples (fig. 26). Most, but not all, of the detections were in samples from wells and springs tapping shallow ground water underlying coarse-grained surficial deposits. Figure 7 shows the distribution of coarse-grained surficial deposits in the study area. One would expect more detections in this environment because pathways for bacteria to enter ground water are shorter and more conductive than those to deep ground water underlying fine-grained surficial deposits.

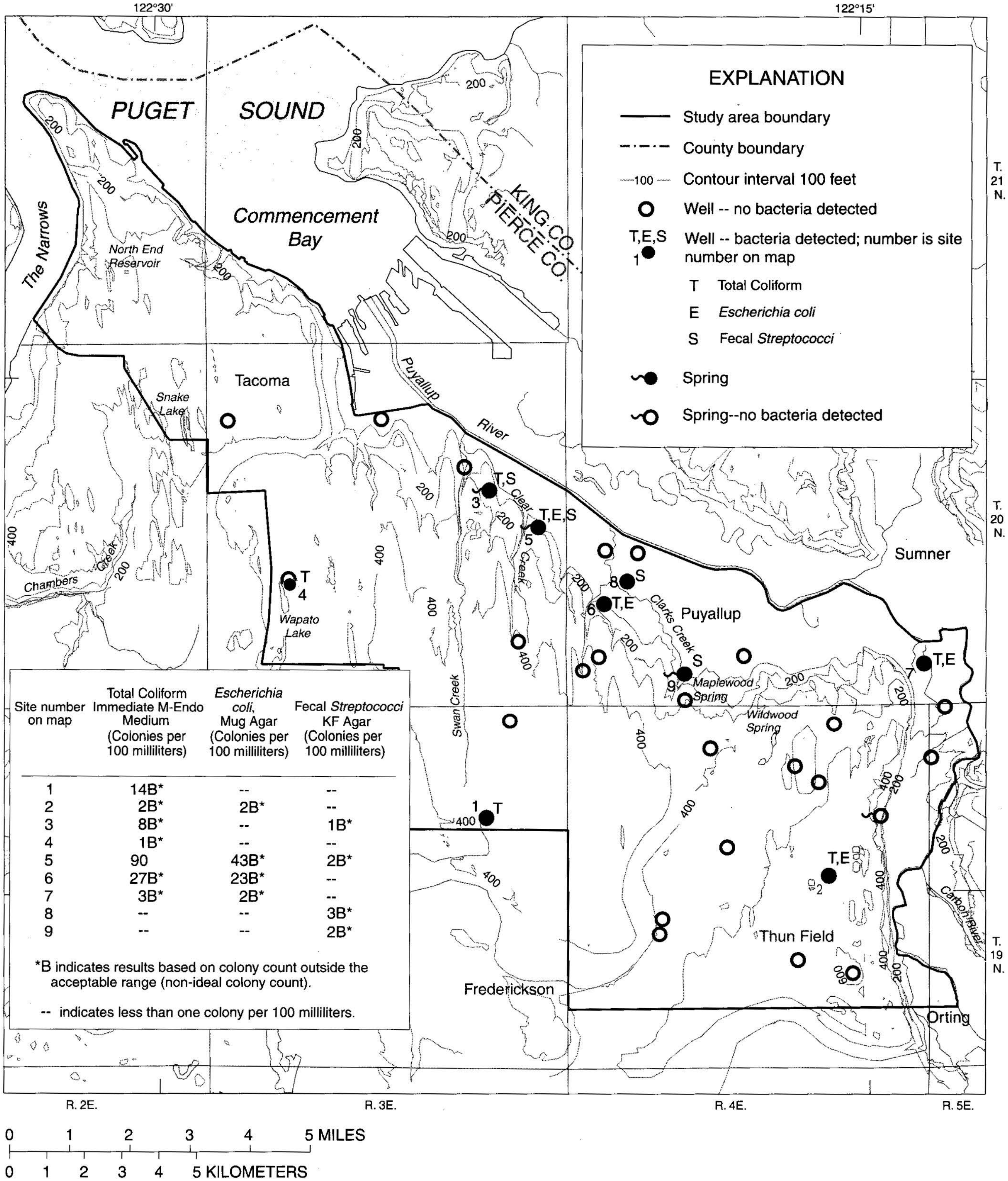
Other Factors Affecting Water Quality

Because nitrate in ground water is usually derived from sources at or near the land surface, nitrate concentrations in ground water underlying developed areas usually decrease with depth and distance down flowpaths (Mueller and others, 1995). This relation was observed in the upland part of the study area, where highest concentrations of nitrate were in shallow ground water, and low concentrations (less than 1 mg/L) were mostly in the deepest sampled ground water (fig. 27). In contrast, nitrate concentrations were low (ranging from less than 0.05 to 0.08 mg/L) in both shallow and deep ground waters sampled in the Puyallup River Valley (fig. 21).



Site number on map	Compound detected	Compound concentration in micrograms per liter
1	1,1,1-Trichloroethane	0.17
2	1,1,1-Trichloroethane	0.16

Figure 25. Locations of wells and springs sampled for volatile organic compounds (VOCs) and where VOCs were detected, 1996 in the Tacoma-Puyallup area, Washington.

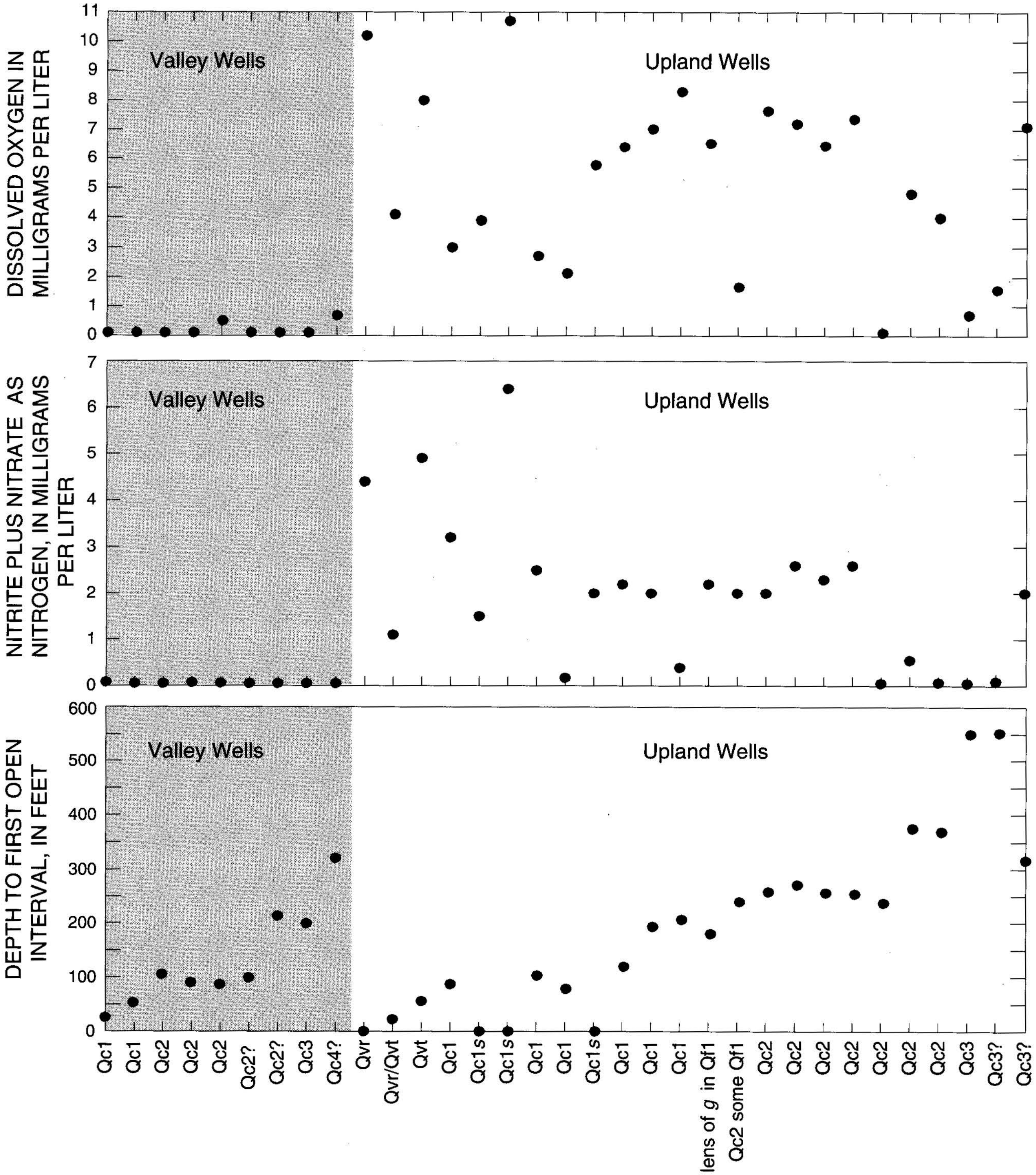


Site number on map	Total Coliform Immediate M-Endo Medium (Colonies per 100 milliliters)	*Escherichia coli*, Mug Agar (Colonies per 100 milliliters)	Fecal *Streptococci* KF Agar (Colonies per 100 milliliters)
1	14B*	--	--
2	2B*	2B*	--
3	8B*	--	1B*
4	1B*	--	--
5	90	43B*	2B*
6	27B*	23B*	--
7	3B*	2B*	--
8	--	--	3B*
9	--	--	2B*

*B indicates results based on colony count outside the acceptable range (non-ideal colony count).

-- indicates less than one colony per 100 milliliters.

Figure 26. Locations of wells and springs sampled for bacteria and where bacteria were detected, 1996 in the Tacoma-Puyallup area, Washington.



Qvr Shallow aquifer; *s* designates spring
Qvt Upper semiconfined unit
Qc1 Upper confined aquifer; *s* designates spring
Qf1 Semiconfined unit below Qc1; *g* designates gravel
Qc2 Second confined aquifer
Qc3 Third confined aquifer
Qc4 Fourth confined aquifer

Figure 27. Relation between hydrogeologic unit and depth to the first opening, concentrations of nitrate, and dissolved oxygen in the Tacoma-Puyallup area, Washington.

Low concentrations of nitrate in shallow Puyallup River Valley ground water, particularly in water from wells open at less than 150 ft below land surface, do not imply the lack of nitrogen sources or the lack of nitrogen compounds in ground water, but instead result from the absence of dissolved oxygen in the ground water (fig. 27)--a condition that is unfavorable for the presence of nitrate. The absence of dissolved oxygen in the shallow ground water is most likely because of the oxidation by bacteria of carbon present in the valley sediments. If enough carbon is available, all of the oxygen is depleted, and in the absence of oxygen, reduced nitrogen compounds like ammonia are not converted to nitrate, and nitrate can be removed by denitrification or reduction (Korm, 1992). This study did not investigate the occurrence of carbon in valley sediments, but accumulations of decomposed vegetal material resembling peat or muck are known to occur locally in the alluvial sediments of larger streams in central Pierce County (Walters and Kimmel, 1968). The drillers' logs for two of nine valley wells sampled during this study (20N/04E-33A01 and 20N/04E-20E06) indicated the presence of layers of peat or wood in the sediments.

Alhajjar (1985) found that if oxygen was present in and downgradient from septic-system drain fields, ammonia produced by the decomposition of organic nitrogen was rapidly oxidized to nitrate. In the absence of oxygen, no conversion took place, and ammonia migrated from the drain fields to the underlying ground water. In a previous study of the lower Puyallup River Valley and adjacent uplands, Ebbert and others (1987) reported the presence of ammonia in some ground-water samples containing low concentrations of oxygen and nitrate. Concentrations of ammonia ranged from less than 0.01 to 19 mg/L as nitrogen; many of the detections were in the range of 1 to 3 mg/L. Although that study did not determine if the ammonia was derived from septic systems, from the decomposition of nitrogenous organic matter deposited with the valley sediments, or from some other source, the finding was consistent with the hypothesis that low concentrations of dissolved oxygen in valley ground water retard the conversion of ammonia to nitrate.

Concentrations of nitrate in deep ground water in the Puyallup River Valley may be low because this is old ground water that has followed long flowpaths from the upland areas (see fig. 20). It is not known if any of the valley wells sampled intercept old ground water, but one would expect this water to contain little or no nitrate, like the deepest wells sampled in the upland areas. Old ground water was recharged at a time that predates development and probably never had high concentrations of nitrate.

QUALITY ASSURANCE OF WATER-QUALITY DATA

The quality-assurance plan for this study (M. A. Jones, U.S. Geological Survey, written commun., 1995) calls for quality-control procedures at all levels of data collection and analysis. Whereas many of the procedures address only methodology, some require the collection and analysis of quality-control samples. The resulting data are reviewed to determine the quality of the project data.

The water-quality data in this study was good, with some exceptions. Errors associated with most standard and duplicate samples were within project criteria for most constituents. Exceptions were large percentage errors from constituent concentrations near detection limits with otherwise small absolute errors. Concentrations in blanks, various internal sample checks, and comparisons of field and laboratory determinations were within acceptable limits for most constituents and samples. The results of the quality-assurance analyses did not affect any interpretations of ground-water-quality data.

In the following sections, data from standard reference samples, sample duplicates, blanks, cation-anion balance, and checks on field values are discussed.

Standard Reference Samples

Standard reference samples of various concentrations for selected inorganic constituents are routinely inserted as blind samples into the laboratory sample runs at the USGS NWQL, in Arvada, Colo. Each standard sample is submitted several times to obtain enough data to be statistically meaningful. Results are summarized and are available through computer programs maintained by the USGS's Branch of Quality Assurance (BQA) (Ludtke and Woodworth, 1997). The summary provides the mean concentration determined by the NWQL for each standard during a given period, along with the standard deviation of the laboratory concentrations, coefficient of variation, and number of times the standard was submitted and analyzed. These data for standards submitted from June 1 through July 31, 1996, were used to assess the error in the analytical accuracy of samples collected during that period from wells and springs in the study area. The standards used in the assessment were selected to bracket the range of concentrations in samples. In cases where that was not possible, those standards that best represented the sample concentrations were used.

First, the standard deviation of the concentration of a standard reference sample from the true concentration was determined for each standard reference sample using the following equation:

$$s_i = \sqrt{s_s^{\,2} + \left(\bar{u}_s - MPV_s\right)^2} \;, \qquad (8)$$

where

s_i = the standard deviation of the concentration of the standard reference sample from the true concentration;

s_s = the standard deviation from the mean concentration determined by the NWQL;

u_s = the mean concentration of the standard reference sample as determined by the NWQL; and

MPV_s = the most probable value of the standard reference sample. This is an estimate of the true concentration of the standard reference sample based on the average result from as many as 150 independent laboratories.

Then equation 10 was used to determine the coefficient of variation (CV_i) for the analysis of each standard:

$$CV_i = \frac{s_i}{MPV_s} \;, \qquad (9)$$

Then the overall coefficient of variation for a particular constituent was determined by averaging the squares of the coefficients of variation for all the standards that were in the range of concentrations found in the study area. This average was weighted by the number of times each standard was analyzed in the period as follows:

$$CV_o = \sqrt{\frac{\sum_{i=1}^{m}\left(n_i - 1\right)CV_i^2}{\sum_{i=1}^{m}\left(n_i - 1\right)}} \;, \qquad (10)$$

where

CV_o = overall coefficient of variation of all standards for a constituent;

n_i = number of times the standard was submitted and analyzed; and

m = number of standards.

The overall coefficient of variation was used to estimate the overall error of analysis of the standard reference samples for the constituent at the 95-percent confidence level. The following equation was used:

$$E = \left(1.96 \times CV_o\right)100 \;, \qquad (11)$$

where E = overall error of analysis, in percent.

This error represents the average percent error in analytical accuracy of the samples from the study area and is shown in table 11 for each constituent. It also includes a degree of analytical precision. However, the accuracy and precision are difficult to separate in the given data, and in the interest of conservation, the error is considered to be entirely in the accuracy.

The average absolute standard deviation (s_o) for each constituent, in units based on concentration, was calculated using equation 13 and is also shown in table 11.

$$s_o = \sqrt{\frac{\sum_{i=1}^{m}\left(n_i - 1\right)s_i^2}{\sum_{i=1}^{m}\left(n_i - 1\right)}} \;, \qquad (12)$$

The estimated errors for the common ions, silica, and nitrate determined in this study were generally reasonable. Quality-assurance goals for this study called for an error of 10 percent or less for these constituents. The average percent errors for calcium, magnesium, sodium, sulfate, and chloride met this goal (table 11). The average error for potassium of 40 percent was elevated because a value of 0.1 mg/L was reported for a standard with a *MPV* of 5.72 mg/L. If that one value is dropped from the error computation, then the average error of the analysis is 13 percent instead of 40 percent. The average error for fluoride of 52 percent was elevated in part because a value of 0.1 mg/L was reported for a standard with a *MPV* of 0.41 mg/L. If that one value is deleted from the error computation, then the average error of the analysis is 38 percent, which is the largest error (after adjustments) for the common ions, silica, and nitrate. The larger error for fluoride was a result of errors in the analysis of standards with concentrations close to the detection limit. The errors for silica and nitrate were 14 and 19 percent, respectively, and are probably representative. At these low concentrations, acceptable small absolute errors, as represented by

Table 11.--*Estimated error in analysis of inorganic constituents*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations; µg/L, micrograms per liter]

Constituent	Number of standards	Number of times standards submitted	Median concentration in ground-water samples	Range of concentrations in ground-water samples	Range of concentration of standards	Average absolute standard deviation of standards	Average[a] percent error in analysis
Calcium	11	45	16	7.4 - 39	6.60 - 39.5	0.56	8.2
Magnesium	9	38	7.7	2.4 - 21	2.00 - 14.5	0.26	8.3
Sodium	3	12	7.0	4.4 - 20	11.8 - 23.1	0.79	8.7
Potassium	9	35	2.0	0.5 - 6.8	0.66 - 7.83	1.4	40
Sulfate	2	7	5.2	0.3 - 23	19.1 - 19.8	0.53	10
Chloride	3	11	5.4	1.6 - 10	7.06 - 18.4	0.48	10
Fluoride	6	23	<0.1	<0.1 - 0.5	0.16 - 0.59	0.14	52
Silica	4	20	35	16 - 62	6.63 - 10.4	0.69	14
Nitrate	2	32	1.1	<0.05 - 6.4	0.24 - 0.78	0.04	19
Iron (µg/L)	8	41	6	<3 - 12,000	65.6 - 171	4.9	8.6
Manganese (µg/L)	8	40	1	<1 - 1,100	3.64 - 317	4.0	16
Arsenic (µg/L)	3	11	<1	<1 - 10	2.95 - 10.1	0.87	31
Barium (µg/L)	3	17	4	<2 - 24	15.5 - 42.4	1.3	14
Boron (µg/L)	4	20	20	7.6 - 68	8.78 - 28.7	2.4	47
Cadmium (µg/L)	3	11	<1	<1 - <1	5.59 - 33.8	2.3	15
Chromium (µg/L)	3	10	<1	<1 - <1	7.71 - 18.1	0.23	14
Copper (µg/L)	2	9	<1	<1 - 3	28.1 - 41.5	3.3	17
Lead (µg/L)	2	5	<1	<1 - <1	2.18 - 9.39	0.41	16
Mercury (µg/L)	3	12	<0.1	<0.1 - 0.1	0.35 - 1.16	0.15	29
Selenium (µg/L)	4	13	<1	<1 - <1	4.95 - 15.6	0.93	31
Silver (µg/L)	3	12	<1	<1 - <1	2.03 - 5.88	0.0	3.9
Zinc (µg/L)	4	19	3.5	<3 - 88	26.2 - 37.9	4.2	34

[a] At 95-percent confidence level. Computed using equations described in the text and data supplied by the U.S. Geological Survey's Branch of Quality Assurance. Error criterion is 10 percent for cations, anions, silica, dissolved solids, and nutrients. Error criterion is 20 percent for metals and trace elements.

the absolute standard deviation, produce large percent errors. For example, an absolute error of 0.2 mg/L is a 20-percent error for a concentration of 1.0 mg/L, but is only a 2-percent error for a concentration of 10 mg/L.

Errors for trace elements ranged from 3.9 to 47 percent (table 11). For 8 of 13 trace elements, the error was within the goal of 20 percent. Even though the average percent error was above 20 percent for five metals, the absolute error, as represented by the average absolute standard deviation, was generally reasonable. For some of the trace elements, copper and cadmium for example, the average absolute standard deviation was large relative to the range of concentrations in ground-water samples, but was acceptable relative to the range of concentrations in standards. Because concentrations of trace elements in standards were usually larger than concentrations in ground-water samples, the absolute standard deviation resulting from multiple analyses of actual samples probably would be smaller than those reported from analysis of standards.

Internal surrogate standards were injected into each sample to be analyzed for concentrations of VOCs or pesticides, and samples prepared with known concentrations of analytes (spiked samples) were analyzed during sample runs. The surrogate and spiked samples were used to determine percent recoveries, and those that were not detected within a certain percentage of the known concentrations (variable, dependent upon the compound) were identified by the NWQL. No samples were reported to have substandard VOC recoveries; however, recoveries of some pesticides were considered not acceptable. Pesticide compounds with poor recoveries or with other problems associated with their analysis are footnoted in tables 2 and 3 in the Water-Quality Methods section of this report.

Duplicate and Replicate Samples

Duplicate samples were analyzed for boron, nitrate, radon, and MBAS (table 12), and replicate samples were analyzed for bacteria (table 13). Overall the results were very good; however, one of the boron duplicate pairs did not meet the precision criteria of 10 percent outlined in the quality-assurance plan for this study (M. A. Jones, U.S. Geological Survey, written commun., 1995). Although no precision criteria were set for bacteria determinations, results of replicate analyses indicate generally good precision.

Blanks

Blanks of deionized water or specially prepared blank water were processed in the same manner as water samples and sent to the NWQL for analysis. Although no criteria were set for constituent concentrations in blanks, the significance of any constituent present in a blank was based on how close the constituent concentration was to the detection limit and how small it was compared with the median sample concentration. Also important was the number of times the constituent was detected in blank samples. These data are presented in table 14, and, when compared with these criteria, concentrations in blanks were insignificant for all constituents, but of possible concern for potassium, boron, and fecal-*streptococci* bacteria. Potassium was detected in only one of four blanks, but the reported concentration of 1.9 mg/L was large relative to the range of concentrations in ground-water samples of 0.5 to 6.8 mg/L. Boron was detected at a concentration of 6.7 μg/L in one of the three blank samples. Six colonies of fecal-*streptococci* bacteria were detected in 100 milliliters in 1 of 18 blanks.

Cation-Anion Balance

Various sums, differences, and ratios based on the principles of aquatic chemistry were computed for each sample. These computations check the consistency between constituent concentrations in a sample and provide a gross check in the accuracy and completeness of the analysis. One of the most useful computations is the cation-anion balance, which is discussed in the following paragraphs.

The cation-anion balance was calculated as a percent difference, using the following equation:

$$\frac{\sum cations - \sum anions}{\sum cations + \sum anions} \times 100\ percent \quad , \qquad (13)$$

where

$\sum cations$ = the sum of the concentrations of cations, in milliequivalents; and

$\sum anions$ = the sum of the concentrations of anions, in milliequivalents.

Table 12.--*Constituent concentrations in duplicate samples*

[Concentrations in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; pCi/L, picocuries per liter; MBAS, methylene blue active substances; --, no data; <, less than]

Well at which duplicate was collected	Boron (µg/L)		Nitrate		Radon (pCi/L)		MBAS	
	Reported	Duplicate	Reported	Duplicate	Reported	Duplicate	Reported	Duplicate
19N/03E-11Q01	--	--	--	--	460	450	--	--
19N/04E-02F01	--	--	--	--	470	510	--	--
19N/04E-20K03	12.3	12.7	2	2	--	--	<0.02	<0.02
20N/03E-07F01	--	--	3.2	3.2	--	--	<0.02	<0.02
20N/04E-20N01	22.8	18.7	--	--	--	--	<0.02	<0.02
20N/04E-31F02	16.5	9.5	--	--	--	--	--	--

Table 13.--*Replicate sample results for bacteria determinations*
[--, no data]

Local well number	Milliliters filtered	Replicate number	Colony counts per plate: Fecal *Streptococci*	Colony counts per plate: Total coliform	Colony counts per plate: *Escherichia coli*
19N/03E-11Q01	100	1	0	2	0
		2	0	27	0
		3	0	12	0
19N/04E-12N01S	30	1	0	0	--
		2	0	0	--
		3	0	0	--
	100	1	0	0	--
		2	0	0	--
		3	0	0	--
19N/04E-14P01	30	1	2	0	--
		2	0	0	--
		3	0	2	2
	100	1	0	2	2
		2	0	4	4
		3	0	1	1
19N/04E-20K03	100	1	0	0	--
		2	0	0	--
		3	0	0	--
20N/03E-14H01S	30	1	1	3	0
		2	1	0	--
		3	0	1	0
	100	1	0	8	0
		2	2	8	0
		3	1	12	0
20N/04E-19G01	30	1	0	0	--
		2	0	0	--
		3	0	0	--
	100	1	0	0	--
		2	0	0	--
		3	0	0	--
20N/04E-20E06	100	1	0	0	--
		2	0	0	--
		3	--	0	--
20N/04E-36H03	30	1	0	1	1
		2	0	1	0
		3	1	3	2
	100	1	0	2	2
		2	0	1	0
		3	0	3	3

Table 14.--*Summary of constituent concentrations reported for blank samples*
[Concentrations in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; pCi/L, picocuries per liter; cols. per 100 mL, colonies per 100 milliliters; ND, not detected]

Constituent	Number of field blanks	Number of equipment blanks	Number of detections	Maximum concentration in blank
Calcium	3	1	0	ND
Magnesium	3	1	0	ND
Sodium	3	1	0	ND
Potassium	3	1	1	1.9
Alkalinity	3	1	4	1.5
Sulfate	3	1	0	ND
Chloride	3	1	0	ND
Fluoride	3	1	0	ND
Silica	3	1	1	0.2
Nitrate	3	1	1	0.06
Iron (µg/L)	3	1	0	ND
Manganese (µg/L)	3	1	0	ND
Arsenic (µg/L)	1	1	0	ND
Barium (µg/L)	1	1	0	ND
Boron (µg/L)	2	1	1	6.7
Cadmium (µg/L)	1	1	0	ND
Chromium (µg/L)	1	1	0	ND
Copper (µg/L)	1	1	0	ND
Lead (µg/L)	1	1	0	ND
Mercury (µg/L)	1	1	0	ND
Selenium (µg/L)	1	1	0	ND
Silver (µg/L)	1	1	0	ND
Zinc (µg/L)	1	1	0	ND
Total organic carbon	1	1	0	ND
Methylene Blue active substances	1	1	0	ND
All other organic compounds				
Volatiles (µg/L)	1	1	0	ND
Pesticides (µg/L)	1	0	0	ND
Total coliform (cols. per 100 mL)	10	10	1	1
Fecal *Streptococci* (cols. per 100 mL)	8	10	1	6

Ideally, this value is zero, but nonzero values are common and may be large when a cation or anion concentration is in error or when an ion present in large concentrations (often a metal) is not analyzed for. The acceptable percent difference varies with the total sum of cations and anions, as shown in figure 28. The cation-anion balance was acceptable for all of the samples collected in the study area.

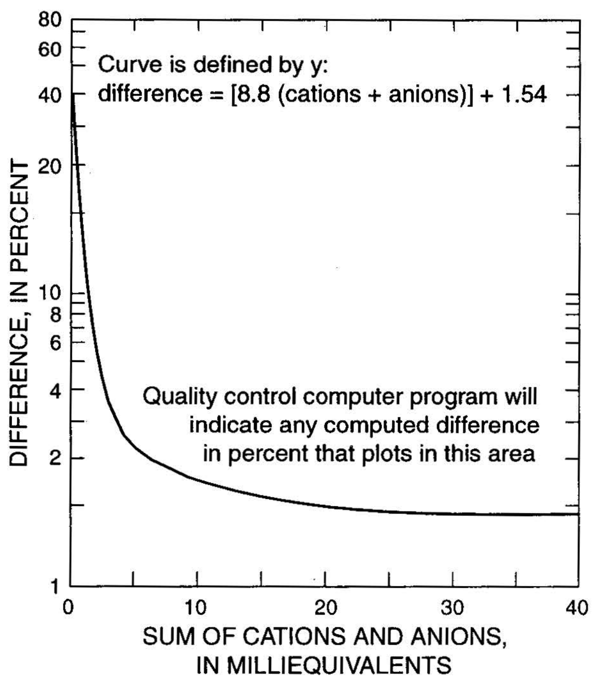


Figure 28. Cation and anion percent difference (Friedman and Erdmann, 1982).

Checks on Field Values

The primary controls on the determinations of field values of pH, specific conductance, dissolved oxygen, and temperature are proper instrument calibration and field procedures. Specific conductance and pH are also determined in the laboratory. Laboratory determinations of pH values are made to evaluate samples that may require special processing and are not considered indicative of field values. Specific conductance is more stable, and laboratory values provide a good check of field values. Based on a paired t-test, there was no significant difference at the 95-percent confidence level between laboratory and field specific conductance values.

Alkalinity, which is part of the anion-cation balance, was also measured in the field. The acceptable balance for all determinations provides a check on this determination.

SUMMARY AND CONCLUSIONS

The study area, which encompasses 88 mi^2 of the northwestern portion of Pierce County, is a product of the last glaciation and more recent alluvial processes of the Quaternary Period. It consists of an upland drift plain that ranges in altitude from 200 to 600 ft above sea level and has been transected by outwash channels and the Puyallup River Valley.

Subsurface stratigraphy of the unconsolidated deposits was correlated using lithologic information from published surficial geology maps, from the interpretation of 255 drillers' logs, and from 17 generalized hydrogeologic sections oriented north-south and east-west across the study area. Ten hydrogeologic units were delineated. They include five aquifers--Qvr, Qc1, Qc2, Qc3, and Qc4--consisting predominantly of coarse-grained glacial outwash and alluvium deposits. These units are separated by semiconfining units Qvt, Qf1, Qf2, Qf3, and Qf4, consisting predominantly of fine-grained till, clay, and silt deposits. These 10 units are underlain by an undifferentiated unconsolidated unit, Qdu, of unknown hydrologic characteristics more than 1,000 ft thick. Maps were prepared depicting the configuration of the tops of the five uppermost hydrogeologic units, showing their general extent and geometry.

Unit Qvr is present at the land surface and generally represents the recessional outwash deposits of the Fraser Glaciation. It is considered an aquifer where saturated. The median thickness of this aquifer is 22 ft. Aquifer Qc1 generally lies beneath unit Qvt throughout the study area. Its median altitude and thickness within the study area are 238 ft and 41 ft, respectively, with a median hydraulic conductivity of 110 ft/d. Aquifer Qc2, the most widely used aquifer by public-supply purveyors, lies beneath semiconfining unit Qf1. Its median altitude and thickness are 55 ft and 27 ft, respectively, with a median hydraulic conductivity of 170 ft/d. Aquifer Qc3 lies beneath semiconfining unit Qf2. The top of this unit is generally below sea level, with a median altitude of -128 ft. Few wells penetrate to this depth; from the available data, the thickness of this unit is estimated at 55 ft, and the hydraulic conductivity is estimated at 100 ft/d. Some information was available for delineating hydrogeologic units Qf3, Qc4, and Qf4, but this information is sparse. In general all remaining undifferentiated deposits are grouped into a hydrogeologic unit designated Qdu. This unit also includes part of the other 10 units in areas at depth where there is no information available to delineate them.

Maps of the water-level altitudes of aquifers Qc1 and Qc2 reflect the local and regional horizontal movement of the ground-water system, respectively. The pattern of ground-water movement in both aquifers is similar, with flow toward the east and northeast into the Puyallup River and north to Commencement Bay, The Narrows, and Puget Sound. Ground-water movement in aquifer Qc1 is also to the southwest through the Clover Creek Channel. Horizontal ground-water gradients in the southeast corner of the study area for Qc1 are about 100 ft/mi. In this same area ground-water gradients for aquifer Qc2 are 150 ft/mi due to the steep topography in this area. Overall ground-water gradients for aquifer Qc2 are about 70 ft/mi throughout the study area. Vertical ground-water movement is downward in the upland part of the study area and upward in the lower reach of the Puyallup River Valley.

Most of the recharge to the local ground-water system is derived from the infiltration of precipitation and at depth from ground-water inflow from outside the study-area boundaries. Recharge was estimated at 14 in/yr for the study area, based on the distribution of the annual precipitation, surficial geology, land use, and sanitary and stormwater systems. Ground-water movement across the study area boundaries was not quantified due to a lack of available data.

Spring-flow and baseflow from the creeks whose drainage basins are contained within the study area and from the water-wells was assessed to quantify some of the ground-water discharge in the area. The estimated average annual spring discharge totaled 14 ft^3/s. This value is only considered a minimum estimate of the actual discharge from spring flow. The sum of baseflows in three creeks in the study area, Clarks, Clear, and Swan Creeks, was estimated at 59 ft^3/s, based on the available hydrograph data from three continuous gaging stations.

Approximately 6,890 Mgal of ground water was withdrawn from the study area in 1996. About 97 percent of that total was for residential, commercial, and industrial purposes, with smaller amounts, about 3 percent, used for agriculture, aquaculture, irrigation, and system losses. Aquifer Qc1 supplied most (2,790 Mgal) of the water, followed by Qc2 (2,320 Mgal), Qc3 (968 Mgal), Qc4 (497 Mgal), and from all remaining units (313 Mgal).

Based on the configuration of the study area and its general location in the regional ground-water system, the recharge to the ground-water system within the study area moves through the shallow ground-water system along relatively short flowpaths before being discharged to cliff faces as seeps and springs or to creeks. Assuming minimal ground-water inflow from outside the study area to these upper units, a local ground-water budget was approximated for the shallow ground-water system, units Qc1 and above. This local water budget indicates that 86 percent of the quantified recharge within the study area discharges through the shallow ground-water system. Thus, units in the shallow ground-water system constitute a local ground-water-movement system, and the hydrogeologic units below Qc1 are part of a more regional ground-water system.

Water from 33 sites, which include 29 wells and 4 springs, was sampled and analyzed to determine the quality of ground water in the study area. All 33 samples were analyzed for nitrite plus nitrate, major ions, arsenic, iron, manganese, and bacteria, but only some of the samples were analyzed for trace elements, MBAS, boron, radon, pesticides, TOC, and VOCs. Other properties of the water (pH, temperature, specific conductance, alkalinity, and dissolved-oxygen content) were determined for all 33 samples.

The overall quality of ground water in the study area was good; only four constituents were found at concentrations above those allowed by drinking water standards or guidelines. Two of the four constituents, the pesticide dieldrin in water from one well and total-coliform bacteria in water from four wells or springs, were at levels exceeding standards or guidelines related to human health. Concentrations of iron or manganese in water from eight wells and springs exceeded the amount allowed by secondary drinking water standards, which are not health related. Concentrations of iron and manganese in ground water above secondary drinking water standards is fairly typical for the Puget Sound region. Concentrations of other trace elements met drinking water standards or guidelines.

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Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington*

EXPLANATION

[NP, unit not present; --, well does not penetrate to stratigraphic position where unit may or may not be present; 0, sea level (NGVD of 1929); ?, log incomplete at surface]

Latitude and Longitude:	Most well locations are believed to be accurate to within 1 second of latitude and longitude. The least accurate locations are probably within 10 seconds of latitude and longitude.
Land surface altitude:	Most altitudes were assigned from topographic maps (1:24,000 with 10- or 20-foot contour intervals) and are generally accurate to within 10 feet. In steep terrain, or where the precise location of the well is in doubt, the error may be as great as 50 feet. Some wells (<10 percent) have been surveyed and are accurate to within 1 foot.
Hole depth:	Total depth penetrated during drilling; does not necessarily equal finished depth of well.

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
19N/03E-01A01	471007	1222136	460	303	NP	460	423	270	245	--	--	--	--	--
19N/03E-01C01	471009	1222201	430	190	NP	430	401	270	255	--	--	--	--	--
19N/03E-01C02	470959	1222200	445	195	NP	445	384	286	264	--	--	--	--	--
19N/03E-01E01	470958	1222230	473.8	285	NP	474	311	297	218	--	--	--	--	--
19N/03E-01G02	470944	1222146	450	619	NP	450	310	286	233	215	NP	100	--	--
19N/03E-01J01	470941	1222137	475	407	NP	475	311	308	274	247	125	113	--	--
19N/03E-03B01	471000	1222420	430	316	NP	430	239	209	182	131	--	--	--	--
19N/03E-03B02	471010	1222421	425	839	NP	425	229	172	148	122	85	7	-192	
19N/03E-03F02	470949	1222445	405	387	NP	405	249	211	NP	160	91	31	--	--
19N/03E-03F04	470951	1222447	405	371	NP	405	235	205	NP	160	85	--	--	--
19N/03E-03G01	470959	1222420	430	415	NP	430	235	210	144	140	118	--	--	--
19N/03E-03G02	470955	1222423	430	422	NP	430	245	227	169	154	70	11	--	--
19N/03E-11G03	470852	1222306	420	254	NP	420	247	245	202	--	--	--	--	--
19N/03E-11Q01	470833	1222302	415	242	NP	415	355	265	178	--	--	--	--	--
19N/03E-13R01	470733	1222127	455	161	NP	455	297	--	--	--	--	--	--	--
19N/03E-25C01	470629	1222212	350	51	350	348	--	--	--	--	--	--	--	--
19N/04E-01A01	471006	1221344	90	96	NP	NP	90	NP	0	--	--	--	--	--
19N/04E-01H01	470949	1221344	95	197	NP	NP	NP	95	25	--	--	--	--	--
19N/04E-01Q01	470925	1221403	110	104	NP	NP	NP	110	16	--	--	--	--	--
19N/04E-02F01	470955	1221542	410	624	410	342	227	174	31	1	-125	--	--	--
19N/04E-02J01	470931	1221500	500	425	NP	500	NP	279	77	--	--	--	--	--
19N/04E-03A01D1	471008	1221628	445	847	445	428	265	263	104	35	-20	-95	-275	-311
19N/04E-03K02	470938	1221650	460	34	460	--	--	--	--	--	--	--	--	--
19N/04E-03K03	470937	1221648	460	45	460	--	--	--	--	--	--	--	--	--
19N/04E-03K04	470939	1221651	450	37	450	--	--	--	--	--	--	--	--	--
19N/04E-03Q01	470930	1221637	500	44.5	NP	500	--	--	--	--	--	--	--	--
19N/04E-03R01D2	470919	1221632	530	810	NP	530	403	288	114	94	-22	-82	-192	-221
19N/04E-04L01	470935	1221819	355	240	355	313	175	169	149		--	--	--	--
19N/04E-04L02	470934	1221819	355	264	355	313	206	190	135	91	--	--	--	--
19N/04E-04Q01	470928	1221805	410	327	410	393	NP	250	146	--	--	--	--	--
19N/04E-05P02	470922	1221945	435	258	NP	435	299	273	240	--	--	--	--	--
19N/04E-06J02	470934	1222011	440	207	NP	440	370	340	257	--	--	--	--	--
19N/04E-07A01	470911	1222010	415	36.6	NP	415	--	--	--	--	--	--	--	--
19N/04E-07D01	470912	1222105	450	326	NP	450	NP	325	259	184	--	--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
19N/04E-07D02	470912	1222103	450	275	NP	450	NP	319	249	229	--	--	--	--
19N/04E-07F01D1	470901	1222057	460	604	NP	460	233	217	181	156	2	-71	-131	--
19N/04E-07F02	470900	1222100	455	257	NP	455	233	216	--	--	--	--	--	--
19N/04E-07N01	470826	1222118	475	12.9	NP	475	--	--	--	--	--	--	--	--
19N/04E-08A01	470911	1221859	346.29	304	346	300	290	146	118	--	--	--	--	--
19N/04E-08A06	470909	1221851	366.5	353.3	366.5	299.5	291.5	126.5	91.5	15.5	--	--	--	--
19N/04E-08D01	470913	1221958	420	258	NP	420	241	232	184	--	--	--	--	--
19N/04E-08K01	470849	1221915	440	341.5	NP	440	NP	340	155	105	--	--	--	--
19N/04E-09B01	470914	1221808	410	324	?	?	?	?	72	--	--	--	--	--
19N/04E-09B02	470914	1221807	410	316	?	?	?	?	80	--	--	--	--	--
19N/04E-09B03	470914	1221808	410	363	410	386	378	129	123	--	--	--	--	--
19N/04E-10A01	470905	1221619	570	271	NP	570	335	--	--	--	--	--	--	--
19N/04E-11D01	470903	1221600	450	119.5	450	398	355	--	--	--	--	--	--	--
19N/04E-11D02	470905	1221613	560	280	NP	560	302	--	--	--	--	--	--	--
19N/04E-12A02	470911	1221342	110	76	NP	NP	NP	110	55	--	--	--	--	--
19N/04E-12B01	470906	1221404	110	54	NP	NP	110	84	58	--	--	--	--	--
19N/04E-12H02	470902	1221358	110	140.5	NP	NP	NP	110	34	--	--	--	--	--
19N/04E-12H03	470859	1221355	110	124	NP	NP	NP	110	30	--	--	--	--	--
19N/04E-12J02	470845	1221353	110	125	NP	NP	NP	110	-13	--	--	--	--	--
19N/04E-12R02	470825	1221345	120	77	NP	NP	NP	120	47	--	--	--	--	--
19N/04E-13B01	470818	1221412	120	117	NP	NP	NP	120	38	--	--	--	--	--
19N/04E-13G01	470802	1221401	115	80	NP	NP	115	65	45	--	--	--	--	--
19N/04E-13K02	470755	1221406	120	14	NP	NP	120	--	--	--	--	--	--	--
19N/04E-14P01	470742	1221550	550	22	550	530	--	--	--	--	--	--	--	--
19N/04E-15F01	470801	1221700	510	71	NP	510	443	--	--	--	--	--	--	--
19N/04E-16E01	470800	1221842	450	305	NP	450	NP	413	165	--	--	--	--	--
19N/04E-16E02D2	470805	1221843	450	440	NP	450	NP	371	169	119	65	--	--	--
19N/04E-16G03	470806	1221757	460	400	NP	460	432	135	125	--	--	--	--	--
19N/04E-17K01	470752	1221910	480	374	NP	480	NP	398	212	197	135	--	--	--
19N/04E-17N01	470737	1222001	355	170	NP	355	283	193	--	--	--	--	--	--
19N/04E-19A01D1	470731	1222017	485	210	NP	485	--	--	--	--	--	--	--	--
19N/04E-19D01	470730	1222120	445	9.7	NP	445	--	--	--	--	--	--	--	--
19N/04E-19N01	470642	1222115	410	90	410	403	--	--	--	--	--	--	--	--
19N/04E-20F02	470719	1221932	395	139.5	395	316	276	--	--	--	--	--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
19N/04E-20K03	470705	1221921	465	195.5	NP	465	275	--	--	--	--	--	--	--
19N/04E-20M01	470705	1221957	355	124	355	339	276	--	--	--	--	--	--	--
19N/04E-20Q01D1	470651	1221925	400	325	NP	400	300	253	158	153	85	--	--	--
19N/04E-20R04	470646	1221905	460	246	NP	460	312	296	222	--	--	--	--	--
19N/04E-20R05	470646	1221905	465	261	NP	465	309	298	260	--	--	--	--	--
19N/04E-21D01	470730	1221835	450	231	NP	450	NP	335	243	--	--	--	--	--
19N/04E-21K01	470705	1221752	480	11.3	480	--	--	--	--	--	--	--	--	--
19N/04E-22D01	470732	1221722	465	243	465	NP	405	285	235	--	--	--	--	--
19N/04E-22D02	470731	1221722	465	463	465	411	386	268	217	169	--	--	--	--
19N/04E-25K02	470610	1221408	155	97	NP	NP	NP	155	81	--	--	--	--	--
19N/04E-26C01	470627	1221555	585	350	585	551	386	371	345	269	--	--	--	--
19N/04E-26G01	470617	1221520	605	370	605	597	415	405	328	236	--	--	--	--
19N/04E-27A01	470629	1221630	585	225	585	555	387	363	--	--	--	--	--	--
19N/04E-27B01	470634	1221647	570	9	570	562	--	--	--	--	--	--	--	--
19N/04E-27N01	470556	1221725	530	354	NP	530	509	412	230	--	--	--	--	--
19N/04E-28B01	470638	1221752	510	697	510	501	415	351	205	98	-79	-171	--	--
19N/04E-29D02	470629	1221949	360	91	360	346	287	--	--	--	--	--	--	--
19N/04E-29D06	470638	1221949	340	152	340	NP	270	201	--	--	--	--	--	--
19N/04E-29E02	470622	1221958	350	76	350	348	283	--	--	--	--	--	--	--
19N/04E-29E10D1	470619	1221956	400	79	400	398	346	326	--	--	--	--	--	--
19N/04E-29J01	470609	1221855	510	199	510	492	380	--	--	--	--	--	--	--
19N/04E-29K02	470612	1221918	485	180	NP	485	342	--	--	--	--	--	--	--
19N/04E-29L03	470609	1221940	490	202	490	481	332	--	--	--	--	--	--	--
19N/04E-29M02	470606	1221957	470	160	470	456	435	--	--	--	--	--	--	--
19N/04E-29R03	470551	1221905	490	149	NP	490	350	--	--	--	--	--	--	--
19N/04E-30A02	470626	1222017	380	80	380	377	310	--	--	--	--	--	--	--
19N/04E-30A03	470628	1222009	355	40	355	354	325	--	--	--	--	--	--	--
19N/04E-30D03	470633	1222119	385	83	385	378	309	--	--	--	--	--	--	--
19N/04E-30F03	470616	1222046	340	118	340	313	250	--	--	--	--	--	--	--
19N/04E-30Q03	470552	1222030	465	160	NP	465	347	--	--	--	--	--	--	--
19N/04E-31C03	470545	1222100	460	140	NP	460	323	--	--	--	--	--	--	--
19N/05E-06A01	470958	1221232	90	97	NP	NP	NP	90	-1	--	--	--	--	--
19N/05E-06C02	471010	1221317	85	300	NP	NP	NP	85	5	-92	-161	--	--	--
19N/05E-06E01	470950	1221329	95	143	NP	NP	NP	95	27	--	--	--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
19N/05E-06E02	470946	1221337	100	151	NP	NP	NP	100	45	--	--	--	--	--
19N/05E-06F01	470946	1221322	95	173	NP	NP	NP	95	62	--	--	--	--	--
19N/05E-06M04	470937	1221329	100	111	NP	NP	NP	100	15	--	--	--	--	--
19N/05E-06N02	470924	1221337	105	100	NP	NP	NP	105	21	--	--	--	--	--
19N/05E-07L02	470849	1221310	100	83	100	91	24	--	--	--	--	--	--	--
19N/05E-18M01	470748	1221339	125	96	NP	NP	NP	125	55	--	--	--	--	--
19N/05E-30N01	470555	1221341	165	93	NP	NP	NP	165	83	--	--	--	--	--
19N/05E-30P01	470554	1221319	170	78	NP	NP	170	NP	115	--	--	--	--	--
19N/05E-30P02	470549	1221316	170	81	NP	NP	170	148	97	--	--	--	--	--
20N/02E-01A01	471518	1222857	390	35	390	--	--	--	--	--	--	--	--	--
20N/02E-02M01	471448	1223118	310	316	NP	310	170	0	--	--	--	--	--	--
20N/02E-02M02	471448	1223120	323	468	NP	323	168	-3	--	--	--	--	--	--
20N/02E-12H01	471417	1222904	400	218	NP	400	378	--	--	--	--	--	--	--
20N/02E-12M01	471359	1222956	283.96	86	NP	283.96	271.96	--	--	--	--	--	--	--
20N/02E-12M02	471359	1222956	284.45	106	NP	284.45	272.45	--	--	--	--	--	--	--
20N/02E-12Q01	471353	1222931	326.88	117	NP	326.88	294.88	--	--	--	--	--	--	--
20N/03E-03L01	471451	1222440	10	534	NP	NP	NP	10	-120	-143	-167	-226	-334	-370
20N/03E-04M01	471455	1222622	140	25	NP	140	--	--	--	--	--	--	--	--
20N/03E-05C01	471524	1222706	345	24	NP	345	--	--	--	--	--	--	--	--
20N/03E-06M01	471459	1222855	360.11	30	360.11	--	--	--	--	--	--	--	--	--
20N/03E-06M02	471500	1222855	360	30	360	--	--	--	--	--	--	--	--	--
20N/03E-06N01	471441	1222855	360	316	NP	360	287	127	121	54	--	--	--	--
20N/03E-07F01	471420	1222830	330	160	NP	330	303	--	--	--	--	--	--	--
20N/03E-07G01	471420	1222813	350	270	NP	350	335	124	80	--	--	--	--	--
20N/03E-07N02	471351	1222847	250	205	NP	NP	250	186	95		--	--	--	--
20N/03E-07Q01	471354	1222809	270	141	NP	NP	270	176	149	--	--	--	--	--
20N/03E-08K03	471357	1222649	240	38	NP	NP	240	--	--	--	--	--	--	--
20N/03E-09A03	471421	1222513	10	320	NP	NP	NP	10	-98	-118	-144	-243		
20N/03E-09C02	471428	1222557	40	301	NP	40	-50	-69	-150	--	--	--	--	--
20N/03E-09D03	471428	1222615	110	677	NP	NP	110	-150	-165	-240	-265	-541	--	--
20N/03E-09E03	471417	1222615	150	259	NP	NP	150	--	--	--	--	--	--	--
20N/03E-09F01	471419	1222554	60	618	NP	60	NP	-110	-226	-395	-432	-549	--	--
20N/03E-10G01	471419	1222430	40	30	NP	NP	40	--	--	--	--	--	--	--
20N/03E-11K01	471400	1222310	15	97	NP	NP	15	-20	-32	--	--	--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
20N/03E-11P02	471343	1222327	25	41	NP	NP	NP	25	-13	--	--	--	--	--
20N/03E-11P04	471341	1222322	25	90	NP	NP	NP	25	-20	--	--	--	--	--
20N/03E-11P05	471343	1222329	35	25	NP	NP	35	--	--	--	--	--	--	--
20N/03E-11Q02	471351	1222309	10	316	NP	NP	NP	10	-17	-51	-132	-287	-304	--
20N/03E-11Q03	471349	1222305	30	491	NP	NP	NP	30	0	-69	-147	-242	-282	--
20N/03E-13C02	471337	1222215	12	154	NP	NP	12	-11	-61	--	--	--	--	--
20N/03E-13D02	471329	1222219	10	105	NP	NP	NP	10	-50	--	--	--	--	--
20N/03E-13H05	471321	1222137	20	78	NP	NP	20	7	-51	--	--	--	--	--
20N/03E-14A02	471339	1222248	18	24.4	NP	NP	NP	18	-4	--	--	--	--	--
20N/03E-14B01	471330	1222303	185	145	NP	185	122	51	--	--	--	--	--	--
20N/03E-14C02	471340	1222329	20	38	NP	NP	NP	20	-14	--	--	--	--	--
20N/03E-14F01	471322	1222328	200	133	200	195	75	--	--	--	--	--	--	--
20N/03E-14G01	471325	1222255	100	77	NP	100	32	--	--	--	--	--	--	--
20N/03E-14R01	471258	1222239	250	231	250	222	192	150	74	24	--	--	--	--
20N/03E-15F01	471326	1222434	247.5	698	247.5	189.5	NP	42.5	-192.5	-264.5	-293.5	-344.5	-370.5	-397.5
20N/03E-17G01	471325	1222656	370	55	NP	370	--	--	--	--	--	--	--	--
20N/03E-20K01	471222	1222702	350	17.5	NP	350	--	--	--	--	--	--	--	--
20N/03E-20P01	471159	1222714	315	299.4	NP	315	224	--	--	--	--	--	--	--
20N/03E-20P02	471159	1222714	315	299.4	NP	315	224	111	71	--	--	--	--	--
20N/03E-21C01	471241	1222553	355	238	NP	355	253	178	137	--	--	--	--	--
20N/03E-22B01	471238	1222421	320	--	--	--	--	--	--	--	--	--	--	--
20N/03E-23H01	471227	1222251	380	256	NP	380	206	157	147	--	--	--	--	--
20N/03E-24A01	471238	1222135	25	70	NP	NP	25	-35	--	--	--	--	--	--
20N/03E-25C01	471144	1222218	360	227	NP	360	202	195	173	--	--	--	--	--
20N/03E-25C02	471145	1222218	360	305	NP	360	230	200	172	107	74	--	--	--
20N/03E-26K01	471128	1222315	410	27.5	NP	410	--	--	--	--	--	--	--	--
20N/03E-28F02	471131	1222556	400	36.5	NP	400	--	--	--	--	--	--	--	--
20N/03E-28J01	471133	1222508	420	35	NP	420	--	--	--	--	--	--	--	--
20N/03E-30R01	471107	1222802	300	30	300	280	--	--	--	--	--	--	--	--
20N/03E-31A01	471055	1222756	300	18	300	286	--	--	--	--	--	--	--	--
20N/03E-32D01	471053	1222738	300	15.7	300	287	--	--	--	--	--	--	--	--
20N/03E-32D04	471103	1222738	300	114	NP	300	260	--	--	--	--	--	--	--
20N/03E-34E01	471049	1222453	415	19.8	NP	415	--	--	--	--	--	--	--	--
20N/03E-34L01	471034	1222447	415	505	NP	415	275	185	148	146	95	19	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
20N/03E-34L02	471034	1222449	415	223	NP	415	305	--	--	--	--	--	--	--
20N/03E-34N01	471022	1222509	385	223	NP	385	334	225	167	--	--	--	--	--
20N/03E-35C01	471102	1222331	410	315.6	NP	410	282	212	187	156	--	--	--	--
20N/03E-35F01	471050	1222333	405	18	NP	405	--	--	--	--	--	--	--	--
20N/03E-35L01	471027	1222324	420	187	NP	420	243	--	--	--	--	--	--	--
20N/03E-35R01	471013	1222242	450	315	NP	450	277	219	194	154	--	--	--	--
20N/03E-36D01	471103	1222236	415	34.2	NP	415	--	--	--	--	--	--	--	--
20N/03E-36F01	471050	1222202	390	372	NP	390	326	270	183	124	82	--	--	--
20N/03E-36P01	471021	1222206	428	597	NP	428	313	248	233	168	83?	-54	--	--
20N/04E-18M03	471303	1222114	15	203	NP	NP	NP	15	-109	-149	--	--	--	--
20N/04E-18Q01D2	471250	1222034	20	336	NP	NP	NP	20	-96	-210	-280	--	--	--
20N/04E-19G01	471225	1222030	25	70	NP	NP	25	-40	--	--	--	--	--	--
20N/04E-19Q01	471202	1222043	25	118	NP	NP	25	NP	-43	--	--	--	--	--
20N/04E-20D04D1	471236	1222009	30	390	--	--	--	--	--	--	-266	--	--	--
20N/04E-20D06	471237	1222009	30	298	NP	NP	30	-32	-88	-110	-246	--	--	--
20N/04E-20E04	471234	1221954	30	56	NP	NP	30	5	--	--	--	--	--	--
20N/04E-20E06	471225	1221948	25	121	NP	NP	NP	25	-70	-90	--	--	--	--
20N/04E-20K01	471211	1221925	25	267	NP	NP	NP	25	13	-67	-80	--	--	--
20N/04E-20N05	471203	1221956	30	193	NP	NP	NP	30	-50	-97	--	--	--	--
20N/04E-20P02	471204	1221929	25	103	NP	NP	NP	25	-17	-72	--	--	--	--
20N/04E-21A01	471244	1221739	40	40	NP	NP	40	--	--	--	--	--	--	--
20N/04E-21P01	471204	1221821	30	230	NP	NP	30	-32	NP	-80	-160	--	--	--
20N/04E-25N01	471107	1221454	70	113	NP	NP	NP	70	-10	--	--	--	--	--
20N/04E-25P01	471106	1221429	70	92	NP	NP	NP	70	-20	--	--	--	--	--
20N/04E-25Q01	471112	1221417	60	105	NP	NP	NP	60	-35	--	--	--	--	--
20N/04E-26E01	471133	1221605	45	169	NP	NP	45	5	-105	--	--	--	--	--
20N/04E-26M01	471130	1221604	40	20.5	NP	NP	40	--	--	--	--	--	--	--
20N/04E-26M02	471130	1221605	40	21.5	NP	NP	40	--	--	--	--	--	--	--
20N/04E-26Q01	471116	1221526	65	122	NP	NP	65	39	-48	--	--	--	--	--
20N/04E-27H01	471133	1221619	40	190	NP	NP	40	-5	-114	-119	-143	--	--	--
20N/04E-27J01	471124	1221623	55	233	NP	NP	55	35	-95	-100	-152	--	--	--
20N/04E-27L01	471127	1221711	45	285	NP	NP	NP	45	NP	-90	-203	--	--	--
20N/04E-28E01	471137	1221833	40	82	NP	NP	40	17	--	--	--	--	--	--
20N/04E-28H04	471131	1221739	40	253	NP	NP	40	-5	NP	-85	-208	--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
20N/04E-28H05	471143	1221734	40	20	NP	NP	40	--	--	--	--	--	--	--
20N/04E-28H06	471131	1221741	40	252	NP	NP	40	-45	NP	-90	-207	--	--	--
20N/04E-29D03	471148	1221949	30	362	NP	NP	NP	30	-45	-100	--	--	--	--
20N/04E-29P03	471116	1221931	50	119	50	NP	23	-3	-47	--	--	--	--	--
20N/04E-30C02	471150	1222049	50	115	NP	50	-2	-44	-54	--	--	--	--	--
20N/04E-30C03	471154	1222049	30	42	NP	NP	30	--	--	--	--	--	--	--
20N/04E-30F01	471135	1222046	230	195	NP	NP	230	NP	132	--	--	--	--	--
20N/04E-30G02	471141	1222032	60	80	NP	60	3	--	--	--	--	--	--	--
20N/04E-30H01	471132	1222009	40	332	NP	NP	40	34	NP	-104	-257	--	--	--
20N/04E-30L02	471128	1222046	320	270	NP	320	212	192	115	90	54	--	--	--
20N/04E-30P02	471104	1222048	390	450	NP	390	238	204	191	178	95	--	--	--
20N/04E-31F02	471042	1222057	400	190	NP	400	304	246	--	--	--	--	--	--
20N/04E-31G01	471050	1222030	350	126	NP	350	238	--	--	--	--	--	--	--
20N/04E-31H05	471039	1222017	380	192	380	280	240	--	--	--	--	--	--	--
20N/04E-32E01	471045	1221954	265	16.5	265	--	--	--	--	--	--	--	--	--
20N/04E-32E02	471043	1221955	270	295	270	236	212	164	117	54	-14	--	--	--
20N/04E-32H01	471038	1221851	31.7	170	NP	NP	32	-42	-75	-133	--	--	--	--
20N/04E-32H02	471039	1221851	30	171.5	NP	NP	30	-53	-77	-131	--	--	--	--
20N/04E-32J02	471039	1221852	30	166	NP	NP	30	-48	-77	-132	--	--	--	--
20N/04E-32R02	471015	1221851	300	294	300	289	240	178	122	-9	--	--	--	--
20N/04E-33A01	471055	1221733	40	345	NP	NP	40	-60	-95	-122	-186	-200	-265	--
20N/04E-34B01	471053	1221640	55	42	NP	NP	55	--	--	--	--	--	--	--
20N/04E-34C01	471054	1221711	45	264	NP	NP	45	-85	-109	-127	-202	--	--	--
20N/04E-34E01	471048	1221731	50	43	NP	NP	50	--	--	--	--	--	--	--
20N/04E-34G01	471041	1221650	140	573.5	NP	140	NP	55	-70	-94	-154	-227	-282	-330
20N/04E-34N01	471015	1221720	330	347	330	303	NP	75	40	15	--	--	--	--
20N/04E-35A02	471100	1221515	70	116	NP	NP	70	44	-24	--	--	--	--	--
20N/04E-35B01	471053	1221521	80	22	NP	NP	80	--	--	--	--	--	--	--
20N/04E-35D01	471102	1221600	65	61	NP	NP	65	-3	-60	--	--	--	--	--
20N/04E-35E01	471049	1221603	65	46	NP	NP	65	--	--	--	--	--	--	--
20N/04E-35J06	471029	1221500	260	250	NP	260	185	170	15	--	--	--	--	--
20N/04E-35M01	471034	1221559	280	296.5	280	263	213	146	11	--	--	--	--	--
20N/04E-35M02	471034	1221559	280	341	280	263	198	146	10	--	--	--	--	--
20N/04E-35R02	471020	1221506	280	220	NP	280	213	173	75	--		--	--	--

Table 15.--*Altitude of top of hydrogeologic units in wells in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Latitude	Longitude	Land surface altitude (feet)	Hole depth (feet)	Altitude of top of hydrogeologic unit, in feet									
					Qvr	Qvt	Qcl	Qfl	Qc2	Qf2	Qc3	Qf3	Qc4	Qf4
20N/04E-35R03	471020	1221511	310	23.5	NP	310	--	--	--	--	--	--	--	--
20N/04E-35R04	471018	1221518	370	30	NP	370	--	--	--	--	--	--	--	--
20N/04E-36A01	471052	1221342	75	100	NP	NP	NP	75	-20	--	--	--	--	--
20N/04E-36H03	471048	1221342	75	86.5	NP	NP	NP	75	5	--	--	--	--	--
20N/04E-36H04	471037	1221346	75	140	NP	NP	NP	75	-5	--	--	--	--	--
20N/04E-36R02	471024	1221342	85	82	NP	NP	NP	85	45	--	--	--	--	--
20N/05E-31H02	471046	1221237	60	96	NP	NP	NP	60	-15	--	--	--	--	--
20N/05E-31H03	471047	1221231	80	135	NP	NP	NP	80	-35	--	--	--	--	--
21N/02E-23A01	471759	1223032	113.99	103.5	113.99	88.99	48.99	--	--	--	--	--	--	--
21N/02E-23A02	471756	1223025	55.95	70	NP	55.95	-3.05	--	--	--	--	--	--	--
21N/02E-23G01	471746	1223041	145	423	145	135	42	-48	-84	-172	--	--	--	--
21N/02E-23H03	471749	1223027	144.86	160.5	144.86	120.86	14.86	--	--	--	--	--	--	--
21N/02E-24D01	471759	1223012	24.97	55	NP	24.97	-8.03	-29.03	--	--	--	--	--	--
21N/02E-24E01	471752	1223001	22.88	46.5	NP	22.88	-9.12	-17.12	--	--	--	--	--	--
21N/02E-34N02	471541	1223243	10	432	NP	NP	10	-2	-62	-106	-205	-271	-391	--
21N/03E-31M01	471549	1222843	345	920	NP	345	275	202	51	-28			--	--
21N/03E-32K01	471546	1222656	280	81	NP	280	268	--	--	--	--	--	--	--

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington*

EXPLANATION

Land surface altitude: In feet above sea level. Most altitudes were determined from topographic maps (scale 1:24,000 with 10- or 20-foot contour intervals) and are generally accurate to within half of the contour interval, 5 or 10 feet, respectively. In steep terrain or where the precise location of the well is in doubt, the error may be as great as 50 feet. Some wells (<10 percent) have been surveyed and have land surface altitudes accurate to within 1 foot.

Tag number: Washington Department of Ecology identification tag.

Latitude and Longitude: Most well locations are believed to be accurate to within 1 second of latitude and longitude. The least accurate locations are probably within 10 seconds of latitude and longitude.

Well depth: Feet below land surface.

Water use: Primary water use: A, air conditioning; B, bottling; C, commercial; D, de-water; H, domestic; J, industrial cooling; I, irrigation; N, industrial; P, public supply; Q, aquaculture; S, stock; U, unused; Z, other; --, no data.

Hydrogeologic unit: Hydrogeologic unit tapped by well: MLT, well taps multiple units; --, unit tapped not determined.

Water level: Feet below land surface. Minus sign indicates water level above land surface. Water levels measured with steel tape are accurate to nearest 0.01 foot; with electric tape accurate to nearest 0.1 foot; *, reported water levels; D, dry; F, flowing; P, pumping; R, recently pumped; S, nearby well pumping; T, nearby well recently pumped; --, no data.

Date: Date water level measured. In some cases, only incomplete dates are available.

Hydraulic conductivity: Feet per day; [a], duration of pumping unknown, assumed pumping time of 1 hour for calculation of hydraulic conductivity.

Remarks: D, driller's log available; G, geologist's log available; X, used in constructing hydrogeologic section; W, project observation well for water level and where available specific conductance; I, sampled for major ions, bacteria, arsenic, and nitrate; M, sampled for MBAS detergents and boron; T, sampled for trace elements; V, sampled for volatile organic carbons; P, sampled for pesticides; R, sampled for radon; C, sampled for organic carbon.

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
19N/03E-01A01	ACA800	471007	1222136	460	291	P	Qc2	P	06-26-95	28	D
19N/03E-01C01		471009	1222201	430	184	H	Qc2	173.*	09-10-53	1,700	D
19N/03E-01C02	ACA601	470959	1222200	445	192	H	Qc2	181.36	05-11-95	1,900	D
19N/03E-01E01	ACA797	470958	1222230	473.8	282	P	Qc2	210.5*	03-21-51	25	D,X,I,R,C
19N/03E-01G02	ACA796	470944	1222146	450	236	P	Qc2	198.10	06-29-95	150	D,X,W
19N/03E-01J01		470941	1222137	475	230	U	Qc2	193.1*	05-10-50	96	D,X
19N/03E-03B01		471000	1222420	430	294	P	MLT	181.*	04-14-70	--	D
19N/03E-03B02		471010	1222421	425	427	U	Qc3	202.22	07-25-95	9.6	D,W
19N/03E-03F02		470949	1222445	405	383	P	Qc3	158.65*	03-13-85	99	D,X
19N/03E-03F04		470951	1222447	405	370	P	Qc3	194.93 S	05-15-95	310	D,X
19N/03E-03G01		470959	1222420	430	415	U	MLT	191.71 S	05-15-95	--	D
19N/03E-03G02		470955	1222423	430	422	U	Qc2	183.*	01-01-58	33[a]	D,X
19N/03E-10P02		470838	1222444	380	13	U	Qvt	1.79	05-09-95	--	
19N/03E-11G03	ABS617	470852	1222306	420	238	P	MLT	169.05	07-29-95	--	D,W
19N/03E-11Q01	ACA604	470833	1222302	415	237	H	Qc2	157.31	05-09-95	--	D,I,R,C
19N/03E-13R01	ACA851	470733	1222127	455	161	H	Qc1	148.65	05-02-95	306	D
19N/03E-25C01	ACA883	470629	1222212	350	51	H	Qvt	18.68 S	06-08-95	23	D
19N/04E-01A01		471006	1221344	90	96	U	Qc2	--	--	260	D
19N/04E-01D01S		471011	1221457	320	--	U	Qvr	--	--	--	
19N/04E-01H01	ACA511	470949	1221344	95	197	H	Qc2	13.90	05-09-95	--	D
19N/04E-01J01[1]		470930	1221348	105	100	I	Qc2	11.*	06-10-51	186	
19N/04E-01Q01	ACA509	470925	1221403	110	104	I	Qc2	23.22	05-09-95	420.[a]	D,X
19N/04E-02F01	ACA505	470955	1221542	410	623	P	Qc3	322.5	07-05-95	100	D,I,R,C
19N/04E-02J01		470931	1221500	500	425	U	Qc2	387.*	04-29-59	41	D,X
19N/04E-03A01D1	ACA528	471008	1221628	445	740	P	MLT	400.00	08-25-95	--	D,X
19N/04E-03K02		470938	1221650	460	33	U	Qvr	24.72	07-24-95	--	G,W
19N/04E-03K03		470937	1221648	460	45	U	Qvr	28.89	07-24-95	--	G,W
19N/04E-03K04		470939	1221651	450	35	U	Qvr	27.04	07-24-95	--	G,W
19N/04E-03Q01		470930	1221637	500	42.3	U	Qvt	32.85	07-24-95	--	G,X,W
19N/04E-03R01D2		470919	1221632	530	612	P	Qc3	409.*	02-24-81	120	D,X,I,M,T,R,C
19N/04E-04L01	ACA985	470935	1221819	355	240	U	Qc2	238.40	06-04-85	41	D
19N/04E-04L02	ACA895	470934	1221819	355	264	P	Qc2	219.*	10-15-64	1,600	D,I
19N/04E-04Q01		470928	1221805	410	327	U	Qc2	264.*	11-----58	1,800	D
19N/04E-05P02	ABR143	470922	1221945	435	258	P	Qc2	223.64	06-20-95	12,000	D,X
19N/04E-06J02	ACA512	470934	1222011	440	207	P	Qc2	176.65	05-04-95	53	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
19N/04E-06K01[1]		470941	1222040	480	203	H	Qc2	168.*	04-30-63	300	
19N/04E-06N01		470929	1222109	420	22.8	U	Qvt	1.48	02-28-40	--	
19N/04E-07A01		470911	1222010	415	36.6	U	Qvt	19.70	05-10-60	--	D
19N/04E-07D01	ACA798	470912	1222105	450	326	P	Qc2	195.*	04-29-55	--	D
19N/04E-07D02	ACA795	470912	1222103	450	220	P	Qc2	194.67*	08-22-66	--	D
19N/04E-07F01D1	ACA794	470901	1222057	460	602	P	Qc4	271.15	06-30-95	--	D
19N/04E-07F02		470900	1222100	455	239.58	U	Qc1	210.*	02-01-88	19	D
19N/04E-07N01		470826	1222118	475	12.9	U	Qvt	2.69*	02-29-40	--	D
19N/04E-08A01		470911	1221859	346.29	297	P	Qc2	219.*	07-20-95	2,200.[a]	D,X
19N/04E-08A02[1]		470912	1221858	349	315	U	Qc2	222	03-07-63	2,700	
19N/04E-08A06		470909	1221851	366.5	353.3	P	Qc2	225.5*	07-02-65	300	D,X
19N/04E-08D01	ACA506	470913	1221958	420	258	H	Qc2	178.*	06-15-81	24	D,X
19N/04E-08K01	ACA894	470849	1221915	440	340	P	Qc2	272.14	06-20-95	--	G
19N/04E-08P01		470837	1221937	460	17.7	U	Qvt	1.8*	05-09-60	--	
19N/04E-09B01	ABS168	470914	1221808	410	324	U	Qc2	273.93	06-20-95	8,500.[a]	D,W
19N/04E-09B02	ABS167	470914	1221807	410	316	P	Qc2	273.38 R	06-20-95	8,700	D,W
19N/04E-09B03	AAT387	470914	1221808	410	350	P	Qc2	273.63	06-20-95	8,100	D,X,W
19N/04E-10A01		470905	1221619	570	271	H	Qc1	235.*	05-16-77	610	D,X
19N/04E-11D01	ACA527	470903	1221600	450	119.5	H	Qc1	88.28	05-12-95	--	D,X,I,M,P
19N/04E-11D02	ACA501	470905	1221613	560	280	H	Qc1	205.81	05-03-95	--	D,X,W
19N/04E-11K02		470850	1221529	515	46	U	Qvt	26.09	05-18-95	--	
19N/04E-12A02	ACA502	470911	1221342	110	76	I	Qc2	12.*	06-24-74	1,800	D
19N/04E-12B01		470906	1221404	110	54	I	Qc2	18.*	08-21-75	152	D
19N/04E-12H02	ACA504	470902	1221358	110	140.5	I	Qc2	12.*	05-12-88	--	D
19N/04E-12H03		470859	1221355	110	124	I	Qc2	14.*	12-27-51	76	D
19N/04E-12J01[1]		470848	1221355	110	85	I	Qc2	19.9	05-16-60	1,500	
19N/04E-12J02		470845	1221353	110	125	I	Qc2	18.*	05-16-60	--	D
19N/04E-12N01S		470834	1221442	300	--	U	Qvr	--	--	--	I,M,T,V,P
19N/04E-12Q01		470832	1221401	120	--	H	--	--	--	--	
19N/04E-12R02		470825	1221345	120	77	I	Qc2	17.65	05-08-95	--	D
19N/04E-13B01		470818	1221412	120	117	I	Qc2	21.11	05-09-95	44	D
19N/04E-13D01S		470820	1221443	295	--	U	--	--	--	--	
19N/04E-13G01	ACA531	470802	1221401	115	80	H	Qc2	11.15	05-18-95	49	D
19N/04E-13K02		470755	1221406	120	14	U	Qc1	6.58	05-16-60	--	D
19N/04E-14M01		470749	1221612	530	11.1	U	Qvr	3.92	05-25-95	--	W

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
19N/04E-14P01		470742	1221550	550	22	S	Qvr	1.59	05-10-95	--	D,X,W,I,M,T,V,P
19N/04E-15F01		470801	1221700	510	71	U	Qc1	54.*	09-28-78	92	D
19N/04E-15J02	ACA526	470755	1221625	530	--	I	Qc2	288.6	05-18-95	--	
19N/04E-16E01	ACA874	470800	1221842	450	300	H	Qc2	267.56	06-01-95	300	D,X
19N/04E-16E02D2	ACA869	470805	1221843	450	440	P	Qc3	295.*	03-12-86	75	D,X
19N/04E-16G03	ACA508	470806	1221757	460	400	I	Qc2	291.99	05-10-95	--	D,I,R,C
19N/04E-17K01		470752	1221910	480	374	P	Qc3	268.*	04-17-84	460	D,X
19N/04E-17N01	ACA868	470737	1222001	355	155	P	Qc1	112.5 P	05-17-95	78	D
19N/04E-19A01D1	ACA852	470731	1222017	485	210	Z	Qvt	202.07	05-03-95	--	D
19N/04E-19D01	ACA855	470730	1222120	445	9.7	U	Qvt	1.65*	02-26-40	--	D
19N/04E-19N01		470642	1222115	410	90	U	Qvt	74.09	05-05-95	200	D
19N/04E-19R01		470648	1222021	430	198	U	Qc1	141.59*	05-09-60	--	
19N/04E-20A02[1]		470732	1221853	453	256	H	Qc2	--	--	30	
19N/04E-20E02[1]		470713	1221955	350	117	H	Qc1	75.*	01-26-80	92	
19N/04E-20F02	ACA856	470719	1221932	395	139.5	H	Qc1	109.26	05-05-95	--	D,X
19N/04E-20K03	ACA872	470705	1221921	465	193	H	Qc1	182.77 R	05-05-95	--	D,X,I,M
19N/04E-20M01	ACA854	470705	1221957	355	124	H	Qc1	60.09	05-04-95	230	D
19N/04E-20Q01D1	ACA858	470651	1221925	400	320	P	Qc3	88.71 R	05-10-95	520	D,X,I,M
19N/04E-20R04	ACA865	470646	1221905	460	246	P	Qc2	136.4	05-17-95	270	D,X
19N/04E-20R05	ACA866	470646	1221905	465	251	P	Qc2	145.00	05-17-95	27	D,X
19N/04E-21D01	ACA853	470730	1221835	450	231	H	Qc2	196.79	05-03-95	76	D
19N/04E-21K01	ACA857	470705	1221752	480	11.3	U	Qvr	5.30	05-09-95	--	W
19N/04E-22D01	ACA875	470732	1221722	465	236	U	MLT	157.76 S	05-17-95	--	D
19N/04E-22D02	ACA876	470731	1221722	465	455	P	Qf2	225.*	03-10-63	124	D
19N/04E-23C01		470729	1221551	555	388	U	Qc2	319.9*	05-09-60	--	
19N/04E-25K01S		470602	1221421	400	--	H	Qc1	--	--	--	
19N/04E-25K02	AAC965	470610	1221408	155	97	H	Qc2	1.33	06-13-95	--	D,X
19N/04E-25Q01S	ACA886	470551	1221418	450	--	H	Qvr	--	--	--	
19N/04E-26C01		470627	1221555	585	307	H	Qc2	264.*	10-15-77	3.7	D,X
19N/04E-26G01	ACA861	470617	1221520	605	369	H	Qc2	344.00	05-12-95	--	D,X,W,I,R,C
19N/04E-27A01	ACA864	470629	1221630	585	225	P	Qc1	184.31 S	05-17-95	220	D,X,W,I
19N/04E-27B01		470634	1221647	570	9	U	Qvr	2.41	05-02-60	--	D,X
19N/04E-27M01	ACA862	470612	1221720	535	200	U	Qf1	138.59	05-15-95	--	
19N/04E-27N01		470556	1221725	530	348	U	Qc2	165.*	10-05-71	--	D
19N/04E-28B01		470638	1221752	510	670	P	Qc3	246.0	05-17-95	16	D,X

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
19N/04E-29D02	ACA882	470629	1221949	360	91	P	Qc1	28.02	06-08-95	1,200	D
19N/04E-29D06	ACA867	470638	1221949	340	137	P	Qc1	22.79*	08-27-90	330	D
19N/04E-29E02	ACA881	470622	1221958	350	76	P	Qc1	19.75	06-08-95	29	D
19N/04E-29E10D1	ACA859	470619	1221956	400	79	H	Qc1	41.90	05-11-95	--	D
19N/04E-29J01	ABM191	470609	1221855	510	199	P	Qc1	143.08	05-15-95	92	D,X
19N/04E-29K02	ACA880	470612	1221918	485	180	H	Qc1	138.26	06-08-95	--	D,X,W
19N/04E-29L03	ACA879	470609	1221940	490	198	S	Qc1	139.84	06-08-95	--	D,X
19N/04E-29M02	ACA860	470606	1221957	470	158	H	Qc1	107.60	05-11-95	--	D,X
19N/04E-29R03	ACA873	470551	1221905	490	149	H	Qc1	121.65 R	05-24-95	300	D,X,W
19N/04E-30A02	ACA871	470626	1222017	380	80	H	Qc1	46.45	05-23-95	15	D
19N/04E-30A03	ACA878	470628	1222009	355	40	H	Qc1	19.17	06-06-95	41	D
19N/04E-30D03		470633	1222119	385	80	U	Qc1	55.*	03-27-81	250	D
19N/04E-30D04D1		470633	1222121	385	98	H	Qc1	56.14	05-23-95	--	
19N/04E-30F03	ACA863	470616	1222046	340	118	C	Qc1	11.69	05-23-95	4,200	D
19N/04E-30H01S		470622	1222016	340	--	U	Qvr	--	--	--	
19N/04E-30Q03	ACA870	470552	1222030	465	160	H	Qc1	99.99	05-24-95	--	D,X
19N/04E-31C03	ACA877	470545	1222100	460	140	U	Qc1	110.5	06-06-95	77	D,X
19N/04E-35Q01S[2]		470500	1221529	545	--	U	Qvr	--	--	--	
19N/04E-36R01S[2]		470508	1221356	--	--	--	--	--	--	--	
19N/05E-06A01	ACA503	470958	1221232	90	94	H	Qc2	11.52	05-11-95	--	D
19N/05E-06C02	ACA526	471010	1221317	85	240.5	P	Qc2	10.63	06-08-95	300	D,I,M,R,C
19N/05E-06E01	ACA532	470950	1221329	95	143	I	Qc2	11.*	12-17-46	--	D
19N/05E-06E02		470946	1221337	100	151	I	Qc2	15.92*	07-11-60	660	D
19N/05E-06F01		470946	1221322	95	173	I	Qc2	13.*	01-01-32	--	D
19N/05E-06M04	ACA510	470937	1221329	100	111	U	Qc2	18.38	05-12-95	120	D
19N/05E-06N02	ABB503	470924	1221337	105	99	H	Qc2	18.28 S	05-11-95	--	D,X,I,M
19N/05E-07D02[1]		470909	1221335	110	101	I	Qc2	16.2	07-11-60	1,200	
19N/05E-07L02		470849	1221310	100	82	H	Qc1	15.*	04-06-92	--	D
19N/05E-18M01	ACA507	470748	1221339	125	96	I	Qc2	15.*	03-13-84	1,500	D
19N/05E-18N01		470743	1221330	130	80	U	Qc2	9.50	05-08-95	--	
19N/05E-30N01	ACA884	470555	1221341	165	93	I	Qc2	8.48	06-09-95	1,700.[a]	D,X
19N/05E-30P01		470554	1221319	170	78	U	Qc2	4.*	12-17-52	580.[a]	D,X
19N/05E-30P02	ABK109	470549	1221316	170	79	H	Qc2	2.09	06-12-95	--	D
20N/02E-01A01		471518	1222857	390	34.6	U	Qvr	33.62*	01-25-95	--	G
20N/02E-02M01	ACA530	471448	1223118	310	304.25	Z	Qc1	141.42	05-14-95	180	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
20N/02E-02M02	ACA529	471448	1223120	323	195.25	Z	Qc1	115.1	06-14-95	--	D
20N/02E-12H01		471417	1222904	400	218	U	Qc1	172.*	--------40	--	D
20N/02E-12M01		471359	1222956	283.96	75	U	Qc1	67.94*	05-04-95	--	G,W
20N/02E-12M02		471359	1222956	284.45	105	U	Qc1	67.04*	05-04-95	--	G,W
20N/02E-12Q01		471353	1222931	326.88	113	U	Qc1	110.19	09-08-95	--	G,W
20N/03E-03L01		471451	1222440	10	527	J	Qc5	-11. F	04-01-60	680	D
20N/03E-04M01		471455	1222622	140	25	U	Qvt	8.*	10-05-93	--	D
20N/03E-04P01		471434	1222558	15	385	U	MLT	F	06-09-60	--	
20N/03E-05C01		471524	1222706	345	24	U	Qvt	--	--	--	G
20N/03E-06M01		471459	1222855	360.11	30	U	Qvr	21.76*	07-13-94	--	G
20N/03E-06M02		471500	1222855	360	30	U	Qvr	D	01-06-94	--	G
20N/03E-06N01		471441	1222855	360	291	U	Qc2	156.84	07-18-95	230	D,W
20N/03E-07F01	ACA890	471420	1222830	330	160	I	Qc1	99.38	06-15-95	130	D,W,I,M,T,V,P
20N/03E-07G01	ACA899	471420	1222813	350	169	I	Qc1	140.00	03-22-60	670	D
20N/03E-07N02		471351	1222847	250	200	U	Qc2	17.*	01-----40	--	D
20N/03E-07Q01		471354	1222809	270	141	J	Qc2	100.*	10-22-34	87	D
20N/03E-08J01S		471359	1222630	180	--	U	Qc1	--	--	--	
20N/03E-08K03		471357	1222649	240	38	U	Qc1	33.*	09-26-92	--	G
20N/03E-09A03	ACA892	471421	1222513	10	248	N	Qc3	1.0 P	06-16-95	250	D,I,R,C
20N/03E-09C02		471428	1222557	40	301	U	Qc2	F	04-----59	14.[a]	D
20N/03E-09D03	ACA893	471428	1222615	110	652	U	Qc3	54.*	05-01-60	31	D
20N/03E-09D04[1]		471425	1222621	105.95	540	B	Qc3	65.*	03-15-60	44	
20N/03E-09E03		471417	1222615	150	259	J	Qc1	78.83	10-08-85	--	D
20N/03E-09E04[1]		471413	1222610	125	710	N	Qc1	112	03-15-60	68	
20N/03E-09F01		471419	1222554	60	618	U	Qc3	F	05-30-85	110	D
20N/03E-09M01S		471358	1222624	180	--	U	Qc1	--	--	--	
20N/03E-09N01S		471347	1222624	175	--	U	Qc1	--	--	--	
20N/03E-09P01S		471347	1222549	165	--	U	--	--	--	--	
20N/03E-09Q01S		471344	1222539	225	--	U	Qc1	--	--	--	
20N/03E-10G01		471419	1222430	40	30	Z	Qc1	12.*	02-23-94	--	G
20N/03E-11K01	ACA887	471400	1222310	15	97	P	Qc2	7.68	06-14-95	130	D
20N/03E-11P02		471343	1222327	25	41	U	Qc2	4.70	05-22-85	20	D
20N/03E-11P04		471341	1222322	25	88	H	Qc2	F	05-22-85	18	D
20N/03E-11P05	ACA885	471343	1222329	35	25	H	Qc1	9.47	06-13-95	--	I,M,T,V,P
20N/03E-11Q02	ACA792	471351	1222309	10	315	P	Qc4	F	07-07-95	61	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
20N/03E-11Q03	ACA896	471349	1222305	30	491	P	Qc4	3.29 R	06-27-95	110	D
20N/03E-13C02	ACA891	471337	1222215	12	153	H	Qc2	0.42	05-16-95	38	D
20N/03E-13D02		471329	1222219	10	105	H	Qc2	4.81	07-04-95	--	D
20N/03E-13H05	ACA888	471321	1222137	20	78	H	Qc2	1.86	06-14-95	--	D
20N/03E-13M01[1]		471307	1222222	30	275	Q	Qc3	--	--	21	
20N/03E-14A01		471340	1222245	15	80	H	--	--	--	--	
20N/03E-14A02		471339	1222248	18	24.4	U	Qc2	3.1	01-23-84	--	D
20N/03E-14B01	ACA897	471330	1222303	185	145	H	Qc1	103.58	06-27-95	--	D,W
20N/03E-14C02		471340	1222329	20	38	H	Qc2	--	--	--	D
20N/03E-14F01	ACH549	471322	1222328	200	133	U	Qc1	117.*	06-25-82	77	D
20N/03E-14G01		471325	1222255	100	73	U	Qc1	18.60	07-07-95	10	D
20N/03E-14H01S		471320	1222252	90	--	P	Qc1	--	--	--	I,M,T,V,P
20N/03E-14R01		471258	1222239	250	226	H	Qc2	172.15	06-14-95	--	D
20N/03E-15F01		471326	1222434	247.5	653	P	MLT	183.0*	07-20-95	--	D
20N/03E-17G01		471325	1222656	370	55	U	Qvt	37.61	07-05-95	--	G,W
20N/03E-20K01		471222	1222702	350	17.5	U	Qvt	D	06-29-88	--	G
20N/03E-20P01	ATT712	471159	1222714	315	117	U	Qc1	89.98*	06-30-95	--	G,W,I,M,T,V,P,R,C
20N/03E-20P02		471159	1222714	315	254	U	Qc2	119.33*	06-30-95	--	G,W,I,R,C
20N/03E-21C01		471241	1222553	355	235	I	Qc2	152.06 T	06-02-95	19	D
20N/03E-22B01		471238	1222421	320	94	U	Qvr	100.*	04-25-40	--	
20N/03E-23D01S		471245	1222336	225	--	U	Qvr	--	--	--	
20N/03E-23H01	ACA613	471227	1222251	380	254	U	Qc2	219.73	06-29-95	7.1	D
20N/03E-24A01		471238	1222135	25	59	H	Qc1	12.2*	04-24-92	--	D
20N/03E-24B01S		471246	1222157	170	--	H	Qc1	--	--	--	I,M,T,V,P
20N/03E-24B03S		471247	1222156	170	--	U	Qc1	--	--	--	
20N/03E-24J01S		471221	1222133	160	--	U	Qc1	--	--	--	
20N/03E-25A01S		471153	1222128	160	--	U	Qc1	--	--	--	
20N/03E-25C01	ACA900	471144	1222218	360	214	P	Qc2	162.96*	03-23-60	850.[a]	D
20N/03E-25C02	ACA799	471145	1222218	360	267	P	Qc2	159.5*	09-26-60	9.7	D
20N/03E-25N01D1		471106	1222222	430	258	H	Qc2	--	--	--	I
20N/03E-26H01		471134	1222249	425	188	S	Qc1	185.*	--------40	--	
20N/03E-26K01		471128	1222315	410	28	U	Qvt	18.19	05-30-95	--	D
20N/03E-28F02		471131	1222556	400	35	U	Qvt	24.18*	01-17-95	--	G
20N/03E-28J01		471133	1222508	420	35	U	Qvt	31.65	05-31-95	--	G
20N/03E-30R01		471107	1222802	300	30	U	MLT	22.80	06-02-95	--	G,X

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
20N/03E-31A01		471055	1222756	300	18	H	Qvr	15.5*	10-04-40	--	D
20N/03E-32D01		471053	1222738	300	15.7	U	Qvr	8.29*	04-22-40	--	D,X
20N/03E-32D02		471100	1222734	300	80	H	Qc1	50.2*	01-24-40	--	
20N/03E-32D04		471103	1222738	300	114	U	Qc1	75.*	12-01-40	--	D
20N/03E-34E01		471049	1222453	415	19.8	U	Qvt	4.34	06-06-95	--	W
20N/03E-34L01		471034	1222447	415	396	P	Qc1	165.*	02-28-51	3,600.[a]	D,X
20N/03E-34L02		471034	1222449	415	215	P	Qc1	184.93 P	05-15-95	2,500	D,X
20N/03E-34N01		471022	1222509	385	223	H	Qc2	156.25 P	05-31-95	23	D
20N/03E-35C01		471102	1222331	410	315.6	P	Qc2	--	--	--	G
20N/03E-35F01		471050	1222333	405	18	U	Qvt	2.04	05-30-95	--	D,X
20N/03E-35F02		471049	1222329	410	288	H	Qc2	206.21	05-30-95	--	
20N/03E-35L01		471027	1222324	420	187	H	Qc1	170.*	09-01-53	--	D
20N/03E-35L02		471025	1222327	410	16	S	Qvt	6.14	05-30-95	--	W
20N/03E-35R01		471013	1222242	450	315	U	MLT	164.*	10-01-52	--	D
20N/03E-36D01		471103	1222236	415	34.2	U	Qvt	3.41	03-11-60	--	
20N/03E-36F01		471050	1222202	390	372	U	Qc2	--	--	4.8[a]	D,X
20N/03E-36P01	ABS150	471021	1222206	428	210	P	Qc2	P	06-26-95	2,400	D
20N/04E-18M01		471313	1222111	10	253	H	--	5.*	03-21-60	--	
20N/04E-18M03		471303	1222114	15	156	U	Qc2	0.*	09-23-82	11	D
20N/04E-18Q01D2		471250	1222034	20	328.33	U	Qc3	-2.42 F	08-05-87	550	D
20N/04E-19B01		471248	1222029	20	97	H	Qc2	63.90 R	05-15-95	--	
20N/04E-19G01	ACA617	471225	1222030	25	58	I	Qc1	5.*	02-23-79	14	D,I,M,T,V,P
20N/04E-19K01	ACA610	471215	1222035	20	818	Z	--	-5.08 F	09-09-88	70	D
20N/04E-19K02		471216	1222036	20	915	U	--	F	09-25-90	34	D
20N/04E-19Q01		471202	1222043	25	118	H	Qc2	F	06-06-95	--	D
20N/04E-20D04D1		471236	1222009	30	390	P	Qc3	-0.88 F	03-21-96	24	D
20N/04E-20D06		471237	1222009	30	298	P	Qc3	-4.00 F	03-21-96	--	D
20N/04E-20E04		471234	1221954	30	56	P	Qf1	15.*	05-19-83	--	D,X
20N/04E-20E06	AAC903	471225	1221948	25	115	S	Qc2	7.40	05-18-95	--	D,X,I,M,V
20N/04E-20K01		471211	1221925	25	267	--	Qc3	F	03-24-53	--	D
20N/04E-20N01	ACA624	471201	1222003	30	90	H	Qc2	-0.8 F	06-29-95	540	I,M
20N/04E-20N05		471203	1221956	30	184	P	Qf2	F	05-04-84	58	D,X
20N/04E-20P02		471204	1221929	25	92	U	Qc2	5.70	06-06-95	18	D,W
20N/04E-21A01		471244	1221739	40	40	D	--	--	--	--	D
20N/04E-21P01		471204	1221821	30	230	U	Qc3	F	04-12-60	--	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
20N/04E-25N01		471107	1221454	70	113	H	Qc2	7.69	06-08-95	250	D
20N/04E-25P01		471106	1221429	70	92	U	Qc2	8.*	04-24-53	170	D,X
20N/04E-25Q01	ACA626	471112	1221417	60	105	I	Qc2	F	07-01-95	170	D,X
20N/04E-26E01		471133	1221605	45	169	I	Qc2	F	05-16-85	2,000	D
20N/04E-26M01		471130	1221604	40	20	U	Qc1	6.97*	03-20-95	--	G
20N/04E-26M02		471130	1221605	40	20	U	Qc1	7.35*	03-20-95	--	G
20N/04E-26Q01	ACA609	471116	1221526	65	118	H	Qc2	4.53	06-17-95	300	D
20N/04E-27H01		471133	1221619	40	190	I	Qc3	F	06-07-95	620	D,X
20N/04E-27J01		471124	1221623	55	233	N	Qc3	F	06-07-95	210	D,X
20N/04E-27L01		471127	1221711	45	285	U	Qc3	F	06-29-95	64[a]	D
20N/04E-27Q01		471106	1221636	55	328	C	Qc3	-11.2 F	03-14-53	--	
20N/04E-28E01		471137	1221833	40	82	U	Qf1	9.*	10-01-41	--	D
20N/04E-28H01		471137	1221749	40	200	U	Qf2	F	04-11-60	--	
20N/04E-28H04		471131	1221739	40	253	N	Qc3	F	04-08-60	--	D
20N/04E-28H05		471143	1221734	40	20	U	Qc1	--	--	--	G
20N/04E-28H06		471131	1221741	40	252	U	Qc3	--	--	350	D
20N/04E-29D03		471148	1221949	30	362	P	--	F	06-09-95	2,000	D,X
20N/04E-29F01		471140	1221930	30	265	U	--	F	03-28-46	130	D
20N/04E-29P03	ACA614	471116	1221931	50	119	H	Qc2	-0.02 F	06-09-95	12	D
20N/04E-30C02	ACA605	471150	1222049	50	115	H	Qc2	9.91	06-20-95	55	D
20N/04E-30C03		471154	1222049	30	40	H	Qc1	4.*	07-30-82	--	D
20N/04E-30F01		471135	1222046	230	195	H	Qc2	145.69	06-13-95	--	D
20N/04E-30G02		471141	1222032	60	78.5	H	Qc1	9.05	06-14-95	--	D,I,M,T,V,P
20N/04E-30H01		471132	1222009	40	332	Q	--	F	03-26-95	57	D
20N/04E-30J01[1]		471125	1222017	160	95	H	Qc1	62.6	03-23-60	51	
20N/04E-30L02		471128	1222046	320	270	U	Qc3	228.32	10-08-85	150	D
20N/04E-30L03S		471129	1222059	230	--	H	Qc1	--	--	--	
20N/04E-30P02	ACA618	471104	1222048	390	450	P	Qc3	275.50 P	06-09-95	7.3	D,W
20N/04E-31B01		471054	1222038	380	56	H	Qvt	34.50	05-22-95	--	W,I,M
20N/04E-31F02	ACA608	471042	1222057	400	180	H	Qf1	125.00	05-23-95	10	D,X,I,M
20N/04E-31G01	ACA620	471050	1222030	350	126	H	Qc1	69.29	04-07-60	13.[a]	D
20N/04E-31H05	ACA603	471039	1222017	380	192	H	Qc1	139.56	06-17-95	28	D,X
20N/04E-32E01		471045	1221954	265	16.5	H	Qvr	5.29	04-08-60	--	D
20N/04E-32E02		471043	1221955	270	295	H	Qc3	178.40	05-23-95	4.1	D,X
20N/04E-32H01		471038	1221851	31.7	170	U	Qc2	F	12-20-56	140	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
20N/04E-32H02	ACA513	471039	1221851	30	162	P	Qc2	107.48 P	08-25-95	--	G,X
20N/04E-32J01S		471029	1221859	50	--	P	Qc1	--	--	--	I,M,T,V,P,R,C
20N/04E-32J02		471039	1221852	30	166	U	Qc2	F	05-28-95	--	D,X
20N/04E-32R02	ACA521	471015	1221851	300	287	P	Qc2	227.18	05-25-95	2,800	D,I
20N/04E-33A01		471055	1221733	40	341	S	Qc4	-5.08 F	02-03-84	--	D,X,I,M
20N/04E-34B01		471053	1221640	55	42	U	Qc1	2.56	06-29-95	140	D,X
20N/04E-34C01		471054	1221711	45	264	U	Qc3	F	03-26-53	--	D,X
20N/04E-34E01		471048	1221731	50	43	I	Qc1	2.81	04-11-60	55	D
20N/04E-34G01	ACA533	471041	1221650	140	573.5	P	--	56.17	07-05-95	100	G,W
20N/04E-34N01		471015	1221720	330	347	H	--	53.00	05-31-95	--	D
20N/04E-34N02S		471014	1221720	330	--	U	Qvr	--	--	--	
20N/04E-34Q01S		471014	1221638	385	--	U	Qvr	--	--	--	
20N/04E-35A02	ACA611	471100	1221515	70	116	H	Qc2	5.20	05-25-95	32.2	D,X
20N/04E-35B01		471053	1221521	80	22	I	Qc1	8.*	10-09-52	--	D
20N/04E-35D01		471102	1221600	65	161	I	Qc1	5.42	05-17-85	--	D,X
20N/04E-35E01		471049	1221603	65	46	I	Qc1	2.90	05-31-95	780.[a]	D,X,W
20N/04E-35J02[1]		471025	1221513	205	195	H	Qc2	100	04-12-60	7.7	
20N/04E-35J06		471029	1221500	260	250	H	Qc2	150.*	05-30-79	120	D
20N/04E-35M01		471034	1221559	280	296.5	U	Qc2	200.*	05-01-89	--	D
20N/04E-35M02	ACA621	471034	1221559	280	341	H	Qc2	257.09	06-14-95	--	D,X
20N/04E-35R02		471020	1221506	280	218	H	Qc2	100.*	05-07-79	610	D
20N/04E-35R03		471020	1221511	310	23	U	Qvt	5.78	06-15-95	--	G
20N/04E-35R04		471018	1221518	370	27.4	U	Qvt	D	12-----82	--	G
20N/04E-36A01	ACA898	471052	1221342	75	100	I	Qc2	8.94	06-28-95	170	D
20N/04E-36B01		471059	1221402	70	15	U	Qf1	--	--	--	
20N/04E-36D03S		471054	1221444	110	--	U	Qc1	--	--	--	
20N/04E-36G01[1]		471047	1221413	80	95	I	Qc2	8.07	04-01-60	200	
20N/04E-36H01[1]		471046	1221350	76	98	H	Qc2	3.22	04-18-69	670	
20N/04E-36H02		471037	1221345	75	78	U	Qc2	7.75	06-30-95	1,400	W,I,M,T,V,P,C
20N/04E-36H03		471048	1221342	75	86.5	I	Qc2	4.92	07-17-96	760	D
20N/04E-36H04	ACA7793	471037	1221346	75	130	I	Qc2	7.32	06-30-95	4,300	D,W
20N/04E-36R02		471024	1221342	85	82	H	Qc2	10.*	08-23-79	430	D
20N/05E-31C01		471051	1221318	80	48	U	Qf1	10.89	07-07-95	--	D
20N/05E-31H02	ABE053	471046	1221237	60	96	I	Qc2	7.99	07-04-95	98	D
20N/05E-31H03	ABE056	471047	1221231	80	135	H	Qc2	8.05	06-20-95	26	D

Appendix 1.--*Physical and hydrologic data for the wells and springs in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Tag number	Latitude	Longitude	Land surface altitude (feet)	Well depth (feet)	Water use	Geo-hydro-logic unit	Water level (feet)	Date	Hydraulic conductivity (feet per day)	Remarks
21N/02E-23A01		471759	1223032	113.99	103.5	U	Qc1	92.98*	09-16-94	--	G
21N/02E-23A02		471756	1223025	55.95	69	U	Qc1	31.39	06-05-91	--	G
21N/02E-23G01		471746	1223041	145	423	U	--	--	--	--	D
21N/02E-23H03		471749	1223027	144.86	158.5	U	Qc1	121.56*	09-16-94	--	G
21N/02E-24D01		471759	1223012	24.97	45	U	Qc1	13.21*	09-18-94	--	G
21N/02E-25B01S		471657	1222938	120	--	U	--	--	--	--	
21N/02E-24E01		471752	1223001	22.88	40	U	Qc1	8.86*	05-15-91	--	G
21N/02E-34E01S		471556	1223230	20	--	U	Qc1	--	--	--	
21N/02E-34F01S		471600	1223218	175	--	U	Qc1	--	--	--	
21N/02E-34F02S		471558	1223215	175	--	U	Qvr	--	--	--	
21N/02E-34F03S		471601	1223215	175	--	U	Qvr	--	--	--	
21N/02E-34M01		471555	1223244	0	240	U	--	--	--	--	G
21N/02E-34N02		471541	1223243	10	428	H	Qc4	4.1*	04-26-62	9.7[a]	D
21N/03E-30M01S		471644	1222841	45	--	U	Qc1	--	--	--	
21N/03E-30M02S		471645	1222839	30	--	U	Qc1	--	--	--	
21N/03E-31M01		471549	1222843	345	925	A	--	307.*	12-01-64	--	D
21N/03E-32K01		471546	1222656	280	80	U	Qc1	--	--	--	G

[1] Wells not inventoried during this project, used for hydraulic conductivity data only.
[2] Spring located outside study area not on figure 3.

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington*
[swl, static water level in feet below land surface; dd, drawdown in feet; gpm, gallons per minute; ft, feet]

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/03E-01E01	Brown clay	4	4	Gaudio	1951
	Blue hardpan	77	81		
	Cemented gravel	82	163		
	Brown fine sand	14	177		
	Gray cemented gravel	23	200		
	Brown sandy clay	15	215		
	Brown sand	1	216		
	Brown sandy clay	17	233		
	Sand and gravel	2	235		
	Clay and gravel	21	256		
	Hard clayey sand and gravel	3	259		
	Loose sand, gravel and water	7	266		
	Gray hardpan	3	269		
	Cemented gravel	16	285		
19N/03E-01G02	Bank run	2	2	Richardson	1985
	Topsoil	1	3		
	Yellow clay, gravel and boulders	21	24		
	Yellow hardpan	79	103		
	Lightly cemented sand, dry	4	107		
	Lightly cemented gravel, sand and cobble, dry	33	140		
	Sand gravel and clay, dry	24	164		
	Clay, sand and gravel	40	204		
	Brown fine-sand and some coarse small gravel, water (10 ft in hole)	1	205		
	Clay, sand and gravel, (water bailing down)	4	209		
	Cemented sand and gravel	8	217		
	Brown clay, streaks of sand and gravel, water	7	224		
	Test bailed at 223 ft-40 gpm with 8 ft dd				
	Hardpan	7	231		
	Brown clay, sand and gravel	3	234		
	Hardpan	1	235		
	Brown clay, sand and gravel	8	243		
	Sandy clay with small gravel	8	251		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/03E-01G02--continued	Clay, sand, gravel, yellow cobble	10	261		
	Yellow hardpan and boulders	21	282		
	Gray hardpan and boulders	36	318		
	Gray-green sticky clay	12	330		
	Gray hardpan	15	345		
	Clay, sand and gray gravel	10	355		
	Clay, sand, yellow gravel, 412 to 416 ft, lots of boulders	76	431		
	Sandy yellow clay	18	449		
	Clay, sand, gravel and boulders	11	460		
	Clay, sand and yellow gravel	9	469		
	Hardpan	4	473		
	Hard clay, sand and brown gravel	20	493		
	Hardpan, boulder at 549 ft	78	571		
	Blue clay with gravel	9	580		
	Blue clay, with sand and gravel	18	598		
	Clay sand and few small gravel with lenses of sticky blue clay	3	601		
	Gritty blue clay and lenses of multi-color clay	18	619		
19N/03E-01J01	Cemented blue gravel	56	56	Gaudio	1950
	Cemented yellow gravel	24	80		
	Cemented yellow gravel, streaks of sand	84	164		
	Sand	3	167		
	Cemented yellow gravel, streaks of sand	34	201		
	Sand and gravel	1	202		
	Cemented gravel	9	211		
	Hard sand and gravel	17	228		
	Gravel and clay	20	248		
	Yellow sandy clay	16	264		
	Yellow clay and coarse gravel	21	285		
	Yellow sandy clay	4	289		
	Yellow-blue cemented gravel	17	306		
	Blue-gray cemented gravel	44	350		
	Hard packed sand and gravel	12	362		
	Yellow cemented clay and gravel	13	375		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/03E-01J01-- continued	Yellow sandy clay	12	387		
	Cemented gravel	20	407		
19N/03E-03F02	Fill	8	8	Armstrong	1985
	Brown claybound sand and gravel	9	17		
	Gray claybound sand and gravel	20	37		
	Blue-gray claybound sand and gravel	59	96		
	Brown claybound sand and gravel	60	156		
	Coarse sand and gravel, some water	25	181		
	Tighter sand and gravel, some water	13	194		
	Brown claybound sand and gravel	10	204		
	Gray to yellow-brown claybound sand and gravel	20	224		
	Sand, gravel and water	5	229		
	Brown claybound sand and gravel, some water 246-280 ft	53	282		
	Sand, gravel and boulders	2	284		
	Gray claybound sand and gravel	30	314		
	Sand, gravel and water	6	320		
	Sand, gravel, boulders and water	5	325		
	Gray claybound sand and gravel, boulders at 350 ft	25	350		
	Gray claybound sand and gravel	6	356		
	Sand, gravel, boulders and water	18	374		
	Gray claybound sand and gravel	13	387		
19N/03E-03F04	Gray clayey fill	8	8	Charon	1993
	Gray clay, sand and gravel	19	27		
	Gravel, sand, silt, some clay	16	43		
	Silty sand and gravel in clay matrix	127	170		
	Brown sand, gravel, cobbles and water	30	200		
	Gray sand and gravel in clay matrix	27	227		
	Sand, gravel and water	1	228		
	Sand, gravel, gray-brown in silt matrix and minor water	17	245		
	Brown sandy clay	7	252		
	Brown sandy clay, gravel and some water	5	257		
	Brown sand and gravel with clay matrix	63	320		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/03E-03F04--continued	Brown sand, gravel with variable silt matrix, water	16	336		
	Brown sand and gravel, silt matrix	17	353		
	Gray-brown silt, sand and gravel	6	359		
	Brown sand, gravel, variable silt matrix, water	12	371		
19N/03E-03G02	Topsoil	2	2	Robinson & Roberts	1958
	Cemented gravel	13	15		
	Hardpan	6	21		
	Boulders and hardpan	3	24		
	Hardpan	31	55		
	Sandy hardpan	13	68		
	Hardpan	12	80		
	Sandy hardpan	10	90		
	Cemented gravel	65	155		
	Gravel and sand	3	158		
	Cemented gravel	27	185		
	Gravel and sand	9	194		
	Cemented gravel, gravel and sand	9	203		
	Cemented gravel	31	234		
	Hardpan	27	261		
	Sand	9	270		
	Gravel and sand	6	276		
	Boulders and hardpan	24	300		
	Gravel and clay	17	317		
	Gravel and sand	13	330		
	Sand	3	333		
	Gravel and sand	2	335		
	Sand	4	339		
	Boulders and hardpan	5	344		
	Hardpan	16	360		
	Sand	5	365		
	Sandy clay	17	382		
	Clayey sand	12	394		
	Sand	25	419		
	Clayey sand	3	422		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-01Q01	Topsoil	2	2	Dorsten	1959
	Shale and series of sand streaks	92	94		
	Coarse gravel and water	10	104		
19N/04E-02J01	Sand and yellow clay	25	25	Richardson	1959
	Clay, sand and gravel	41	66		
	Hardpan	82	148		
	Blue hardpan	12	160		
	Hardpan	14	174		
	Blue hardpan	47	221		
	Clay, sand and gravel	13	234		
	Yellow clay, sand and gravel	39	273		
	Yellow sand and clay	7	280		
	Yellow clay, sand and gravel	93	373		
	Hardpan, seepage	15	388		
	Clay, sand and gravel	27	415		
	Hardpan	8	423		
	Clay, sand and gravel, water	2	425		
19N/04E-03A01D1	Clay, gravel and boulders	17	17	Gaudio	1991
	Cemented clay and gravel	163	180		
	Gravel and clay, some water	2	182		
	Cemented gravel	118	300		
	Sand and gravel, dry	2	302		
	Cemented gravel	39	341		
	Clay, gravel, sand and some water	69	410		
	Cemented gravel and boulders	55	465		
	Clay, sand, gravel and water	65	530		
	Rocks and gravel	10	540		
	Clay, gravel and sand	72	612		
	Cemented gravel	106	718		
	Sand and clay	2	720		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-03A01D1--continued	Sand and water	14	734		
	Sand, gravel and sandstone	22	756		
	Cemented gravel and water	56	812		
	Clay	1	813		
	Gravel, sand and water	6	819		
	Gravel and sand	6	825		
	Silt	1	826		
	Sand, gravel and clay	1	827		
	Clay	20	847		
19N/04E-03Q01	Brown fine to medium silty sand, little gravel, trace organics	4	4	Converse Consultants	1982
	Gray-brown silty sand, little gravel, some cobbles to boulders	15	19		
	Gray-brown gravelly sand, little silt, trace of clay	9	28		
	Gray-brown medium to coarse sand and gravel, some weathered gravel	10	38		
	Brown fine to medium sand, trace coarse sand, gravel, trace silt	6.5	44.5		
19N/04E-03R01D2	Fill	4	4	Richardson	1981
	Topsoil	2	6		
	Hardpan	7	13		
	Sandy Clay	3	16		
	Clay, sand and gravel, brown seepage	4	20		
	Brown sandy clay	6	26		
	Hardpan	8	34		
	Cemented gravel	2	36		
	Cemented sand and gravel	21	57		
	Sand and gravel, little clay	9	66		
	Cemented sand and gravel	26	92		
	Brown sand and gravel	18	110		
	Cemented sand and gravel	17	127		
	Brown sand and gravel	94	221		
	Sand, gravel, water bearing	14	235		
	Sand and gravel, little brown clay	7	242		
	Cemented sand and gravel	32	274		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-03R01D2--continued	Brown cemented sand and gravel	26	300		
	Cemented sand and large dark rocks	10	310		
	Cemented sand and gravel	16	326		
	Sand and gravel, some brown clay	10	336		
	Cemented sand and gravel	54	390		
	Sandy clay some gravel	14	404		
	Sandy clay	12	416		
	Fine sand	2	418		
	Sand, gravel and water	7	425		
	Sand, gravel and brown clay	11	436		
	Brown sandy clay	5	441		
	Cemented sand and gravel	24	465		
	Sand, gravel and brown clay, water	5	470		
	Cemented sand and gravel	1	471		
	Gray sand, gravel and water	8	479		
	Sand, gravel and water	3	482		
	Sand, gravel and brown clay	2	484		
	Cemented sand and gravel, no water, bailing down	8	492		
	Cemented sand and gravel	15	507		
	Sand and gravel	8	515		
	Sand and gravel, 90 percent sand	14	529		
	Dirty sand and gravel	3	532		
	Light brown clay	20	552		
	Sand and gravel, water	7	559		
	Sand and gravel, large rocks, water	16	575		
	Dirty sand and gravel	2	577		
	Cemented sand and gravel	1	578		
	Brown clay some gravel	6	584		
	Sand, gravel and water	9	593		
	Sand and gravel, some cemented gravel	6	599		
	Sand and gravel, large rocks, water	4	603		
	Dirty sand and gravel, large rocks, water	9	612		
	Sand and gravel, brown clay	7	619		
	Brown clay, sand and gravel	8	627		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-03R01D2--continued	Cemented sand and gravel	9	636		
	Sand and gravel, brown clay	4	640		
	Sand and gravel	5	645		
	Sand and gravel, gray clay	1	646		
	Gray silty sand, some gravel	11	657		
	Sand and clay	18	675		
	Dark gray silty sand	27	702		
	Sand and clay	20	722		
	Dark gray silty sand	21	743		
	Gray silty sand and clay	1	744		
	Sand, gravel and water	7	751		
	Gravel, sand and clay	12	763		
	Dirty sand and gravel, clay	10	773		
	Dirty sand and gravel	12	785		
	Dirty sand and gravel, clay	25	810		
19N/04E-05P02	Cemented gravel	136	136	Gaudio	1967
	Rocks and boulders	26	162		
	Cemented gravel	33	195		
	Sand layers and cemented gravel	10	205		
	Sand and gravel, water bearing	53	258		
19N/04E-08A01	Gravel, sand and boulder	200	200	Gaudio	1964
	Yellow silt	5	205		
	Yellow silt, sand and gravel	13	218		
	Yellow silt	6	224		
	Silt, sand and gravel	4	228		
	Sand and gravel	10	238		
	Sand	10	248		
	Gravel	11	259		
	Gravel, up to 6" in diameter, coarse sand streaks of boulders	39	298		
	Sand	6	304		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-08A06	Clay and boulders	22	22	Gaudio	1965
	Gravel and boulders	13	35		
	Rock and gravel	5	40		
	Gravel and rock	27	67		
	Cemented gravel	8	75		
	Gravel and sand	1	76		
	Rocks, sand and gravel	7	83		
	Tight sand and gravel	8	91		
	Gravel and sand	19	110		
	Tight sand and gravel	10	120		
	Gravel and sand	10	130		
	Tight gravel and sand	18	148		
	Sand and gravel (takes water)	15	163		
	Tight sand and gravel	15	178		
	Tight sand, gravel and rock	6	184		
	Streaks of sand and gravel	16	200		
	Rock and sand	15	215		
	Sand and gravel	17	232		
	Sand and gravel, some water	8	240		
	Blue silt	15	255		
	Silty sand	4	259		
	Sand, layer of clay	13	272		
	Tight yellow clay	3	275		
	Sand, layer of clay	11	286		
	Tight sand	14	300		
	Cemented gravel	8	308		
	Streaks	6	314		
	Fine sand, some gravel	4	318		
	Tight gravel and sand	12	330		
	Streaks of gravel and sand	7	337		
	Loose gravel	4	341		
	Tight gravel	1	342		
	Loose gravel	9	351		
	Hardpan	2	353		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-08K01	Claybound sand and gravel	100	100	Hart-Crowser	1985
	Silt and sand	10	110		
	Claybound sand and gravel	55	165		
	Silt and sand	8	173		
	Claybound sand and gravel	22	195		
	Dirty silt and sand	40	235		
	Silt	20	255		
	Silt and sand	10	265		
	Silt	20	285		
	Sand and gravel	50	335		
	Silty sand	7	342		
19N/04E-09B03	Compact sand and gravel, dry	24	24	Unknown	1995
	Gray, soft clay, with sand and gravel	8	32		
	Loose sand and gravel, dry	61	93		
	Loose sand, dry	188	281		
	Gray silt	6	287		
	Brown, medium-coarse sand and gravel, with scattered cobbles	53	340		
	Brown, medium, coarse, sand	17	357		
	Coarse, sandy gravel	6	363		
19N/04E-10A01	Topsoil	1	1	Gustin	1977
	Silty, brown sand, hardpan	12	13		
	Blue clay	3	16		
	Blue clay, sand, gravel and hardpan	11	27		
	Brown sand and hardpan	11	38		
	Gray sand, gravel and hardpan	14	52		
	Brown sand, gravel and hardpan	183	235		
	Brown sand, gravel and hardpan, some water seepage	20	255		
	Gray sand, gravel and hardpan, some water seepage	7	262		
	Brown sand, gravel and hardpan, more water	9	271		
	Hardpacked sand, gravel and water bearing	1	272		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-11D01	Brown, silty, sandy gravel	29	29	Oelke	1979
	Dark brown, silty gravel	9	38		
	Brown sand	14	52		
	Brown silty sandy gravel	43	95		
	Brown silty sandy gravel, wet	14	109		
	Clean gravel and water	10	119		
19N/04E-11D02	Brown topsoil	2	2	Northwest Pump	1991
	Brown cemented sand and gravel	18	20		
	Blue glacial till	15	35		
	Brown cemented sand and gravel	80	115		
	Brown cemented sand and gravel	35	150		
	Coarse gravel with boulders	10	160		
	Brown glacial till	65	225		
	Brown cemented sand and gravel	10	235		
	Blue glacial till	23	258		
	Brown cemented sand and gravel, water bearing	22	280		
19N/04E-14P01	Topsoil	2	2	Unknown	1921
	Sand	4	6		
	Gravel	14	20		
	Hardpan	2	22		
19N/04E-16E01	Topsoil	3	3	Richardson	1975
	Clay and gravel	7	10		
	Hardpan	8	18		
	Hardpan, seepage	1	19		
	Hardpan and boulders	18	37		
	Gravel, clay and boulders	80	117		
	Clay and gravel	41	158		
	Sand and clay	5	163		
	Gravel and clay	26	189		
	Hardpan	47	236		
	Gravel and clay	42	278		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-16E01--continued	Clay and gravel	7	285		
	Clay and gravel, little water	12	297		
	Gravel and water	8	305		
19N/04E-16E02D2	Topsoil	1	1	Ramlo	1986
	Blue clay	3	4		
	Sandy blue clay	12	16		
	Cemented gravel	7	23		
	Hardpan	6	29		
	Cemented gravel	8	37		
	Hardpan	42	79		
	Cemented gravel	35	114		
	Gravel, dry	23	137		
	Cemented gravel	103	240		
	Muddy sand, wet	4	244		
	Silt and sand, dry	5	249		
	Silt and sand, wet	23	272		
	Sand, little water	1	273		
	Cemented gravel	8	281		
	Hard-packed gravel and water	3	284		
	Gravel, some sand, water (good flow)	12	296		
	Gravel and water	14	310		
	Cemented gravel	1	311		
	Sand, gravel and brown clay	1	312		
	Brown silty sand and gravel, water	19	331		
	Brown clay sand and gravel	3	334		
	Brown silty sand and gravel, water	1	335		
	Brown clay sand and gravel	15	350		
	Red-brown silty sand and gravel, water	9	359		
	Loose sand and gravel, water	6	365		
	Gray sand and gravel, water	8	373		
	Gray clay sand and gravel	5	378		
	Gray silty sand and gravel, water	7	385		
	Gray medium sand, some gravel, heaves, water	55	440		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-17K01	Brown, silty topsoil	3	3	Stoican	1984
	Gray sand, clay and gravel	8	11		
	Brown cemented gravel	8	19		
	Blue-gray till	63	82		
	Gray-brown cemented sand and gravel, large rocks	159	241		
	Brown clay and sand	27	268		
	Cemented gray sand and gravel	15	283		
	Brown sandy clay, some gravel	19	302		
	Light, fine medium sand with clay binder	43	345		
	Gray-brown sand and water	15	360		
	Gravel and water	13	373		
	Gray clay	1	374		
19N/04E-20F02	Brown silty sand and gravel	6	6	Oelke	1978
	Medium, coarse, clean sand	3	9		
	Brown sand and gravel	70	79		
	Gray till	26	105		
	Brown silty sand and gravel	14	119		
	Clean, broken gravel and sand	15	134		
	Medium gravel and sand	6	140		
19N/04E-20K03	Till	85	85	Denny	1940
	Cemented gravel	105	190		
	Gravel and sand	5	195		
19N/04E-20Q01D1	Hardpan and boulders	30	30	Ramlo	1986
	Hardpan	70	100		
	Gravel, water bearing	13	113		
	Sand, gravel, water bearing	7	120		
	Brown sandy clay	5	125		
	Brown fine sand, water bearing	12	137		
	Brown medium sand, water bearing	10	147		
	Gray-blue clay with gravel	11	158		
	Cemented gravel, water bearing	84	242		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-20Q01D1--continued	Silty loose sand and gravel, water bearing	5	247		
	Cemented gravel, water bearing	68	315		
	Sand and gravel, water bearing	5	320		
	Cemented gravel, water bearing	5	325		
19N/04E-20R04	Bankrun	5	5	Richardson	1969
	Hardpan	45	50		
	Gravel and clay	8	58		
	Hardpan	90	148		
	Coarse sand and gravel, some water	11	159		
	Coarse sand and clay	1	160		
	Coarse sand and gravel, some water	4	164		
	Gray-blue clay	10	174		
	Sandy clay	2	176		
	Hardpan	4	180		
	Coarse sand and gravel, water	6	186		
	Gray-blue clay and gravel	7	193		
	Gray sandy clay	10	203		
	Blue clay	1	204		
	Blue-gray clay and gravel	18	222		
	Light brown sandy clay and gravel	16	238		
	Clay coated gravel	7	245		
	Coarse gravel	1	246		
19N/04E-20R05	Hardpan	69	69	Holt	1989
	Sand and gravel, silt binder	87	156		
	Sand and gravel, water	11	167		
	Green-gray silt	8	175		
	Silty sand and gravel	16	191		
	Tight silty sand	14	205		
	Loose sand and gravel, some water	15	220		
	Tight sand and gravel, water	41	261		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-25K02	Brown silty sand and gravel	8	8	Oelke	1993
	Brown-gray silty sand with clay	14	22		
	Gray silty sand with clay, some gravel	52	74		
	Coarse to medium sand, gravel, water bearing	23	97		
19N/04E-26C01	Topsoil	3	3	Indrebo	1977
	Brown sand, clay and some rock	21	24		
	Cemented gravel and boulders	4	28		
	Blue hard clay and gravel	4	32		
	Brown clay and gravel, some water	2	34		
	Cemented gravel	131	165		
	Yellow-brown hard clay and gravel	29	194		
	Brown sandy clay, some gravel	5	199		
	Cemented gravel	11	210		
	Cemented gravel and water	4	214		
	Clay and gravel, some boulders, water shutoff	16	230		
	Blue hardpan	10	240		
	Brown clay and gravel, trace water	10	250		
	Blue hardpan	3	253		
	Brown clay and gravel, some water	9	262		
	Brown clay and gravel, water shutoff	10	272		
	Brown clay and gravel, water 2 gpm	3	275		
	Brown clay and gravel, water shutoff	25	300		
	Brown clay and gravel, water	7	307		
	Brown silty clay	2	309		
	Brown silty clay, fine sand and gravel, some water	7	316		
	Brown clay and gravel	34	350		
19N/04E-26G01	Topsoil	5	5	Story/Armstrong	1978
	Large boulders	3	8		
	Gray cemented till	7	15		
	Hard cemented till	6	21		
	Blue hard cemented till	21	42		
	Brown hard cemented till	21	63		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-26G01--continued	Compact sand, with gravel	11	74		
	Dirty compact sand with gravel, no water	11	85		
	Brown sand	3	88		
	Gray cemented sand and gravel	77	165		
	Brown cemented sand and gravel	15	180		
	Gray, very tight cemented sand and gravel	4	184		
	Looser cemented sand and gravel	6	190		
	Brown sand, trace water	3	193		
	Light brown silty material, with gravel	7	200		
	Gray cemented sandy till	17	217		
	Blue cemented till	35	252		
	Blue cemented till, sand and gravel, trace water	2	254		
	Blue-green very tight till	1	255		
	Blue cemented sand and gravel	8	263		
	Gray cemented sand and gravel	5	268		
	Gray-brown cemented sandy till	9	277		
	Sand, trace of gravel	3	280		
	Brown-gray silty sand, trace water	40	320		
	Brown silty sand, with gravel	26	346		
	Hard cemented till, with large rocks	2	348		
	Fine sand, slight trace of water	10	358		
	Brown sand, with gravel, water bearing, getting coarser, very fine gravel with sand	11	369		
	Sticky clay	2	371		
19N/04E-27A01	Blue silty claybound sand and gravel	198	198	Story/Armstrong	1975
	Sand and gravel	6	204		
	Tight silty sand and gravel	1	205		
	Sand and gravel, water bearing	17	222		
	Silty claybound sand and gravel	3	225		
19N/04E-27B01	Sand	8.5	8.5	Unknown	Unk
	Hardpan	0.5	9		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-28B01	Topsoil	2	2	Ramlo	1985
	Sandy gravel, seepage	2	4		
	Gray silty sand and gravel	4	8		
	Gray silty sand and gravel, seepage	1	9		
	Gray hardpan	14	23		
	Brown hardpan, cobbles and large boulders	72	95		
	Clean sandy gravel and cobbles, dry	64	159		
	Brown hardpan, cobbles	6	165		
	Gray hardpan, cobbles	7	172		
	Brown hardpan, seepage 175 ft swl	40	212		
	Brown clay and gravel	7	219		
	Brown silty sand	46	265		
	Brown hardpan, seepage 240 ft swl	40	305		
	Brown silty sand and gravel, clay lenses, water 30-50 gpm	91	396		
	Red-brown silty sand and gravel	10	406		
	Orange stained sandy gravel, water bearing	6	412		
	Gray clay, sand and gravel	3	415		
	Brown clay, sand and gravel, seepage	13	428		
	Brown sandy clay	9	437		
	Brown clay, sand and gravel, seepage	18	455		
	Gray silty sand and gravel, water bearing	2	457		
	Brown clay and gravel	13	470		
	Gray coarse sand, water bearing	2	472		
	Brown clay and gravel	44	516		
	Brown silty sand and gravel, water bearing	3	519		
	Yellow-brown clay and gravel	34	553		
	Brown silty sand and gravel, water bearing	6	559		
	Brown sandy clay	14	573		
	Brown clay and gravel	16	589		
	Brown silty fine sand, clay and gravel lenses, water bearing 240 ft swl	23	612		
	Brown silty sand and gravel, water bearing	15	627		
	Black-brown silty fine sand, water bearing	5	632		
	Gray silty fine sand and gravel, water bearing	6	638		
	Gray clay, sand and gravel	15	653		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-28B01--continued	Gray loose sandy gravel, water bearing, 230 ft swl	5	658		
	Gray clay sand and gravel	6	664		
	Gray silty sand and gravel, water bearing	2	666		
	Gray clay sand and gravel	4	670		
	Gray sandy loose gravel, water bearing, 230 ft swl	11	681		
	Gray clay	16	697		
19N/04E-29J01	Brown soil	2	2	Richardson	1977
	Sand and gravel, little clay, water 5 gpm	16	18		
	Hardpan and boulders	112	130		
	Sand, gravel and brown clay, water 1.5 gpm	12	142		
	Sand, gravel and brown clay, wet	28	170		
	Sand and gravel, water 25 gpm	29	199		
19N/04E-29K02	Brown silty sand and gravel	3	3	Oelke	1982
	Gray hard till, damp	35	38		
	Brown silty sand and gravel, damp	2	40		
	Gray silty sand and gravel, damp	13	53		
	Brown silty sand and gravel, damp	82	135		
	Till	2	137		
	Brown silty sand and gravel, damp	6	143		
	Brown hard silty sand and gravel, wet	37	180		
19N/04E-29L03	Sandy topsoil	2	2	Richardson	1990
	Sand, clay and gravel	7	9		
	Gravel, clay and boulders	13	22		
	Gray hardpan	16	38		
	Yellow hardpan	29	67		
	Large boulder	2	69		
	Brownish hardpan	46	115		
	Yellow hardpan	43	158		
	Sand and gravel, trace water	7	165		
	Brown gravel and clay	26	191		
	Gravel and sand, water	7	198		
	Gravel and clay, water	4	202		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/04E-29M02	Sandy clay	3	3	Kring	1989
	Unconsolidated sand, gravel, and clay	11	14		
	Sandy clay	2	16		
	Consolidated sand, gravel, and clay	19	35		
	Gravel, some sand	100	135		
	Gravel and water	25	160		
19N/04E-29R03	Topsoil and gravel	6	6	Tacoma Pump	1975
	Hardpan	134	140		
	Sand and gravel, water	8	148		
	Loose gravel, water	1	149		
19N/04E-30Q03	Topsoil	3	3	Northwest Pump	1989
	Brown glacial till	8	11		
	Blue glacial till	19	30		
	Brown cemented sand and gravel	88	118		
	Sand and gravel, water bearing	5	123		
	Brown silty sand	19	142		
	Brown cemented sand and gravel	11	153		
	Sand and gravel, water bearing	7	160		
19N/04E-31C03	Brown clay, cobbles, and gravel	7	7	Northern Pump	1986
	Brown clay, gravel, mild sand	105	112		
	Brown clay, sand, and gravel	15	127		
	Brown clay, sand, and gravel, mild	8	135		
	Brown clay and gravel	2	137		
	Gravel, sand and water	3	140		
	Clay, sand mild gravel	1	141		
19N/05E-06N02	Brown topsoil	8	8	Oelke	1994
	Gray silty sand, damp	27	35		
	Gray silty sand, water bearing	21	56		
	Gray silty sand and gravel, water bearing	28	84		
	Coarse gravel and sand, water bearing	16	100		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
19N/05E-30N01	Topsoil	2	2	Jas. L. Bell	1957
	Clay	8	10		
	Blue clay and sand, some water	12	22		
	Gray sand and clay	60	82		
	Hard sand and gravel, water bearing	11	93		
19N/05E-30P01	Topsoil	2	2	Shartion	1952
	Gravel	18	20		
	Sand	35	55		
	Sand and gravel, water bearing	23	78		
20N/03E-30R01	Cobbles and concrete	3	3	Burns	1993
	Silty sand	14	17		
	Gravel	3	20		
	Till and sand	10	30		
20N/03E-32D01	Gravel	13	13	Unknown	1932
	Till	3	16		
20N/03E-34L01	Soil	4	4	Sylte	1951
	Cemented gravel	31	35		
	Blue hardpan	40	75		
	Cemented gravel	65	140		
	Sand and gravel, dry	20	160		
	Cemented gravel	24	184		
	Dirty sand and gravel, some water	7	191		
	Cemented gravel	4	195		
	Sand and small gravel, water	4	199		
	Gravel and water	3	202		
	Cemented gravel	1	203		
	Big gravel and water	9	212		
	Cemented gravel	2	214		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/03E-34L01-- continued	Sand and gravel, water	2	216		
	Dirty sand, wet	7	223		
	Cemented gravel	7	230		
	Hardpan	8	238		
	Cemented gravel	29	267		
	Fine sand, wet	2	269		
	Hardpan	51	320		
	Dirty sand and gravel, wet	10	330		
	Silt, dry	24	354		
	Quick sand	30	384		
	Heavy sand	10	394		
	Sand and gravel, water	2	396		
	Hardpan	33	429		
	Sand and gravel	1	430		
	Hardpan	20	450		
	Silt and gravel, dry	4	454		
	Hardpan	5	459		
	Sand and blue clay	11	470		
	Hardpan	11	481		
	Green clay	4	485		
	Brown hardpan	20	505		
20N/03E-34L02	Yellow clay and gravel	16	16	Richardson	1966
	Blue clay, sand and gravel hard streaks	26	42		
	Hardpan	23	65		
	Cemented sand and gravel	23	88		
	Hardpan, some water	22	110		
	Cemented sand and gravel, water	38	148		
	Fine and coarse sand and gravel, with yellow clay	12	160		
	Cemented sand and gravel	11	171		
	Fine sand, yellow clay and gravel	4	175		
	Cemented sand and gravel	2	177		
	Fine and coarse sand, yellow clay and gravel	7	184		
	Cemented sand and gravel, 12 ft water	4	188		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/03E-34L02--continued	Fine and coarse sand and gravel, hard streaks, 18 ft water at 190 ft	16	204		
	Cemented sand and gravel	7	211		
	Large gravel and coarse sand	2	213		
	Gravel and sand	1	214		
	Yellow clay, sand, and gravel	2	216		
	Fine silty sand and clay, few gravel	7	223		
20N/03E-35F01	Gravelly soil	9	9	Unknown	Unk
	Till	9	18		
20N/03E-36F01	Rocks and loam	27	27	Gaudio	1964
	Hardpan	37	64		
	Sand and gravel, dry	3	67		
	Sand	10	77		
	Sand and some gravel	3	80		
	Sand, water bearing	37	117		
	Sand, dry	3	120		
	Brown silty sand	9	129		
	Hardpan, some water	23	152		
	Brown sand	4	156		
	Hardpan	17	173		
	Gravel, water bearing	1	174		
	Sand and gravel	2	176		
	Hardpan	3	179		
	Sand and gravel, some water	11	190		
	Hardpan	4	194		
	Silty gravel and sand	3	197		
	Hardpan	10	207		
	Brown silty sand, water bearing	32	239		
	Sand and gravel	6	245		
	Silty sand and fine gravel	5	250		
	Brown fine sand	7	257		
	Hardpan	2	259		
	Sand and rocks, water	7	266		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/03E-36F01--continued	Hardpan	15	281		
	Sand, dry	1	282		
	Hardpan	9	291		
	Sand, streak of water	1	292		
	Hardpan	5	297		
	Sand, gravel and clay, water	5	302		
	Hardpan and boulders	6	308		
	Sand and gravel	9	317		
	Gravel, sand, cobbles, clay matrix	50	367		
	Unknown	5	372		
20N/04E-20E04	Topsoil	2	2	Johnson	1983
	Dark brown sand	23	25		
	Gray sandy clay	13	38		
	Gray sand	14	52		
	Sand and gravel, gray water	4	56		
20N/04E-20E06	Topsoil	2	2	Oelke	1993
	Brown silt	7	9		
	Gray silt	51	60		
	Gray coarse sand, small and medium gravel, damp	14	74		
	Brown silt	2	76		
	Gray silty clay, seashells and wood chips	19	95		
	Gray medium sand	20	115		
	Gray fine silt and sand	6	121		
20N/04E-20N05	Sand and clay, wet	60	60	Tacoma Pump	1984
	Sand, clay, and wood, some water	5	65		
	Sandy clay, some water	15	80		
	Heaving sand	47	127		
	Sand, blue clay, and seashells	8	135		
	Compact sand and clay	43	178		
	Coarse sand, water	6	184		
	Sand and clay	6	190		
	Gray clay	3	193		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-25N01	Sand and clay	80	80	Charlton	1952
	Gravel	33	113		
20N/04E-25P01	Topsoil	5	5	Tacoma Pump	1953
	Logs	4	9		
	Sandy clay	11	20		
	Sand, gravel, and water	30	50		
	Clay	25	75		
	Clay, sand, and gravel	15	90		
	Coarse sand	2	92		
20N/04E-25Q01	Sand and clay	95	95	Charlton	1952
	Gravel	10	105		
20N/04E-27H01	Topsoil	1	1	Richardson	1980
	Brown sand	44	45		
	Gray sand and clay	100	145		
	Sand, gravel, and clay	9	154		
	Sand and gravel, seepage	5	159		
	Gray silty clay	24	183		
	Sand and gravel, water	7	190		
20N/04E-27J01	Sand	20	20	Gaudio	1953
	Sandy clay	20	40		
	Soft sandy clay and rocks	46	86		
	Dark gray sand and gravel up to 3"	6	92		
	Fine sand and clay	34	126		
	Sand, clay, and rocks	4	130		
	Sand and clay	20	150		
	Sand and gravel	5	155		
	Clay	30	185		
	Sand and clay	22	207		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-27J01--continued	Dirty sand and gravel	6	213		
	Sand and gravel, finner toward 221 ft	8	221		
	Clay	6	227		
	Sand and gravel	6	233		
20N/04E-29D03	Topsoil	2	2	Valley Pump	1967
	Sandy silt, some water	202	204		
	Silt	27	231		
	Gray sandy clay	33	264		
	Silt	11	275		
	Sandy clay	11	286		
	Clay	51	337		
	Fine sand and pea gravel, water flows	25	362		
20N/04E-31F02	Clay, sand, gravel, and cobbles	15	15	Northern Pump	1987
	Brown mild clay, sand, and gravel	18	33		
	Brown hard clay, sand, and gravel	63	96		
	Brown mild clay, sand, and gravel	58	154		
	Brown hard clay, sand, and gravel	26	180		
	Gravel and water	10	190		
	Clay, sand, and gravel	1	191		
20N/04E-31H05	Topsoil	2	2	Richardson	1978
	Sand with rocks	18	20		
	Gray sand and gravel, wet	47	67		
	Fine gravel	4	71		
	Sand, some gravel, wet and rusty	22	93		
	Gravel and sand, water 5 gpm and rusty	4	97		
	Sand	3	100		
	Gravel and sand, some red clay	40	140		
	Gravel, some sand, 3 gpm, pumped dry	22	162		
	Sand, wet and brown	15	177		
	Gravel, blue, green, brown, and black with some white and yellow	15	192		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-32E02	Topsoil	1	1	S-K Pumps	1992
	Brown sand and gravel	4	5		
	Brown sand, gravel, and clay	16	21		
	Gray sand and gravel, some clay	13	34		
	Brown silty sand and clay	24	58		
	Brown sand and clay, some fine gravel, water 3-4 gpm	2	60		
	Brown sand and clay, some gravel	20	80		
	Gray sand and gravel, some clay	26	106		
	Gray silty sand and clay	4	110		
	Brown silty sand, some clay	43	153		
	Brown silty sand and gravel, water 2 gpm	8	161		
	Brown silty sand, seams of clay, and cemented sand	46	207		
	Brown sand and gravel, some clay, water 2 gpm	9	216		
	Gray sand and clay	33	249		
	Gray sand, gravel and clay, water 3 gpm	11	260		
	Gray sand, clay, and wood	24	284		
	Gray sand and coarse gravel, water 10 gpm	11	295		
20N/04E-32H02	Dark brown, gravelly sandy silt, moist	15	15	Hartcrowser	1992
	Brown sandy gravel, moist to wet	13	28		
	Brown-gray sand with silt interbeds, wet	50	78		
	Gray gravelly sand with silt interbeds, wet	5	83		
	Gray silt, dry	15	98		
	Gray to brown, sandy silt, wet	9	107		
	Brown sandy, very silty gravel, moist	8	115		
	Brown silty gravelly sand, wet	5	120		
	Brown sandy gravel, wet	9	129		
	Brown very gravelly sand, wet	4	133		
	Brown slightly silty, sandy gravel	3	136		
	Brown gravelly sand, silt lense at 138 ft, wet	16	152		
	Brown sandy gravel, wet	5	157		
	Brown gravelly sand, wet	4	161		
	Gray silt, dry	11	172		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-32J02	Clayey peat, some clay	23	23	Jansen	1945
	Medium-coarse sand, fine gravel, some clay, water at 36 ft 10 gpm	13	36		
	Sand and gravel	10	46		
	Medium coarse sand	4	50		
	Sharp sand, several 4-inch discs of gravel	13	63		
	Fine sand	10	73		
	Gravel, 1.5 inches	1	74		
	Fine sand	4	78		
	Clay, fine sand, some gravel, water	29	107		
	Gravel, 4 inches	1	108		
	Sand	4	112		
	Sand, large gravel, clay particles, water	3	115		
	Very coarse sand and large percent of gravel	5	120		
	Sand and gravel, water, test 1,500 gpm dd 5 ft, 12 inch casing	6	126		
	Coarse sand and gravel, water flowing	9	135		
	Coarse gravel, some sand	10	145		
	Coarse gravel and sand, water flowing, aprox 500 gpm	7	152		
	Gravel, coarse clean sand	10	162		
	Blue clay	2	164		
20N/04E-33A01	Topsoil	2	2	Oelke	1984
	Black sand, some gravel	16	18		
	Black silty sand, some gravel	7	25		
	Log	2	27		
	Black silty sand, some gravel	3	30		
	Black, clean coarse sand	10	40		
	Black silty sand and gravel	8	48		
	Black clean medium sand with silt and wood, peat balls	52	100		
	Silt and peat	5	105		
	Black silty fine sand	30	135		
	Black very fine sand	20	155		
	Black medium sand, wood, water	7	162		
	Fine silty sand and wood	22	184		
	Light fine silty sand, peat, gravel	42	226		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-33A01-- continued	Medium fine sand, with silt streaks, water bearing	14	240		
	Siltstone	11	251		
	Silt with gravel	14	265		
	Silt, some gravel	30	295		
	Gray hard silty gravel	10	305		
	Black medium sand	15	320		
	Coarse sand, some wood and gravel	21	341		
	Gray silty gravel	4	345		
20N/04E-34B01	Sand and clay	35	35	Charlton	Unk
	Gravel	7	42		
20N/04E-34C01	Sand	34	34	Webber	1947
	Sand with a little gravel, water	2	36		
	Sand, some water	94	130		
	Sandy clay	24	154		
	Sand	18	172		
	Brown clay and sand	18	190		
	Quicksand	13	203		
	Clay and gravel	2	205		
	Fine sandy clay	42	247		
	Fine silt, heaving	5	252		
	Blue clay	8	260		
	Gravel, some sand	4	264		
20N/04E-35A02	Topsoil	3	3	Richardson	1981
	Black and gray sand	22	25		
	Sand, some water	1	26		
	Gray hardpan	9	35		
	Sand, sulfer water	8	43		
	Gray hardpan	8	51		
	Gray claybound sand	29	80		
	Green clay	14	94		
	Cemented sand and gravel, seepage	16	110		
	Sand and gravel, water	6	116		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-35D01	Open hole	40	40	Service Hardware	1955
	Gravel	28	68		
	Clay and sand	12	80		
	Sand and gravel	5	85		
	Clay	8	93		
	Sand	7	100		
	Gravel	3	103		
	Clay, silt and sand	22	125		
	Sand	8	133		
	Sand and shells	13	146		
	Fine sand	15	161		
20N/04E-35E01	Sand and clay	41	41	Charlton	1942
	Gravel	5	46		
20N/04E-35M02	Topsoil	3	3	Oelke	1991
	Gray sand and gravel	14	17		
	Brown silty sand	19	36		
	Gray silt and gravel	31	67		
	Silty sand and gray gravel	15	82		
	Brown sand and gravel	7	89		
	Gray clean gravel	13	102		
	Gray silt and gravel	18	120		
	Gray gravel	14	134		
	Brown silt, sand, and gravel	53	187		
	Brown silt and sand, some gravel	83	270		
	Gray sand	8	278		
	Brown sand and gravel	12	290		
	Silt and gravel	12	302		
	Brown silt, sand, and gravel	10	312		
	Fine clean angular gravel	3	315		

Appendix 2.--*Drillers' lithologic logs of wells used in construction of hydrogeologic sections, in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
20N/04E-35M02--continued	Tight gravel	4	319		
	Brown tight silty gravel	16	335		
	Brown sandy fine tight gravel	2	337		
	Brown sandy medium angular gravel, water bearing	4	341		

Appendix 3.--*Water-quality data in the Tacoma-Puyallup area, Washington*

EXPLANATION

Location:	u, well located in uplands; v, well located in Puyallup River valley.
Land surface altitude:	In feet above sea level. Most altitudes were assigned from topographic maps (1:24,000 with 10- or 20-foot contour intervals) and are generally accurate to within 10 feet. In steep terrain, or where the precise location of the well is in doubt, the error may be as great as 50 feet. Some wells (<10 percent) have been surveyed and are accurate to within 1 foot.
Well depth:	Feet below land surface.
Hydrogeologic unit:	Hydrogeologic unit tapped by well: g, gravel; Qvr, Vashon recessional deposits; Qvt, Vashon till; Qc1, Qc2, and Qc3 are aquifer units; Qf1 is a semi-confining unit.
General symbols and abbreviations:	--, no data; deg. C, degrees Celsius; mm of Hg, millimeters of mercury; µS/cm, microSiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; cols. per 100 mL, colonies per 100 milliliters; B*, indicates results based on colony count outside acceptable range (non-ideal colony count); pCi/L, picocuries per liter; sigma, one standard deviation.

Appendix 3.--*Water-quality data in the Tacoma-Puyallup area, Washington--Continued*

Local well number	Date sampled	Location	Land surface altitude (feet above sea level)	Well depth (feet)	Depth to first opening (feet)	Hydrogeologic unit(s)	Temperature, water (deg. C)	Barometric pressure (mm of Hg)	Specific conductance, field (µS/cm)	Oxygen, dissolved (mg/L)	pH, field (standard units)
19N/03E-01E01	7/2/96	u	473.8	282	256	Qc2	10.4	746	190	6.4	7.3
19N/03E-11Q01	7/2/96	u	415	237	237	Qc2	10.3	748	141	<0.1	8.2
19N/04E-02F01	6/26/96	u	410	623	550	Qc3	10.6	747	124	0.7	7.9
19N/04E-03R01D2	6/25/96	u	530	612	552	Qc3	10.4	747	122	1.6	7.4
19N/04E-04L02	6/25/96	u	355	264	254	Qc2	10.0	751	190	7.4	6.8
19N/04E-11D01	6/18/96	u	450	119.5	119.5	Qc1	10.1	757	213	6.4	6.4
19N/04E-12N01S	6/17/96	u	300	spring	--	Qvr	10.1	757	339	10.2	7.0
19N/04E-14P01	6/17/96	u	550	22	22	Qvr/Qvt	10.0	750	90	4.1	6.6
19N/04E-16G03	6/28/96	u	460	400	375	Qc2	9.0	754	121	4.8	7.7
19N/04E-20K03	6/25/96	u	465	193	193	Qc1	10.0	753	140	7.0	6.4
19N/04E-20Q01D1	6/24/96	u	400	320	315	Qc3?	9.3	748	166	7.1	6.8
19N/04E-26G01	6/24/96	u	605	369	369	Qc2	11.1	743	116	4.0	7.3
19N/04E-27A01	6/24/96	u	585	225	206	Qc1	9.3	744	103	8.3	6.7
19N/05E-06C02	6/27/96	v	85	240.5	212.75	Qc2	11.1	758	185	<0.1	7.3
19N/05E-06N02	6/27/96	v	105	99	99	Qc2	11.3	759	229	<0.1	6.6
20N/03E-07F01	6/20/96	u	330	160	87	Qc1	12.2	754	280	3.0	6.8
20N/03E-09A03	6/28/96	v	10	248	199	Qc3	11.1	767	119	<0.1	7.6
20N/03E-11P05	6/20/96	v	35	25	25	Qc1	11.8	--	162	<0.1	7.2
20N/03E-14H01S	6/21/96	u	90	spring	--	Qc1	10.3	756	215	3.9	6.7
20N/03E-20P01	6/10/96	u	315	117	103	Qc1	13.4	781	277	2.7	6.9
20N/03E-20P02	6/10/96	u	315	254	239	Qc2 some Qf1	11.8	781	184	1.7	7.5
20N/03E-24B01S	6/19/96	u	170	spring	--	Qc1	16.0	766	223	10.7	6.7
20N/03E-25N01D1	7/1/96	u	430	258	258	Qc2	10.6	754	186	7.6	7.0
20N/04E-19G01	6/19/96	v	25	58	53	Qc1	11.8	760	262	<0.1	6.9
20N/04E-20E06	6/27/96	v	25	115	105	Qc2	12.4	762	376	<0.1	7.4
20N/04E-20N01	7/1/96	v	30	90	90	Qc2?	12.9	766	156	<0.1	8.0
20N/04E-30G02	6/19/96	u	60	78.5	78.5	Qc1	10.6	763	131	2.1	7.7
20N/04E-31B01	6/26/96	u	380	56	56	Qvt	11.2	748	225	8	6.2
20N/04E-31F02	7/2/96	u	400	180	180	lense of g in Qf1	10.1	748	147	6.5	6.6
20N/04E-32J01S	6/18/96	u	50	spring	--	Qc1	9.7	761	184	5.8	7.1
20N/04E-32R02	6/26/96	u	300	287	271	Qc2	9.6	750	188	7.2	7.0
20N/04E-33A01	6/28/96	v	40	341	321	Qc4	12.8	767	136	0.7	8.0
20N/04E-36H03	7/1/96	v	75	86.5	86.5	Qc2	11.8	765	344	0.5	6.9

Appendix 3.--*Water-quality data in the Tacoma-Puyallup area, Washington--Continued*

Carbonate, field (mg/L as $CaCO_3$)	Bicarbonate, field (mg/L as HCO_3)	Nitrate plus nitrite, dissolved (mg/L as N)	Calcium, dissolved (mg/L as Ca)	Magne-sium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)
0	95	2.3	19	8.3	7.0	1.3	5.1	6.4	<0.1	28	<1.0	--
0	86	0.05	13	4.7	9.3	1.9	1.9	1.5	0.1	25	10	--
0	74	<0.05	9.7	6.1	5.7	2.1	1.6	3.3	0.1	47	4.0	--
0	73	0.09	9.6	6.0	5.2	1.8	1.7	3.6	0.1	45	2.0	<2.0
0	97	2.6	17	9.3	6.2	2.0	5.9	6.0	<0.1	32	1.0	--
0	115	2.2	22	9.3	7.4	1.3	5.2	4.9	<0.1	32	<1.0	--
0	190	4.4	30	21	9.1	2.3	6.8	7.5	<0.1	35	<1.0	6.0
0	27	1.1	7.4	2.4	5.6	0.5	5.6	5.2	<0.1	16	<1.0	3.0
0	68	0.55	9.5	6.0	4.7	2.2	2.1	3.3	<0.1	41	2.0	--
0	64	2.0	13	6.5	5.5	1.5	4.3	5.1	<0.1	26	<1.0	--
0	80	2.0	15	7.7	5.7	1.8	5.8	4.5	<0.1	30	<1.0	--
0	66	0.07	9.5	5.2	5.0	2.4	1.8	3.9	0.1	45	2.0	--
0	51	0.39	9.9	3.5	4.4	1.1	3.2	4.9	<0.1	25	<1.0	--
0	111	<0.05	18	6.1	11	2.8	5.4	2.8	0.2	41	8.0	--
0	135	<0.05	20	6.0	8.1	2.9	4.7	7.6	0.3	60	<1.0	--
0	142	3.2	21	19	8.6	2.0	6.9	16	<0.1	34	1.0	6.0
0	72	<0.05	9.4	5.3	6.2	1.3	2.0	2.5	0.1	47	4.0	--
0	95	0.08	12	8.1	7.6	2.4	3.8	6.0	0.1	52	3.0	3.0
0	106	1.5	18	11	7.5	2.2	6.5	11	<0.1	37	1.0	5.0
0	135	2.5	22	17	9.1	1.8	7.1	19	<0.1	33	<1.0	6.0
0	92	2.0	16	9.9	6.9	2.0	6.0	8.4	<0.1	35	2.0	--
0	83	6.4	20	9.0	8.4	1.2	10	12	<0.1	36	<1.0	3.0
0	86	2.0	16	8.9	6.7	1.6	8.6	5.9	<0.1	31	<1.0	--
0	168	0.05	19	11	10	2.3	7.5	0.9	0.1	55	<1.0	16
0	253	<0.05	28	18	20	6.8	3.5	1.2	0.5	58	<1.0	--
0	97	0.07	11	5.9	9.9	2.7	2.0	0.3	0.2	48	<1.0	--
0	79	0.17	11	6.3	6.0	1.2	2.2	2.5	0.1	33	2.0	<2
0	98	4.9	25	7.7	8.8	1.4	5.9	11	<0.1	34	<1.0	--
0	62	2.2	13	5.3	6.4	1.2	6.3	5.7	<0.1	30	2.0	--
0	89	2.0	16	8.8	6.1	2.2	5.4	6.9	<0.1	32	2.0	3.0
0	91	2.6	16	9.1	6.1	2.1	5.9	6.2	<0.1	32	1.0	--
0	83	<0.05	11	5.6	7.8	2.2	1.6	3.2	0.1	40	<1.0	--
0	193	0.06	39	14	8.4	3.5	7.9	23	<0.1	62	<1.0	24

Appendix 3.--*Water-quality data in the Tacoma-Puyallup area, Washington--Continued*

Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Selenium, dissolved (µg/L as Se)	Coliform, total, immediate M-Endo medium (cols. per 100 mL)	Streptococci, fecal, KF Agar (cols. per 100 mL)
--	--	--	--	<3	--	<1	--	--	--	<1	<1
--	--	--	--	8	--	96	--	--	--	27	<1
--	--	--	--	4	--	10	--	--	--	<1	<1
16	<1.0	<1.0	<1.0	<3	<1.0	11	<1.0	4	<1	<1	<1
--	--	--	--	<3	--	<1.0	--	--	--	<1	<1
7.6	--	--	--	6	--	<1.0	--	--	--	<1	<1
32	<1.0	<1.0	<1.0	<3	<1.0	<1.0	<1.0	<3	<1	<1	<1
27	<1.0	<1.0	<1.0	<3	<1.0	1	<1.0	3	<1	2B*	<1
--	--	--	--	7	--	<1.0	--	--	--	<1	<1
12	--	--	--	<3	--	<1.0	--	--	--	<1	<1
14	--	--	--	<3	--	<1.0	--	--	--	<1	<1
--	--	--	--	10	--	2	--	--	--	<1	<1
--	--	--	--	<3	--	<1.0	--	--	--	<1	<1
25	--	--	--	25	--	28	--	--	--	<1	<1
34	--	--	--	12,000	--	1,100	--	--	--	<1	<1
21	<1.0	<1.0	3	8	2	2	<1.0	88	<1	<1	<1
--	--	--	--	220	--	89	--	--	--	<1	<1
21	<1.0	<1.0	<1.0	8	<1.0	<1.0	<1.0	9	<1	<1	<1
16	<1.0	<1.0	<1.0	<3	<1.0	<1.0	<1.0	<3	<1	8B*	1B*
19	<1.0	<1.0	<1.0	6	<1.0	1	<1.0	11	<1	<1	<1
--	--	--	--	<3	--	<1.0	--	--	--	1B*	<1
15	<1.0	<1.0	1	4	<1.0	<1.0	<1.0	<3	<1	90	2B*
--	--	--	--	<3	--	<1.0	--	--	--	<1	<1
22	<1.0	<1.0	<1.0	12,000	<1.0	420	<1.0	4	<1	<1	<1
68	--	--	--	650	--	300	--	--	--	<1	<1
23	--	--	--	140	--	65	--	--	--	<1	3B*
15	<1.0	<1.0	2	15	<1.0	4	<1.0	18	<1	27B*	<1
13	--	--	--	38	--	1	--	--	--	<1	<1
16	--	--	--	18	--	3	--	--	--	<1	<1
9.6	<1.0	<1.0	1	<3	<1.0	<1	<1.0	<3	<1	<1	2B*
--	--	--	--	<3	--	<1	--	--	--	<1	<1
23	--	--	--	24	--	51	--	--	--	<1	<1
29	<1.0	<1.0	<1.0	5,400	<1.0	410	<1.0	<3	<1	3B*	<1

Appendix 3.--*Water-quality data in the Tacoma-Puyallup area, Washington--Continued*

Alkalinity, field (mg/L as $CaCO_3$)	Solids, residue, at 180 deg. C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Mercury, dissolved (µg/L as Hg)	RN-222 two sigma total (pCi/L)	Radon, 222 total (pCi/L)	*E-coli* with Mug Agar (cols. per 100 mL)	Carbon, organic total (mg/L as C)	Hardness, total (mg/L as $CaCO_3$)	Methylene blue active substances (mg/L)	Sodium, percent	Sodium plus Potassium, percent
78	132	132	--	28	810	--	0.3	82	--	16	21
71	97	100	--	23	460	--	0.1	52	--	28	44
61	118	112	--	25	470	--	0.1	49	--	20	37
60	105	109	<0.1	23	440	--	0.1	49	<0.02	19	28
78	134	138	--	--	--	--	--	81	--	14	17
95	139	148	--	--	--	--	--	93	<0.02	15	19
156	216	225	<0.1	--	--	--	--	160	<0.02	11	14
22	57	61	<0.1	--	--	2B*	--	28	<0.02	30	45
56	99	105	--	28	450	--	0.3	48	--	17	27
52	94	102	--	--	--	--	--	59	<0.02	17	23
66	124	119	--	--	--	--	--	69	<0.02	15	21
54	112	106	--	24	450	--	0.4	45	--	19	31
210	72	79	--	--	--	--	--	39	--	20	28
91	135	142	--	23	430	--	0.9	70	<0.02	25	39
111	200	189	--	--	--	--	--	75	<0.02	19	29
116	186	192	<0.1	--	--	--	--	130	<0.02	13	16
59	105	110	--	25	260	--	0.5	45	--	23	34
78	129	139	0.1	--	--	--	--	63	<0.02	20	31
87	142	152	<0.1	--	--	--	--	90	<0.02	15	21
111	182	186	<0.1	27	550	--	0.3	120	<0.02	14	18
75	130	138	--	28	570	--	0.7	81	--	16	22
68	167	166	<0.1	--	--	43B*	--	87	<0.02	18	23
71	129	130	--	--	--	--	--	77	--	16	57
138	192	201	<0 1	--	--	--	--	93	<0.02	19	27
207	246	261	--	--	--	--	--	140	0.02	23	36
80	119	128	--	--	--	--	--	52	<0.02	29	48
65	93	102	<0.1	--	--	23B*	--	53	<0.02	20	27
80	150	164	--	--	--	--	--	94	<0.02	17	22
50	110	108	--	--	--	--	--	54	<0.02	20	28
73	125	130	<0.1	22	450	--	0.7	76	<0.02	15	21
75	128	134	--	--	--	--	--	77	--	15	21
68	104	112	--	--	--	--	--	51	<0.02	25	39
158	261	259	<0.1	--	--	2B*	2.8	160	<0.02	11	15

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