Prepared in cooperation with the
Jefferson County Department of Natural Resources

Ground-Water System in the Chimacum Creek Basin and Surface Water/Ground Water Interaction in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers, Eastern Jefferson County, Washington

Scientific Investigations Report 2004–5058

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph looking southeast towards the community of Chimacum, Washington. (Photograph taken by William F. Simonds, U.S. Geological Survey, 2004)

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U.S. Department of the Interior
Gale A. Norton, Secretary

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Contents

Plate

[In pocket]

Figures

Tables

Conversion Factors and Datum

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second
acre-foot per year (acre-ft/y)	1,233	cubic meter per year
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second (ft^3/s)	724	acre-foot per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per hour (ft/h)	0.3048	meter per day
gallon (gal)	3.785	liter
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
mile (mi)	1.609	kilometer
square mile (mi^2)	259.0	hectare
	2.590	square kilometer

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=1.8\ °C+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Ground-Water System in the Chimacum Creek Basin and Surface Water/Ground Water Interaction in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers, Eastern Jefferson County, Washington

By F. William Simonds, Claire I. Longpré, and Greg B. Justin

Abstract

A detailed study of the ground-water system in the unconsolidated glacial deposits in the Chimacum Creek Basin and the interactions between surface water and ground water in four main drainage basins was conducted in eastern Jefferson County, Washington. The study will assist local watershed planners in assessing the status of the water resources and the potential effects of ground-water development on surface-water systems. A new surficial geologic map of the Chimacum Creek Basin and a series of hydrogeologic sections were developed by incorporating LIDAR imagery, existing map sources, and drillers' logs from 110 inventoried wells. The hydrogeologic framework outlined in the study will help characterize the occurrence of ground water in the unconsolidated glacial deposits and how it interacts with the surface-water system.

Water levels measured throughout the study show that the altitude of the water table parallels the surface topography and ranges from 0 to 400 feet above the North American Vertical Datum of 1988 across the basin, and seasonal variations in precipitation due to natural cycles generally are on the order of 2 to 3 feet. Synoptic stream-discharge measurements and instream mini-piezometers and piezometers with nested temperature sensors provided additional data to refine the positions of gaining and losing reaches and delineate seasonal variations. Chimacum Creek generally gains water from the shallow ground-water system, except near the community of Chimacum where localized losses occur. In the lower portions of Chimacum Creek, gaining conditions dominate in the summer when creek stages are low and ground-water levels are high, and losing conditions dominate in the winter when creek stages are high relative to ground-water levels.

In the Quilcene Bay area, three drainage basins were studied specifically to assess surface water/ground water interactions. The upper reaches of Tarboo Creek generally gain water from the shallow ground-water system throughout most of the year and the lower reaches have little or no gains. The Big Quilcene River generally gains water from the shallow ground-water system after it emerges from a bedrock canyon and loses water from the town of Quilcene to the mouth of the river in Quilcene Bay. The Little Quilcene River generally loses water to the shallow ground-water system, although two localized areas were found to have gaining conditions. The Big Quilcene and Little Quilcene Rivers incur significant losses on the alluvial plain at the head of Quilcene Bay.

Each of the creeks examined had a unique pattern of gaining and losing reaches, owing to the hydraulic conductivity of the streambed material and the relative altitude of the surrounding water table. Although the magnitudes of gains and losses varied seasonally, the spatial distribution did not vary greatly, suggesting that patterns of gains and losses in surface-water systems depend greatly on the geology underlying the streambed.

Introduction

Increased use of surface-water and ground-water resources in drainage basins of Washington State has created concern that insufficient instream flows remain for fish and other uses. In response, the Washington State legislature passed the Watershed Management Act of 1998 (House Bill 2514), which provides funding for watershed planning and delegates planning to a local level. The planning process allows interested parties in a watershed area (designated as a Water Resources Inventory Area, or WRIA) to assess the status of water resources and prepare a plan for managing the water available for allocation and use within the WRIA that accommodates a variety of locally competing water uses.

WRIA 17, located primarily in eastern Jefferson County, covers about 400 mi^2 and is home to most of the county's population (fig. 1). The population in eastern Jefferson County is projected to increase in the coming years, with a corresponding increase in land development and the need for domestic and municipal water supplies. To plan for this growth, Jefferson County and the WRIA 17 Watershed Planning Unit are coordinating efforts to better understand local water resources. One step toward this end was a comprehensive assessment of existing hydrologic information for WRIA 17 that also identified the need for additional data, information, and studies (Parametrix, Inc., 2000). Foremost among those needs were more detailed information on the area's ground-water resources and a better understanding of interactions between surface-water and ground-water systems. This information is important because of the potential effects of further ground-water development on surface-water resources in the WRIA 17 area.

In 2002, the U.S. Geological Survey (USGS) in cooperation with the Jefferson County Department of Natural Resources began a 3-year study of (1) the ground-water system in the Chimacum Creek Basin in the northeastern part of the WRIA 17 area, and (2) the interaction between surface water and ground water in Chimacum Creek and in Tarboo Creek and the lower parts of Big and Little Quilcene Rivers in the Quilcene Bay area. The first part of the study included defining the hydrogeologic framework and describing a conceptual model of ground-water flow in the basin. The second part of the study included identifying gaining and losing reaches, the quantity of surface water gained or lost in a reach, and any seasonal variations. This study addresses the need for a more detailed hydrogeologic framework and expands on the previous assessment of ground-water resources of eastern Jefferson County (Grimstad and Carson, 1981) and provides new information about surface water/ground water interactions in the area.

Purpose and Scope

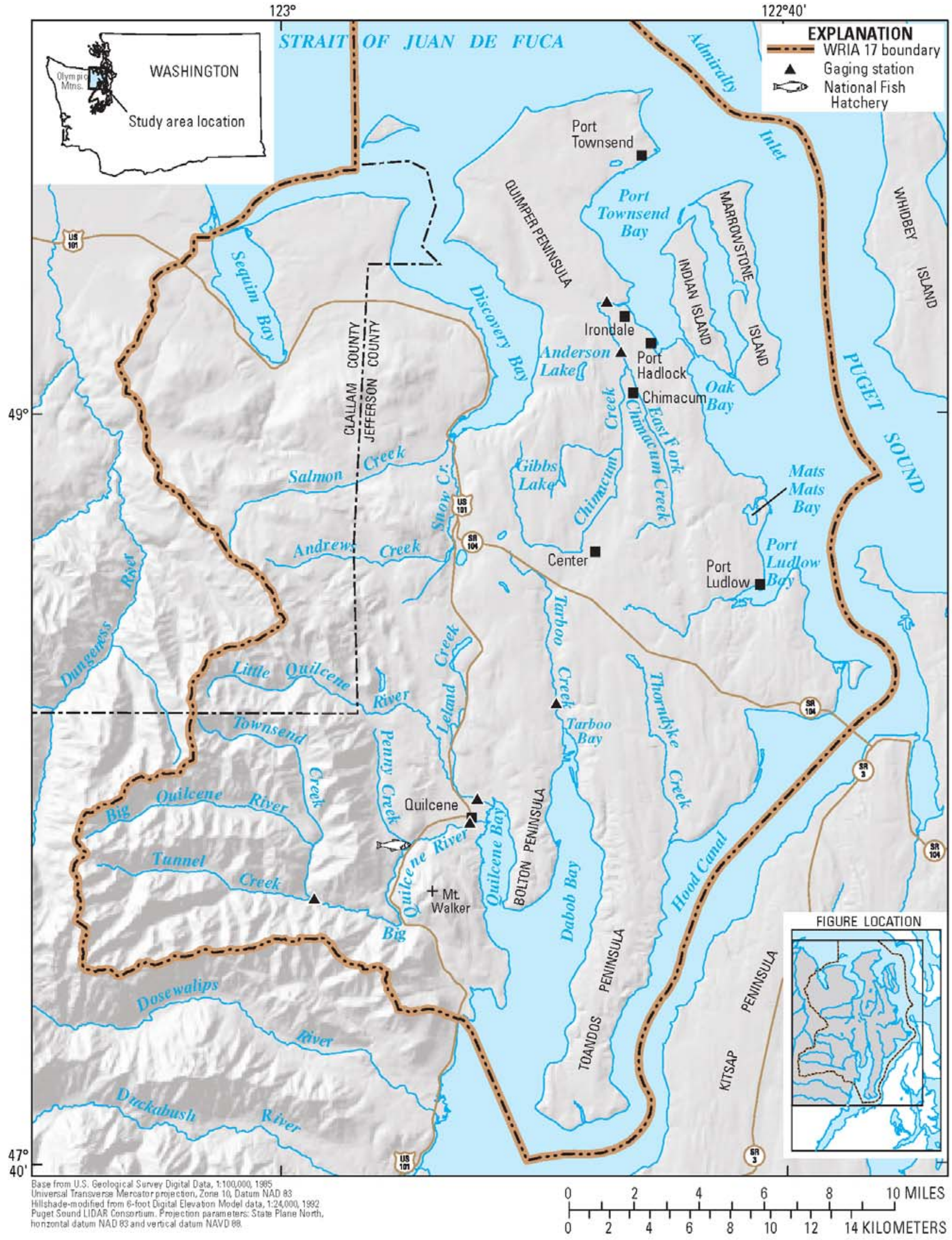
This report presents the results of the study to (1) assess the ground-water system in the Chimacum Creek Basin and (2) describe the interaction of surface water and ground water in the four main drainage basins in the WRIA 17 area. The assessment of the ground-water system includes defining the hydrogeology and determining the thickness of hydrogeologic units, the horizontal and vertical movement of ground water, and areas of recharge and discharge. The interaction of surface water and ground water includes determining boundaries of gaining and losing reaches in streams, the quantity of surface water gained or lost, seasonal variations, and a comparison of the four drainage basins. Information provided in this report will support the development of a comprehensive watershed plan for WRIA 17 and help assess the effects of future ground-water development. The report includes an assessment of additional studies needed.

Previous Studies

Several important sources of information preceded this study. This study builds largely upon the work of Grimstad and Carson (1981), who described the geology and ground-water resources of eastern Jefferson County. Geologic investigations by Tabor and Cady (1978) and subsequent mapping investigations have been compiled and put into digital format by the Washington State Department of Natural Resources. The area's water and biological resources were further characterized in the Dungeness-Quilcene Water Resources Management Plan, which includes parts of Clallam County (Jamestown S'Kallam Tribe, 1994). A detailed technical assessment of available data was compiled by Parametrix, Inc. (2000). Other sources of data include the Tri-Area Ground-Water Study prepared by CH2M Hill (1996) and the Soil Survey of Jefferson County Area, Washington, by Fred McCleary (U.S. Department of Agriculture, 1975).

Acknowledgments

The authors wish to thank all members of the WRIA-17 Planning Unit, particularly Susan Gulick, who leads the group. Special thanks to William Graham of the Jefferson County Public Utilities District #1, who performed much of the monthly well monitoring in both rain and shine. Thanks to Glen Gately of the Jefferson County Conservation District, who provided useful data, field help, and insight. Thanks to the many others who helped in various aspects of the study, including the Port Gamble S'Klallam Tribe, the staff at the National Fish Hatchery in Quilcene, and the many long-time residents of the area, who took interest in the project, allowed repeated access to their wells, and whose knowledge of historical events was invaluable.



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
Universal Transverse Mercator projection, Zone 10, Datum NAD 83
Hillshade-modified from 6-foot Digital Elevation Model data, 1:24,000, 1992
Puget Sound LIDAR Consortium. Projection parameters: State Plane North,
horizontal datum NAD 83 and vertical datum NAVD 88.

Figure 1. Drainages of Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers in Water Resource Inventory Area 17, eastern Jefferson County, Washington.

Description of Study Area

The study area is located on the northeastern corner of the Olympic Peninsula in eastern Jefferson County, Washington and includes four major drainage basins: Chimacum Creek/East Fork Chimacum Creek, Tarboo Creek, and the Big and Little Quilcene Rivers (fig. 1). Chimacum Creek flows south from its source, turns east toward the community of Center, then flows north toward the community of Chimacum eventually draining into Port Townsend Bay near the community of Irondale. A major tributary, locally known as the East Fork of Chimacum Creek, flows north and joins the main stem near the community of Chimacum. Tarboo Creek flows south from State Route 104 toward Dabob Bay on the west side of the Toandos Peninsula (fig. 1). The Big and Little Quilcene Rivers originate on the eastern flank of the Olympic Mountains and drain into Quilcene Bay near the community of Quilcene (fig. 1). All of these drainage basins lie within the western Puget Sound Lowland and are therefore influenced by glacial landforms formed during the Pleistocene ice age epoch. The distribution of bedrock and the overlying unconsolidated glacial deposits is an important factor affecting the location, quantity, and quality of ground-water resources, as well as surface water/ground water interactions in the area.

Topography, Climate, and Vegetation

The land-surface topography of the western Puget Sound Lowland consists of narrow, regularly spaced parallel ridges and grooves, oriented in a north-south direction that are characteristic of a fluted glaciated surface (Ritter, 1978). This surface has been incised locally by fluvial and post-glacial erosion, producing steep valley sides and hummocky valley bottoms. Thick accumulations of peat occur along the axis of larger valleys and provide rich soils for agricultural use. Bedrock outcrops generally are low and exhibit glacial-scouring features.

The climate in the study area varies, but generally is marine, with cool, dry summers and mild, wet winters. Precipitation across the study area ranges from 70 to 80 in/yr in the eastern foothills of the Olympic Mountains to 15 to 20 in/yr in Port Townsend. Precipitation in the study area is influenced by the rainshadow effect on the leeward side of the Olympic Mountains: near the outside edge of the rainshadow, Quilcene receives an average of 55.8 in/yr, whereas farther inside the rainshadow, Chimacum receives an average of 29.7 in/yr. Most of the precipitation occurs as rain, between the months of November and May. Snow that falls in the higher altitudes of the Olympic Mountains provides snowmelt runoff for the drainages of the Big and Little Quilcene Rivers during the spring and early summer.

Vegetation across the study area ranges from dense coniferous forest in the moderately steep uplands to agricultural pasture lands in the lower parts of each drainage basin. Harvesting and processing of forest products provide a major economic resource for the region. The valleys of Chimacum Creek and East Fork of Chimacum Creek, portions of the Tarboo Valley, and other glacial depressions are characterized by thick sequences of poorly drained soils rich in organic material. Many of these areas are used extensively for hay and pasture and have managed drainage and irrigation systems. Other farm products include a variety of berries, small grains, vegetables, and specialty crops.

Land use in the Chimacum Creek Basin is divided between zoned forest lands in the upland areas and zoned residential land along Port Townsend Bay and around the Tri-Area, which includes the communities of Chimacum, Port Hadlock, and Irondale (fig. 1). The fertile lands in the center of the Chimacum Valley are zoned primarily for commercial agriculture, but are flanked by areas zoned for residential use. Land use in the Quilcene Bay area is zoned predominantly as forest land, with residential development dominating the lowland area around Quilcene Bay. Upland areas adjacent the Olympic National Park are zoned forest lands and the park itself is designated wilderness.

Population and Water Use

The population of Jefferson County in the 2000 census was 25,953 residents. The population increased to 26,835 in 2003 (WRIA 17 Watershed Plan, Cascadia Consulting Group, 2003, unpub. data) and could conceivably increase to nearly 40,000 residents by the year 2016 (Jefferson County, 1998). Most of the increase is expected in three main centers: the Quimper Peninsula area (Port Townsend urban growth area), the Port Ludlow area, and the Tri-Area (Chimacum, Port Hadlock, and Irondale). The effect of the increasing population has resulted in a gradual shift from agricultural and forestry to more residential land use in the area. Water usage also is expected to increase as the population increases. Demand for water, especially in the residential and commercial sectors, is of primary concern for water managers. Water needs for industrial and agricultural water users, such as the Port Townsend Paper Company, the National Fish Hatchery in Quilcene, Chimacum Valley Irrigation, and the U.S. Navy at Indian Island, have not increased, and water consumption in recent years has been reduced through conservation efforts (table 1).

Table 1. Estimated water use, eastern Jefferson County, Washington, 1992

[Data from Jamestown S'Kallam Tribe, 1994]

Type of use	Water use (million gallons per year)		
	Surface water	Ground water	Total use
Residential/commercial	605	508	1,113
Industrial	4,850	0	4,850
Agricultural	158	72	230
Hatchery/Fisheries	4,024	257	4,281
U.S. Navy	27	0	27
Total	9,664	837	10,501

Water-resource managers are looking increasingly to ground water as a source to accommodate residential and commercial growth. Currently, most residential, commercial, and industrial water users in eastern Jefferson County are served by class A and class B water systems. (Class A systems are defined as 15 or more service connections serving 25 or more residents; class B systems have fewer than 15 service connections and serve fewer than 25 residents). These water systems rely on ground water from well fields, as well as surface water diverted from the Big Quilcene and Little Quilcene Rivers. Most private residences are served by ("exempt" wells, which are single-family domestic wells that use less than 5,000 gal/d). Because of restrictions on future surface-water rights, any expansion of existing water systems may rely heavily on use of ground-water resources if it can be shown that the use will not adversely affect surface-water flows.

Precipitation and Streamflow

All surface-water and ground-water resources in eastern Jefferson County are ultimately derived from precipitation. Water that is not lost to evapotranspiration or surface-water runoff or held as soil moisture eventually recharges aquifers that make up the ground-water system. The amount of precipitation varies spatially across the area, and seasonal and annual variations can be quite large. Stream discharge is closely tied to precipitation for all the lowland drainage basins, but snowmelt can have a large effect on flows in the Big and Little Quilcene Rivers, which have headwaters at high altitudes in the Olympic Mountains. Catastrophic floods can occur anytime during the winter, but typically result from rain-on-snow events. In dry months, streamflow is maintained entirely by ground-water discharge, or base flow.

Streamflow in the drainage basins of concern in this study is currently monitored by gaging stations operated by the USGS, Washington State Department of Ecology (WDOE), and the Jefferson County Public Utilities District (PUD) #1 (fig. 1). Chimacum Creek currently has two gaging stations, one operated by PUD at river mile 2.67 and a new WDOE station (ID17B050) installed near the mouth of the creek. New WDOE stations were installed on Tarboo Creek at river mile 0.6 (ID17G060) and on the Big Quilcene River at river mile 0.65 near Linger Longer Road in Quilcene (ID17A060). Both stations are equipped with Geostationary Orbiting Earth Satellite (GOES) data-collection platforms and transmit streamflow data in real time. Long-term streamflow data for the Big Quilcene River are available from the USGS gaging station (12052210) at river mile 9.4, which has collected continuous streamflow data since January 1994. A staff gage and discharge rating are maintained by the USGS for the Big Quilcene River at the National Fish Hatchery at Penny Creek to monitor instream flows and hatchery diversions (fig. 1). A new WDOE station that transmits streamflow data in real time also was installed on the Little Quilcene River at Center Road in Quilcene (ID17D060). Miscellaneous discharge is measured periodically by the USGS on the Little Quilcene River below the diversion for the City of Port Townsend. Stream stage (water level) and discharge data for Chimacum Creek were collected by the Jefferson County PUD #1 and for the Big and Little Quilcene Rivers by the WDOE. Streamflow data are available through the USGS Water Resources web site (http://nwis.waterdata.usgs.gov/wa/nwis/inventory/?site_no=12052210) or the WDOE web site (http://www.ecy.wa.gov/apps/watersheds/flows/state.asp).

Precipitation data for the WRIA 17 area are collected by the National Weather Service at station Chimacum 4 S, located in the community of Center, and at station Quilcene 2 SW, located at the National Fish Hatchery near Quilcene (fig. 1). Precipitation data for the period of this study from station Chimacum 4 S, located at Center, are shown in figure 2.

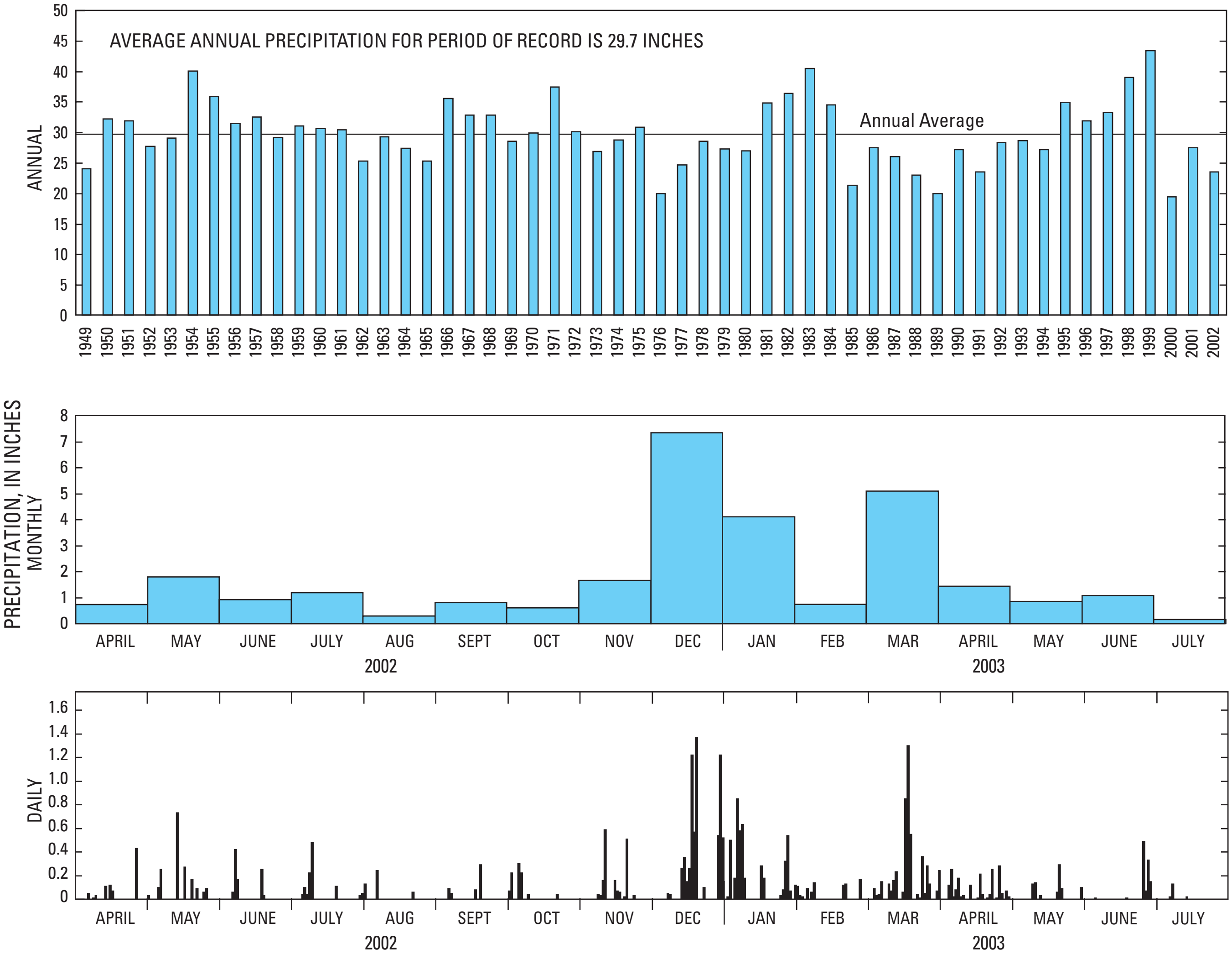


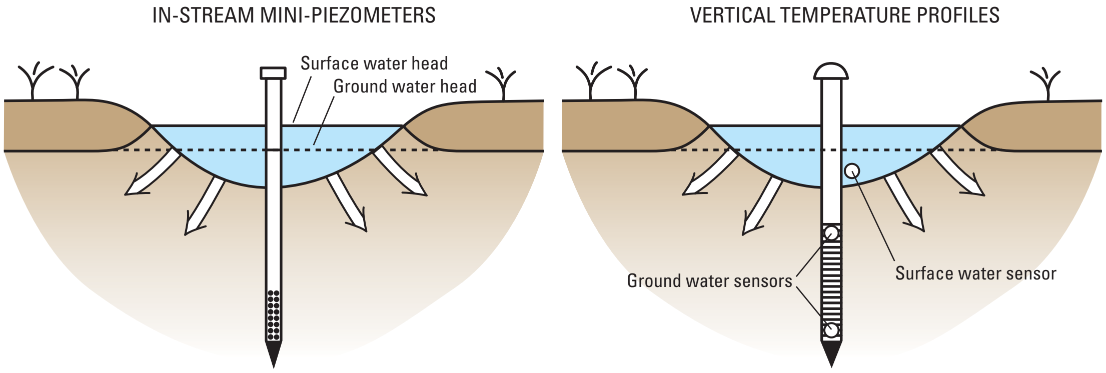
Figure 2. Annual (1949-2002), monthly (April 2002-July 2003), and daily (April 1, 2002-July 30, 2003) precipitation at National Weather Service station Chimacum 4S, Center, Washington.

Study Methods

This study was conducted in two parts: (1) an assessment of the ground-water system that included characterizing the hydrogeology and developing a conceptual ground-water-flow model for the Chimacum Creek Basin, and (2) assessment of surface water/ground water interactions along Chimacum Creek, Tarboo Creek, the Big Quilcene River, and the Little Quilcene River.

Water levels were measured during a well inventory in spring 2002 to characterize the hydrogeology of the Chimacum Creek Basin. In autumn of 2002, synoptic water-level measurements were made in order to remeasure water levels during the dry season. A subset of nine wells was selected for monthly water-level monitoring, and one of these wells was instrumented with a continuous data logger. Water-level data, drillers' logs, geologic maps, and previous studies then were compiled and analyzed to define a conceptual model of ground-water flow in the Chimacum Creek Basin.

Two sets of seepage runs were conducted and instream mini-piezometers were installed on each creek to assess surface water/ground water interactions. Temperature data loggers were installed at two sites on Chimacum Creek and at one site each on the Big and Little Quilcene Rivers in order to generate continuous vertical temperature profiles. Seepage runs, instream mini-piezometers, and vertical temperature profiles provide three independent methods to assess surface water/ground water interactions (fig. 3).




Hydrologist using a manometer board to measure head differences between surface water and ground water.


Hydrologists measuring stream discharge.

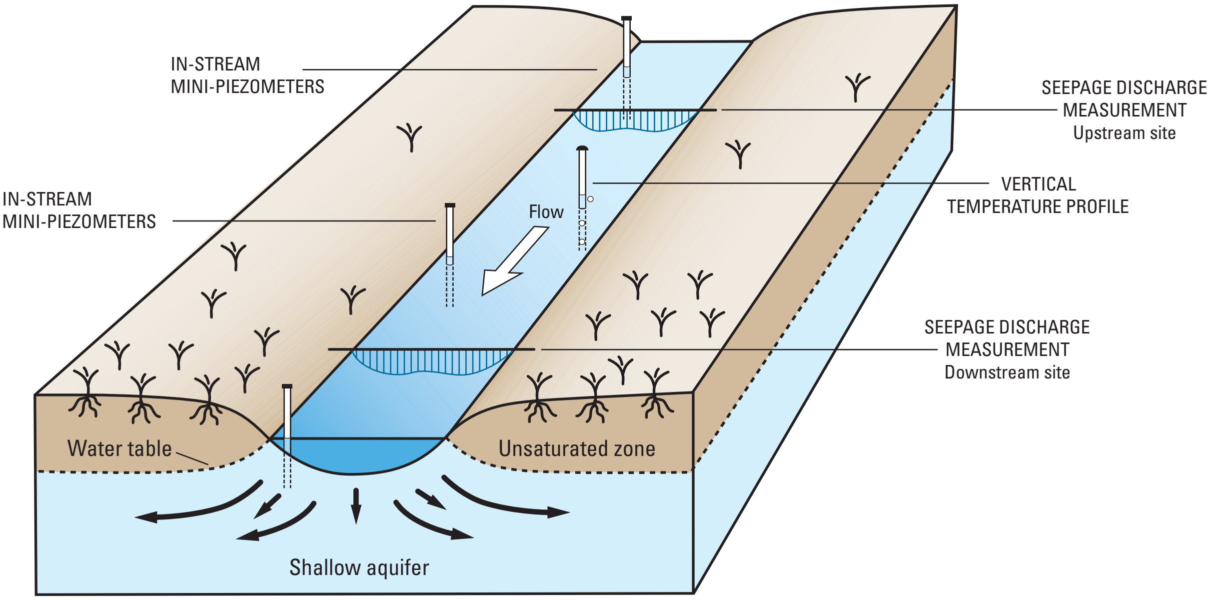


Figure 3. Typical instream mini-piezometer and vertical temperature profile and configuration of a seepage run along a reach of a stream.

Well Inventory

Throughout May 2002, 110 wells were inventoried in the Chimacum Creek Basin. The results of the inventory are shown in table 8 (at back of report). Criteria for site selection included availability of a drillers' report and lithologic information (obtained from WDOE, local drillers, and well owners), location and depth of well, permission from the owner to visit the site, and ease of access to the well. Data from wells identified by Grimstad and Carson (1981) were taken into consideration, even though the physical locations of these wells could not be precisely determined. These wells are approximately located on the basis of previously mapped positions (pl. 1).

The inventory was designed to have an even spatial distribution of inventoried wells within the unconsolidated deposits throughout the study area. However, this was not possible in all areas because much of the basin is not developed and, to a much lesser extent, because permission to measure some wells could not be obtained. Information gathered at all wells included site location, land-surface altitude, primary use of water, well-construction details, and a drillers' log. Depth to water (water level) was measured in 49 wells using a calibrated electric tape or graduated steel tape, both with accuracy to 0.01 ft, and entered into the USGS Ground Water Site Inventory (GWSI) data base. In some cases, water levels were not measured because of difficult access or other complications. Latitude and longitude locations were obtained for field-located wells using a Global Positioning Satellite (GPS) receiver with a horizontal accuracy of 0.5 second. Geographic Information Systems (GIS) software was used to interpolate altitudes of the land surface at each site from imagery obtained using LIght Distance And Ranging (LIDAR), a multiple-return scanning laser altimeter in a fixed-wing aircraft flown in a pattern over the area. All information collected during the inventory is stored as part of the USGS National Water Information System (NWIS) database.

The well-numbering system used in this report is based on the township, range, section, 40-acre tract within the section, and sequence of wells within that tract. For example, well 29N/01W-35J01 refers to township (T. 29 N) and the range (R. 01 W) north and west of the Willamette Base Line and Meridian (fig. 4). The first number following the hyphen indicates the section (35) within the township, and the letter (J) following the section number gives the 40-acre subdivision of the section. The number (01) following the letter is the sequence number of the well within the 40-acre subdivision. This number indicates that the well was the first one inventoried by USGS personnel in that 40-acre subdivision.

In October 2002, synoptic water-level measurements were made in 48 of the inventoried wells over a relatively short period of time to calculate water-level altitudes in the basin. Nine wells were selected for monthly monitoring to provide an indication of seasonal variations in different parts of the Chimacum Creek Basin. One of the monthly monitoring wells (29N/01W-15B01) was equipped with a continuous water-level data logger to provide a continuous water-level record.

Water-level altitudes from the initial well inventory and from the synoptic measurements were plotted on a map and used to construct water-level-altitude contours. In order to further refine their positions, contours were adjusted to match the altitudes of ephemeral streams, springs, and flowing wells. Contours were drawn so that water-level altitudes were above stream altitudes in gaining reaches and below stream altitudes in losing reaches of Chimacum Creek. The water-level altitude contours were used to infer directions of ground-water flow in the basin.

Hydrogeology

Well logs from field-inventoried wells were compared with data from previous studies, and hydrogeologic units were delineated primarily on the basis of grain size and stratigraphic position. Altitudes of the tops of each unit were entered into a graphical software package (Rockworks^{TM}) so that hydrogeologic units could be correlated and hydrogeologic sections constructed.

Available surficial-geologic maps and the latest LIDAR imagery were consulted to refine the geology of the Chimacum Creek Basin. LIDAR data were acquired in early 2000 and early 2001 under a contract for the Puget Sound LIDAR Consortium. The data were processed to remove return signals from forest canopy and buildings by automatic geometric filtering or virtual deforestation. The final image represented bare-ground altitudes with a horizontal resolution of about 6 ft and a vertical resolution of about 1 ft. The high-resolution LIDAR data were used to refine the previously mapped surficial geology (pl. 1). Geologic contacts were modified to match the level of detail visible in the LIDAR imagery. Maps of extent and thickness of hydrogeologic units were generated using a combination of available geologic mapping, hydrogeologic sections, and drillers' logs.

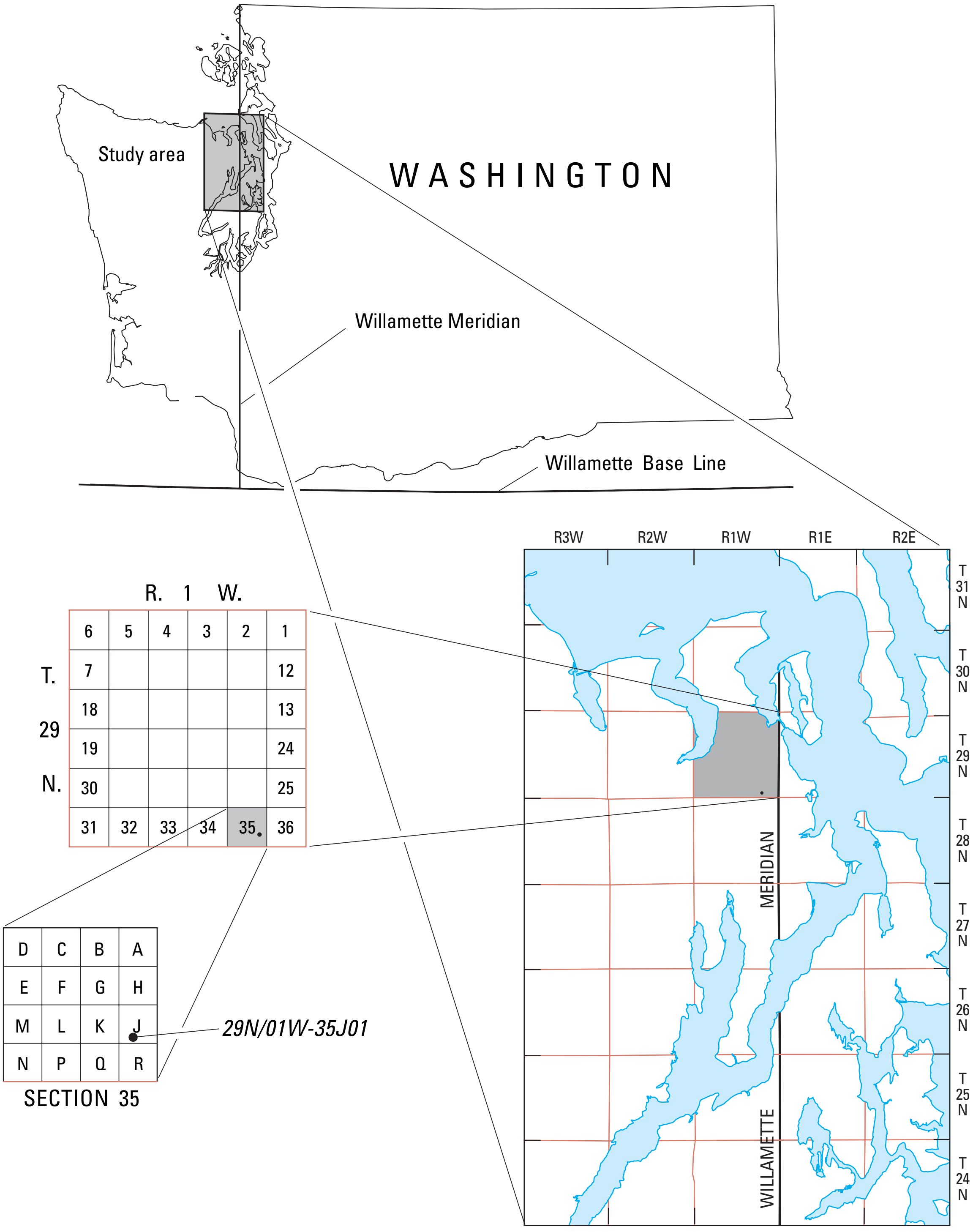


Figure 4. Well-numbering system used in Washington.

Surface-Water and Ground-Water Interactions

Three techniques were used to gain understanding of the exchange of surface water and ground water in Chimacum Creek, Tarboo Creek, and the Big and Little Quilcene Rivers. (1) Seepage runs were conducted in the spring and autumn of 2002 to determine the quantity of water being gained or lost from the surface-water system. (2) Instream mini-piezometers were installed to delineate boundaries between gaining and losing reaches and periodically measured to estimate seasonal variations. (3) Piezometers with nested temperature sensors were installed and programmed to record continuous temperature data. The three techniques were used in concert (see fig. 3) to improve accuracy and aid in the interpretation of the data.

Seepage Runs

Two seepage runs were conducted on each of the four stream systems, one in late June or early July 2002 and one in late October 2002. Seepage runs consist of multiple discharge measurements made at nearly the same time at different points along the river during a period of stable base-flow (all ground-water discharge) conditions. To calculate stream discharge, the velocity of water is multiplied by the cross-sectional area of the stream (stream depth times stream width) using the integrated-cross-section method described by Rantz and others (1982). Most velocity measurements were made using either a Price AA current meter or a Swoffer Model 2100 horizontal-axis current meter. Side-by-side comparisons of the two meters yielded differences of less than 3 percent. Small tributary streams with flows less than 0.5 ft^3/s were measured using either a pygmy meter, a Parshall Flume, or by simply timing the fill of a 5-gallon bucket.

To determine the volume of water gained or lost by the stream, the discharge measurements are used in a mass balance calculation as follows.

$$\text{Net seepage gain or loss} = Q_d - T - Q_u + D, \qquad (1)$$

where

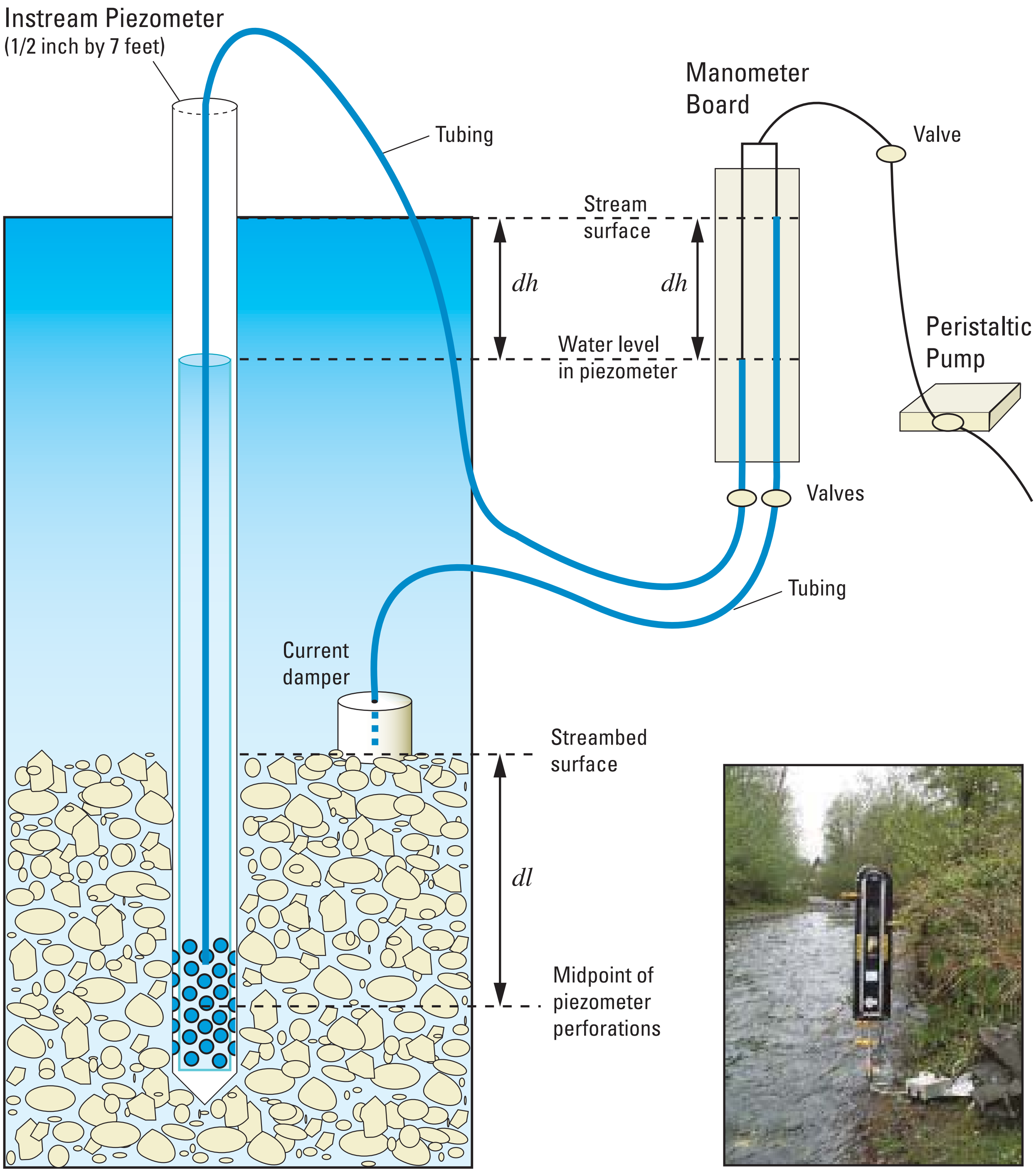
Q_u = discharge at the upstream end of a reach (ft^3/s);
Q_d = discharge at the downstream end of a reach (ft^3/s);
T = sum of all tributary inflows within a reach (ft^3/s); and
D = sum of all irrigation or diversion outflows within a reach (ft^3/s).

Seepage runs are conducted only under base-flow conditions; rapidly changing flow conditions and storm events are avoided. In order to better understand how ground-water discharge varies between spring high flow and late-summer low flow, seepage runs typically are conducted at different times of year. During a seepage run, all tributary inflows and irrigation outflows are measured, so that discrepancies in the water budget between measuring points reflect only gains or losses through the streambed. The resulting gain or loss computed between measuring points is an estimate of the net rate of water exchanged between surface water and ground water, averaged over the entire reach. Therefore, no information is provided about gains or losses that occur at a smaller scale within the reach. Mini-piezometers are used to obtain information about hydraulic conditions at specific points within a reach of stream.

Mini-Piezometers

Instream mini-piezometers are miniature monitoring wells driven directly into the streambed for direct comparison of surface-water and ground-water levels. Each mini-piezometer consists of a 7-foot length of 0.5-inch-diameter pipe, crimped and perforated with small holes at one end. Each mini-piezometer is hand-driven with a slide hammer to a depth of about 4 ft below the streambed at distances of 0.5 to 1 mi along the reach of the stream. A total of 11 mini-piezometers were installed in Chimacum Creek: 4 in the main stem between the mouth of the creek and the confluence with the East Fork, 2 in the East Fork, and 5 in the main stem extending upstream to river mile 8.8. Five mini-piezometers were installed in Tarboo Creek between the mouth and river mile 4.0. Six mini-piezometers were installed in the Little Quilcene River between the mouth and river mile 2.5. Five mini-piezometers were installed in the Big Quilcene River between the mouth and river mile 2.7.

Each instream mini-piezometer is installed directly in the stream at a calm location away from point bars or riffles that could locally induce surface-water flow through the streambed material (hyporheic flow). A direct comparison of surface-water head (the term "head" as used in this report is defined as the height of the free surface of a body of water above a given subsurface point) and ground-water head can be made at each site using a manometer board (fig. 5). In some places, hydraulic conductivity of the streambed material is too low to produce enough water for the manometer board to work effectively (the time for ground-water levels to achieve equilibrium after pumping water through the manometer board is too excessive to be practical). An alternative to the manometer board is to measure the difference in head directly with a steel tape. Steel-tape measurements are made by measuring the distance from a measuring point (typically the top of the pipe) to the ground-water level inside the mini-piezometer and comparing that distance with the stream water level outside the mini-piezometer. Steel-tape measurements usually are identical to those made with the manometer board.



(DIAGRAM NOT TO SCALE)

Manometer board in use

Figure 5. How a manometer board is used to measure hydraulic head differences throughout a streambed. *dh* is the difference in head (water level) between surface water and ground water. *dl* is depth below the streambed to the midpoint of piezometer perforations. Vertical hydraulic gradient is determined by dividing *dh* by *dl*.

By convention, when ground-water levels inside the mini-piezometer are higher than stream-water levels, the ground water is determined to have a positive, or upward, hydraulic gradient. Conversely, when ground-water levels inside the mini-piezometer are lower than stream-water levels, the ground water is determined to have a negative, or downward, hydraulic gradient. Upward hydraulic gradients indicate gaining or effluent conditions in which ground-water flow is toward the stream and contributes to streamflow. Downward hydraulic gradients indicate losing or influent conditions in which surface-water flow drains from the stream into the ground. In this way, areas of gaining and losing streambed conditions can be mapped and compared with seepage-run data.

To normalize for variations in depth of mini-piezometer emplacement, the vertical hydraulic gradient is computed using the equation:

$$i_v = \frac{dh}{dl}, \qquad (2)$$

where

i_v = vertical hydraulic gradient (unitless);

dh = measured difference between head in mini-piezometer and stream stage, in units of length; and

dl = vertical distance between streambed and mid-point of mini-piezometer perforations, in units of length.

Negative values of i_v indicate losing conditions and positive values indicate gaining conditions.

Instream mini-piezometer measurements represent hydraulic conditions at the point of the mini-piezometer at that particular point in time. All mini-piezometers were measured periodically over a 1-year period from July 2002 to July 2003 to determine how hydraulic conditions vary seasonally. The seasonal variations in hydraulic gradients can be compared with water temperatures to better understand how gaining or losing conditions change with time.

Vertical Temperature Profiles

Surface-water temperatures in eastern Jefferson County typically range from 0 to 25 $^{\circ}$C over the course of a year because of variations in seasonal air temperature. Superimposed on the annual cycle is a diurnal cycle of 2 to 4 $^{\circ}$C in stream temperatures caused by warming during the day and cooling at night. Ground water is insulated from daily heating and cooling, and thus remains at a nearly constant temperature (seasonal temperature variations cause ground-water temperatures to vary by a few degrees over the course of several seasons). When surface water enters the streambed, it carries with it a thermal energy signature with a diurnal pattern that can affect temperatures locally in the adjacent aquifer. When ground water enters the streambed and discharges into surface water, the thermal signature from the surface water can change abruptly. Thus, the thermal signatures throughout a vertical section of the streambed can be used to indicate the directions of flow through the streambed and assess gaining and losing conditions. Because temperature is a relatively easy parameter to measure, multiple temperature sensors can be programmed to record continuous data providing detailed information on how surface water/ground water exchanges vary with time.

In this study, four specially constructed piezometers were installed in the streambed. Each was instrumented with temperature sensors recording water temperature at different depths below the streambed and in the stream itself. Each piezometer consists of a 5-foot length of 1.5-inch-diameter pipe attached to a 2-foot-long screen and drive-point assembly (fig. 3). The piezometers were hand-driven into the streambed to a depth of 4 or 5 ft and temperature data loggers were installed at the top and bottom of the screened section. Another data logger was placed on the streambed and anchored to the outside of the piezometer to record stream temperatures. All temperature loggers were programmed to record every 2 hours for a total of 12 temperature readings per day. Temperature data were collected at two sites on Chimacum Creek, one site on the Big Quilcene River, and one site on the Little Quilcene River from May 2002 to July 2003. The surface-water temperature loggers matched occasional field measurements within a degree and recorded good-quality data. Ground-water temperatures could not be verified with field measurements without disturbing the temperature profile. Big Quilcene surface-water data were lost from November 27, 2002, to April 23, 2003, when the data logger was washed away by a flood in March 2003. During extreme low-flow conditions in the late summer of 2002, surface-water data for the Big Quilcene River did not accurately reflect river temperatures because the data logger was isolated in a shallow pool disconnected from the main channel. Some of the data could be substituted with temperature data from a nearby site operated by the City of Port Townsend. The uppermost data logger in the piezometer on Chimacum Creek near the high school also was out of the water for periods during extreme low-flow conditions.

Ground-Water System in the Chimacum Creek Basin

Eastern Jefferson County is situated between two major physiographic features, the Olympic Mountains to the west and the Puget Sound Lowland to the east. These two features dominate both the geologic history and the present hydrologic regime. The occurrence of ground-water resources is intimately tied to the geology and the climatic setting created by these features.

The Olympic Mountains are a prominent landform on the west coast of Washington State formed by tectonic forces related to subduction of oceanic crust beneath the western coast of North America. The Olympic Mountains represent a unique geologic situation where a portion of oceanic crust was not subducted, but rather was crumpled and ultimately accreted against the North American continent. The central core of the Olympic Mountains consists of metamorphosed Eocene-age marine sedimentary rocks that were uplifted and faulted against a peripheral assemblage of oceanic crust and sedimentary rocks that form an arc shape around the north and east flanks of the Olympic Mountains (Tabor and Cady, 1978). The peripheral rocks (fig. 6*A*) consist of Eocene-age, dark volcanic basalts and breccias, intrusive andesites, and marine sandstones and conglomerates that wrap around the central core of metamorphic sedimentary rocks. These deformed peripheral rocks form the bedrock beneath eastern Jefferson County.

The Olympic Mountains and Puget Sound Lowland have since been shaped by mountain glaciers and massive continental ice sheets. From 2 million years ago to about 10,000 years ago, eastern Jefferson County was blanketed by at least four Cordilleran ice sheets that advanced southward from British Columbia. Evidence of the youngest advance, known as the Vashon Stade of the Fraser glaciation, which covered the area with nearly 4,000 ft of ice between 17,000 and 12,000 years ago, is well preserved in western Washington (Easterbrook, 1979). The Fraser Glaciation consisted of two lobes of ice, the Juan de Fuca lobe, extending west into the Strait of Juan de Fuca, and the Puget lobe, extending down the Puget Sound Lowland and stopping just south of Olympia, Washington (fig. 6*B*). Each sequence of glaciations left behind a wide variety of deposits, including unconsolidated sediments deposited in front of the advancing ice front, unsorted and highly compacted tills deposited beneath the ice sheet, and sediments deposited behind the receding ice front, including ice-dam lake deposits (table 2). Interglacial periods also are marked by paleosols, glaciomarine drift, and peat bog or marsh deposits. Thus, the stratigraphy of unconsolidated sediments in eastern Jefferson County is complex, owing to the juxtaposition of environments of deposition and erosion of units by the advancing ice and recessional fluvial systems.

The modern-day drainage pattern is affected by the geomorphology of the post-glacial surface. Most of the major drainages follow pathways established either by mountain glaciers (Big Quilcene and Little Quilcene Rivers) or by Vashon recessional outwash channels (Chimacum and Tarboo Creeks). The spatial variation in precipitation plays an important role in determining the amount of water available for surface-water flow and for recharging the ground-water system. The rainshadow zone behind the Olympic Mountains generally results in drier climatic conditions in the Chimacum area and wetter conditions and higher streamflows in the Quilcene area.

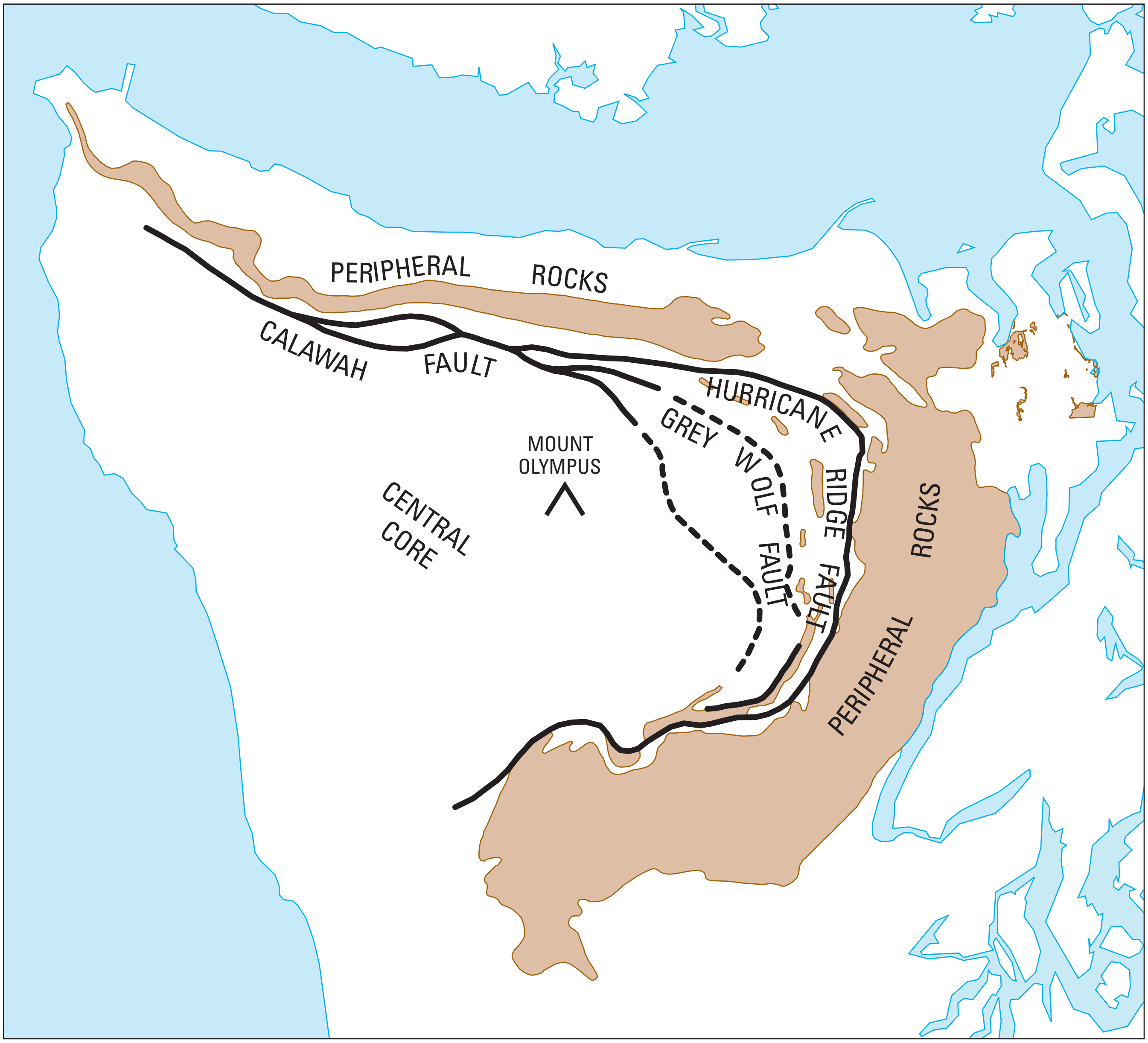
Hydrogeologic Units

Quaternary Alluvium

The youngest deposits in the study area are Holocene-age alluvial deposits (Qa, pl. 1) that include silt, sand, and peat deposits in flat valley bottoms and small lake basins, dune and beach sands along the Puget Sound shoreline, and small landslide deposits. The most notable Holocene deposits are the alluvial sediments through which Chimacum Creek, Tarboo Creek, and the lowermost reaches of the Big and Little Quilcene Rivers flow. In the Chimacum Creek area, this material consists of very poorly drained, organic rich soil known as the Semiahmoo Muck (U.S. Department of Agriculture, 1975). These deposits form fertile agricultural lands adjoining Chimacum Creek and the East Fork of Chimacum Creek, although they typically need to be drained of saturated water before they can be used for agricultural purposes. Many of the tributaries to Chimacum Creek and parts of Chimacum Creek itself have been modified by dredging to improve drainage for the adjacent bottomland.

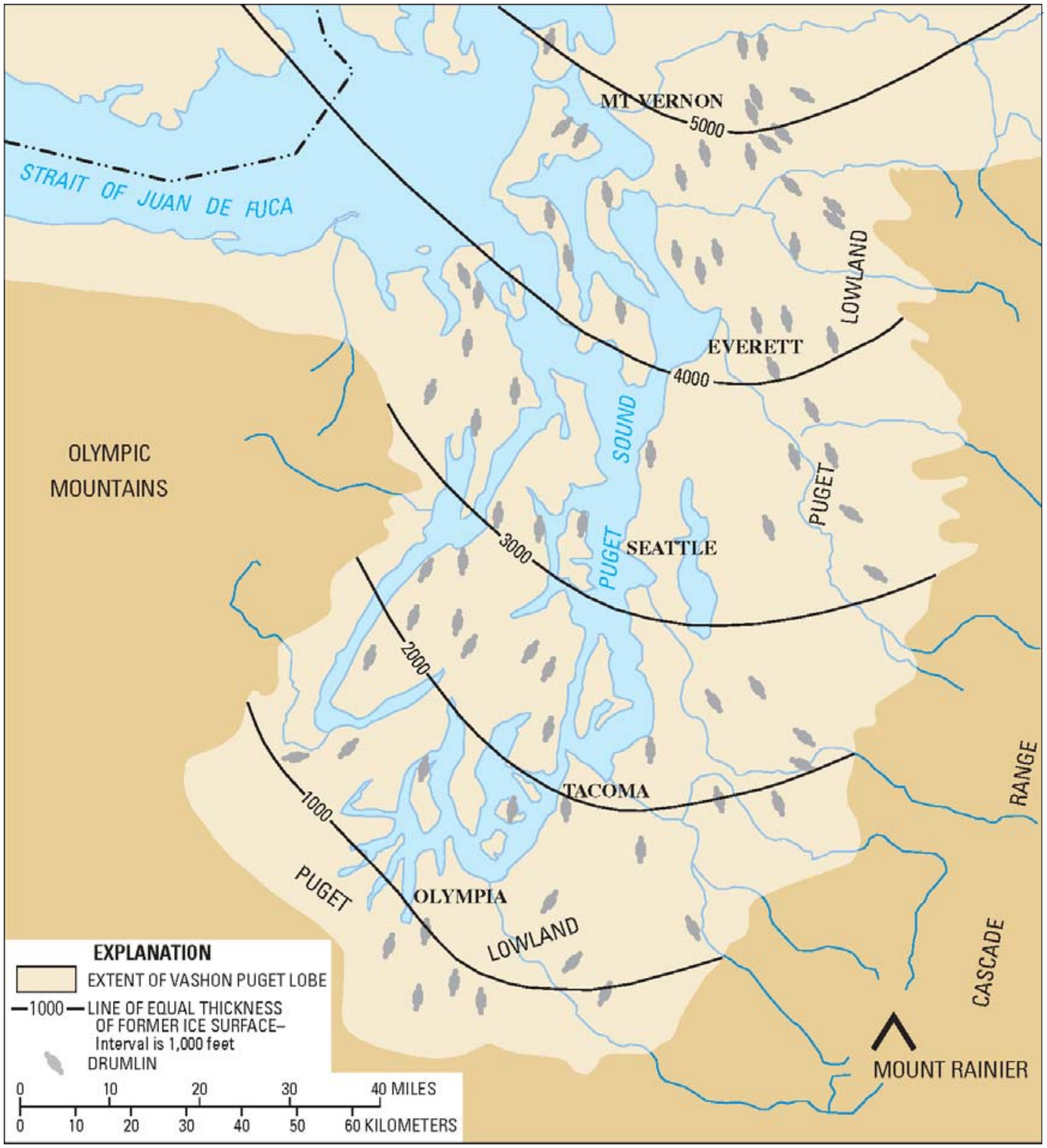
Although they may be saturated for much of the year, the alluvial deposits are not a good source of water. The soils are either too fine-grained to yield water or too rich in organic matter to be useful for household use. The peat deposits in the Chimacum and Tarboo Valleys are essentially impermeable (or transmit water at a very slow rate), therefore they act as a barrier to surface-water and ground-water exchange. In the Quilcene area, the alluvial deposits are more permeable, thus surface-water and ground-water exchanges are more pronounced.

Ground-water recharge through these organic-rich alluvial materials is very limited. Although hydraulic gradients were detected in mini-piezometers emplaced in the Semiahmoo Muck, the mini-piezometers did not yield much water and took days or weeks to equilibrate. Therefore, ground-water recharge and discharge through all of the fine-grained Holocene alluvial materials is considered negligible.



A. Generalized geology of the Olympic Mountains (from Tabor and Cady, 1978).

Figure 6. Generalized geology of the Olympic Mountains (from Tabor and Cady, 1978) and the extent of the Vashon Puget lobe of the Fraser Cordilleran glaciation (from Easterbrook, 1979).



B. Extent of Vashon Puget lobe of the Fraser Cordilleran glaciation (from Easterbrook.1979).

Figure 6.—*Continued.*

Table 2. Summary of lithologic and hydrologic characteristics of geologic units in the Chimacum Creek Basin, eastern Jefferson County, Washington

[**Range of thickness:** Values are based on observed thicknesses of units derived from lithologic logs of inventoried wells. **Number of inventoried wells open to unit:** Wells open to only one hydrogeologic unit were included. –, thickness of bedrock was not estimated]

Geologic unit	Unit label	Range of thickness [estimated average thickness] (feet)	Lithologic and hydrologic characteristics	Number of inventoried wells open to unit
Quaternary Alluvium	Qa	0–50 [15]	Unit occurs in the axis of the main stream valleys and generally is poorly drained. Subdivided into fine- grained alluvial deposits and organic rich soil, peat, and muck deposits.	0
Vashon Recessional Outwash	Qvr	0–100 [<50]	Unit occurs in most stream valleys and is subdivided into coarse-grained sand and gravel zones and fine- grained silt and clay zones. Water-bearing zones generally are unconfined and may be in hydraulic continuity with surface-water systems.	5
Vashon Lodgement Till	Qvt	0–100 [40]	Unit forms grooved surface over much of the area and consists of fine-grained, highly compacted clay, sand, and gravel. One local area of coarse-grained sand and gravel was subdivided. Unit generally occurs above the water table.	0
Vashon Advance Outwash	Qva	100–200 [100]	Widespread unit consisting of well-sorted layers of sand and gravel interfingered with zones of silt, clay, and peat. Subdivided into coarse-grained zones, fine-grained zones, and local peat interbeds. A major water-bearing unit with one highly productive zone known as the Sparling Aquifer.	57
Older Glacial deposits (undivided)	Qgo	200–1,000+ [300]	Widespread unit consisting of well-sorted layers of sand and gravel interfingered with till and fine-grained interglacial deposits. Unit occurs throughout the study area but is only exposed on the east side of Chimacum Valley. Coarse-grained zones generally are water bearing.	39
Eocene Bedrock	OEm Eva Em Evcf	–	Widespread unit underlying all glacial deposits. Subdivided by formation and includes sandstone, siltstone, shale, conglomerate, basaltic flows and breccias, and andesite flows and breccias. Locally yields usable quantities of water where rocks are fractured. Yields generally are small.	9

Vashon Recessional Outwash

Sediments that were deposited as the Pleistocene-age Vashon ice sheet retreated include a variety of materials collectively known as the Vashon Recessional Outwash (Qvr, pl. 1). The Qvr consists of sorted and stratified sands and gravels with relatively good porosity and permeability. These materials were deposited by high-energy streams that eroded and re-deposited till and other materials; they were not compacted by subsequent ice sheets. Some of the fine-grained sediments were deposited in a lake that formed as the retreating ice margin blocked drainage to the north. The resulting large lake, known as Lake Leland, filled much of Puget Sound, including both forks of Chimacum Creek, until the ice dam was breached and the water drained.

The Qvr deposits are found partly filling the bottoms of the main drainages, including Chimacum Creek, Tarboo Creek, and the Big and Little Quilcene Rivers. Isolated remnants also occur in depressions or low areas on the till surface. The Qvr generally is less than 50 ft thick but may exceed 100 ft north of the community of Chimacum. The coarse-grained layers generally are water-bearing and may form an unconfined water-table aquifer when not overlain by fine-grained impermeable layers. Because the main surface-water drainages in eastern Jefferson County occupy valleys underlain by Qvr, there is a strong tendency for surface water to interact with ground water from this unit.

Because Qvr contains highly permeable materials, the unit can be recharged from multiple sources, including the direct infiltration of precipitation onto the surface of the unit, through lateral flow from underlying units, and from seepage of surface water along losing reaches of creeks that cross the unit. Discharge from Qvr occurs along gaining reaches of creeks that cross the unit and through the bottom of the unit into the underlying materials.

Vashon Lodgement Till

Vashon Lodgement Till (Qvt, pl. 1) is a poorly sorted mixture of sand, gravel, and boulders representing eroded materials smeared at the base of the Pleistocene-age Vashon ice sheet. This material was compressed as nearly 4,000 ft of ice moved over it (fig. 6*B*). In some places, the material is highly compacted and very resistant and commonly is referred to by drillers as "hard pan." In other places, the till has been reworked and is not compacted. Drillers' logs sometimes do not distinguish till from other materials. The Qvt is widely exposed in the study area and forms the distinctive fluted surface consisting of narrow, regularly spaced parallel ridges and grooves oriented in a north-south direction. In the Quilcene area, Qvt is found on the sides of valleys in the upper reaches of the Big Quilcene River (Grimstad and Carson, 1981). The till is not present in areas where ice was in direct contact with bedrock or in the main river valleys, where recessional outwash streams eroded the till away.

The Qvt is not a significant producer of water because the unit generally lies above the water table. In addition, its primary porosity and permeability have been reduced by the effects of compaction. The low hydraulic conductivity of the till acts to retard the infiltration of precipitation, causing lakes or wetlands to form in depressions on the Qvt surface. The thickness of Qvt ranges from 40 ft or less to as much as 100 ft across the study area. Ranges in thickness are due in part to erosion but also to inconsistent descriptions of the material in drillers' logs.

The Qvt is recharged through the direct infiltration of precipitation onto the surface of the unit. Till generally is considered a relatively impermeable unit. However, the percentage of precipitation that (1) runs off to form surface-water flow, (2) is lost through evapotranspiration, or (3) is able to recharge underlying aquifers is not known. The lack of a dense drainage network, abundant lakes, or wetlands suggests that a large portion of precipitation does infiltrate, despite the low hydraulic conductivity of the till. Lateral ground-water flow probably is very slow, so that the primary ground-water discharge from the till is through the bottom of the unit into the underlying materials.

Vashon Advance Outwash

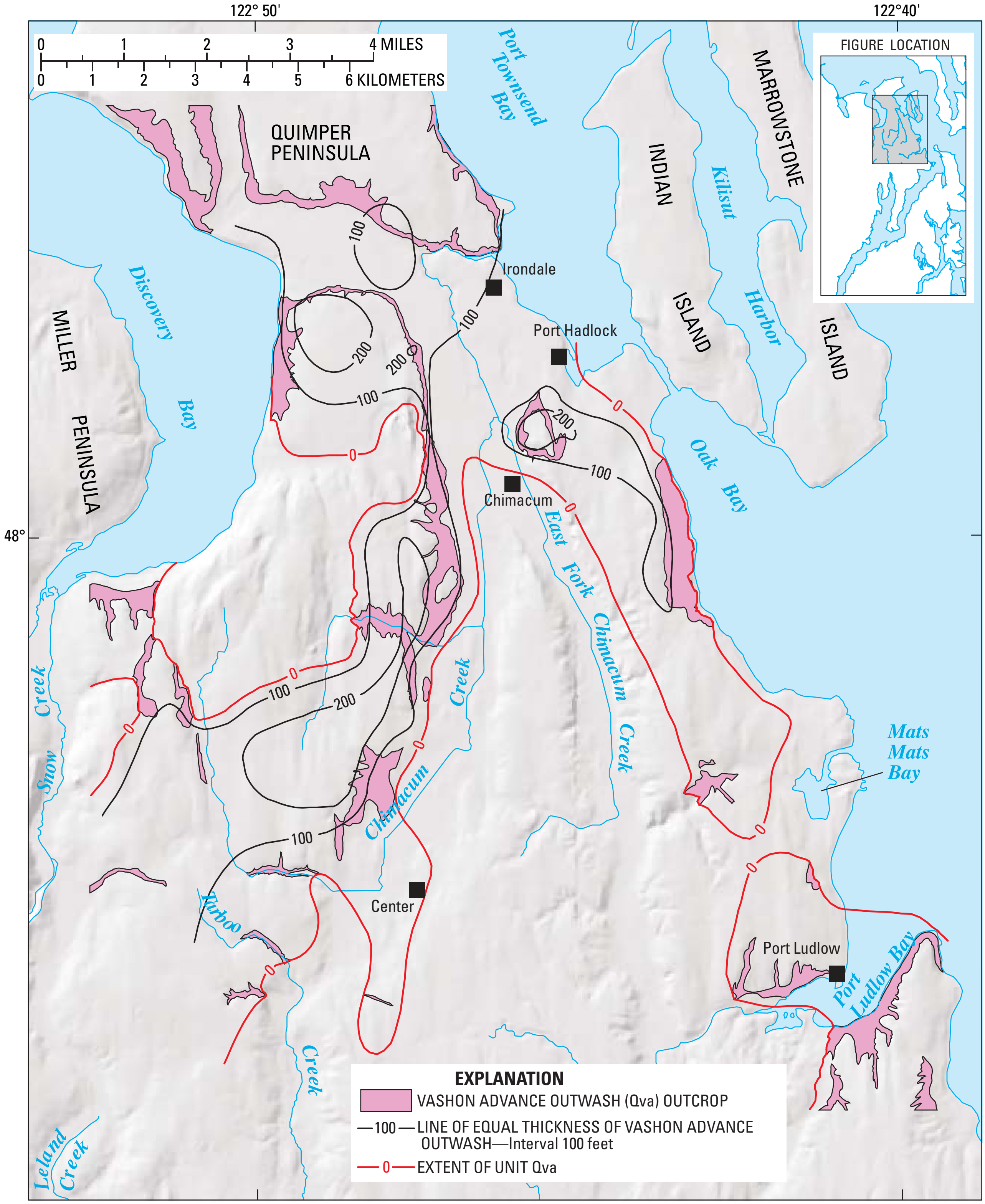
The Vashon Advance Outwash (Qva, pl. 1) is a stratified sequence of silts, clays, and peat deposits that interfinger with well-sorted sands, gravels, and cobbles. The sequence was deposited by melt-water streams preceding the advancing Pleistocene-age Vashon ice sheet. This material is found in outcrops beneath till on the west side of the Chimacum Valley and in isolated outcrops near the coastlines of Oak Bay and Port Ludlow Bay. The Qva is notably absent beneath the till on the east side of the Chimacum Valley (pl. 1), as well as on the east side of Tarboo Creek and on the Bolton Peninsula (Grimstad and Carson, 1981). The absence of these deposits beneath till in these areas suggests that the unit either never was deposited or was subsequently scraped off by the advancing Vashon ice sheet.

The Qva is the most prolific water-bearing unit in the area because of its lateral continuity and favorable primary porosity and permeability. The thickness of the unit ranges from 0 to a little more than 200 ft (fig. 7). On the east side of Chimacum Valley, limited exposures indicate that Qva may be present but it is not clear if the unit is laterally continuous. West of Chimacum Creek, copious amounts of ground water are produced from coarse-grained layers within Qva for both domestic and public-supply uses. Some layers within the unit are estimated to be capable of producing more than 1,000 gal/min (CH2M Hill, 1996). The Jefferson County PUD #1 currently withdraws water at a rate of about 555 gal/min from a highly transmissive layer known as the Sparling Aquifer to supply the communities of Chimacum, Irondale, and Port Hadlock. Additional water rights are being sought in order to expand the system and provide Marrowstone Island with a public water supply.

Recharge to Qva is primarily through the overlying till or by direct infiltration of precipitation on exposed areas. Because some layers of Qva are highly transmissive, lateral ground-water velocities may be high. Ground-water discharge is evident in springs and seeps at the base of valley slopes where the unit is exposed. Water also may discharge where Qva is in lateral contact with overlapping recessional outwash materials (Qvr). Ground water also is discharged through pumping for domestic use.

Older Glacial Deposits

Little is known about the distribution of materials deposited during the Pleistocene-age glaciations preceding the Vashon Stade of the Fraser glaciation. These materials are largely buried. The best exposures are in shoreline bluffs along the Toandos and Bolton Peninsulas south of the study area (Grimstad and Carson, 1981; Easterbrook, 1986). Older Glacial Deposits (Qgo, pl. 1) also can be found on the steep valley flanks of the East Fork of Chimacum Creek and on the east side of the Tarboo Valley. The Qgo consists of a variety of materials including two densely compacted tills that are correlated with the Possession Drift and the Double Bluff Drift (Easterbrook, 1986). Elsewhere within this unit are fine-grained silts and clays deposited during inter-glacial periods. The depositional sequence is further complicated by erosion and reworking of sediments by successive glaciations. The result is discontinuous lenses of permeable sands and gravels separated by fine-grained materials with lower permeability.



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
Universal Transverse Mercator projection, Zone 10, Datum NAD 83
Hillshade-modified from 6-foot Digital Elevation Model data, 1:24,000, 1992
Puget Sound LIDAR Consortium. Projection parameters: State Plane North,
horizontal datum NAD 83 and vertical datum NAVD 88.

Figure 7. Extent and thickness of the Vashon Advance Outwash in the Chimacum Creek Basin, eastern Jefferson County, Washington.

The distribution and thickness of the Qgo is largely conjectural. Although there are relatively few outcrop exposures, these deposits are presumed to underlie much of the study area. The thickness of the Qgo ranges from 0 to more than 700 ft because of the variation in depth to bedrock and the varied surface topography expressed throughout the Chimacum Creek Basin (fig. 8). The unit may be more than 1,000 ft thick to the north as the depth to bedrock increases beneath the Quimper Peninsula. A number of domestic wells use ground water from sandy lenses within the Qgo; however, whether these lenses have sufficient water to support larger scale development is unknown.

Recharge to permeable layers within the Qgo most likely moves vertically from the overlying units. Where till overlies Qgo, recharge is probably a slow process, but where Qva overlies Qgo recharge could be much faster. Some recharge may infiltrate directly where the unit is exposed on valley slopes. Ground-water discharge is evident along the eastern coastline adjacent to Oak Bay, Mats Mats Bay, and Port Ludlow Bay, where the ground-water flow path follows the contact with bedrock to the surface. Occasional springs, seeps, and artesian wells are reported in these areas.

Bedrock

Eastern Jefferson County is underlain by a thick assemblage of Eocene-age oceanic rocks that form a broad arc around the north and east flanks of the Olympic Mountains. Not only are these rocks faulted and highly deformed, but they also are poorly exposed and therefore poorly understood. For the purposes of this study, bedrock units are lumped into four general categories. From oldest to youngest, these include oceanic crustal rocks of volcanic origin generally known as the Eocene Crescent Formation (Evcf); rocks of marine sedimentary origin generally known as the Eocene Lyre Formation or the Eocene Twin River Formation (Em); intrusive andesites associated with the Lyre Formation (Eva); and undivided marine sedimentary rocks of Eocene to Oligocene age (OEm) (Tabor and Cady, 1978; pl. 1). The Evcf consists of basalts, basaltic breccias, and volcaniclastic rocks that are exposed south of Port Ludlow, west of Mats Mats Bay, along the southeastern side of Discovery Bay, and in the upper reaches of the Big and Little Quilcene Rivers. The Em consist primarily of sandstones and siltstones, but also of minor amounts of shale, conglomerates, and interbedded andesite flows and breccias that outcrop along the coastline of Oak Bay, on Indian Island, and in a broad swath from the south end of Discovery Bay to the north end of Quilcene Bay (Tabor and Cady, 1978, Grimstad and Carson, 1981). Intrusive andesites mapped as part of the Lyre Formation are exposed in the vicinity of Anderson and Gibbs Lakes (Tabor and Cady, 1978). Other sedimentary rocks that are interpreted to be of Eocene to Oligocene age are exposed in outcrops distributed along the coastline of Oak Bay and south of Discovery Bay. Most of the contacts between bedrock units are structural and were not mapped as part of this study. Bedrock contacts shown on plate 1 are generalized and are not intended to represent structural interpretation.

The altitude of the bedrock surface throughout the Chimacum Creek Basin ranges from 800 ft above NAVD 1988 to about 900 ft below NAVD 1988 (fig. 9) (Jones, 1996). An apparent trough in the bedrock surface extends in a north-south direction beneath the communities of Center, Chimacum, and Irondale. North of Irondale, the depth to bedrock increases beneath the Quimper Peninsula.

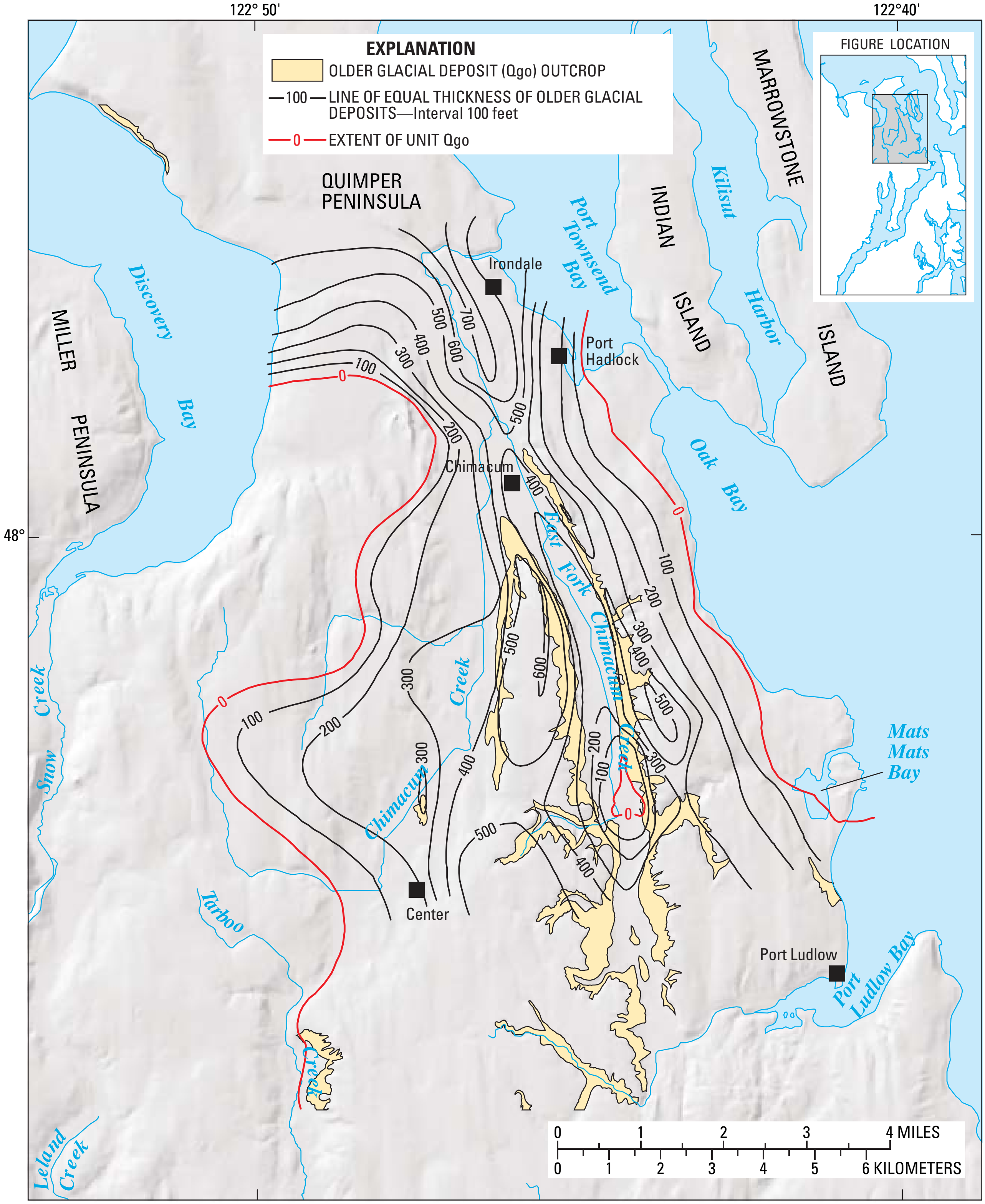
In places where bedrock is at or near the surface, the potential for developing ground-water resources is small. The Eocene volcanic rocks generally lack sufficient primary porosity and permeability to support more than small-scale domestic water supplies. The Eocene sedimentary rocks also are poorly producing, owing to the degree of cementation, which decreases effective pore space. In some areas, however, interconnected fractures, joints, and permeable layers may yield significant quantities of water, but the locations of high-yielding areas within bedrock areas are extremely difficult to predict.

Because of the impermeable nature of the bedrock units, most precipitation falling on bedrock areas runs off to local streams. For this reason, bedrock areas generally have a higher density of small drainages. Ground-water recharge in bedrock areas is likely a small proportion of the total precipitation. A small amount of discharge is possible in bedrock areas in the form of springs or seeps, primarily near the coast.

Hydraulic Properties

Hydraulic conductivity is a measure of a material’s ability to transmit a given fluid, and in unconsolidated sediment is dependent of the size, shape, distribution, and packing of individual particles. Because these characteristics vary greatly within each hydrogeologic unit, hydraulic-conductivity values also vary greatly.

The horizontal component of hydraulic conductivity for the main hydrogeologic units was estimated using drawdown data collected by drillers where water levels were measured after wells were pumped for periods ranging from 1 to 168 hours. Only data from those wells that had a drillers’ log containing discharge or pumping rate, time of pumping, drawdown, static water level, well-construction data, and lithologic logs were used. Data from air tests were not included.



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
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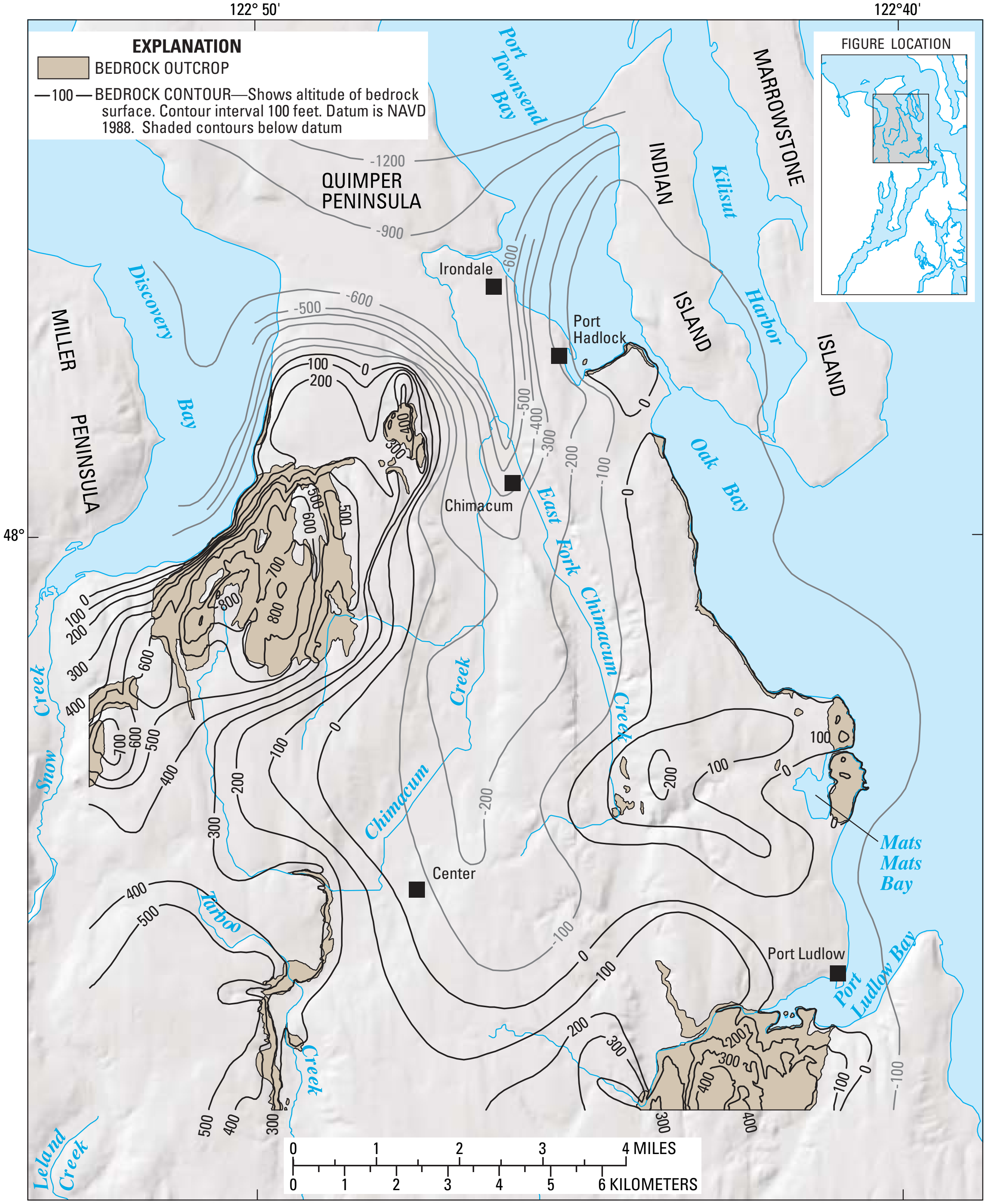
Puget Sound LIDAR Consortium. Projection parameters: State Plane North, horizontal datum NAD 83 and vertical datum NAVD 88.

Figure 8. Extent and thickness of the Older Glacial Deposits in the Chimacum Creek Basin, eastern Jefferson County, Washington.



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
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Puget Sound LIDAR Consortium. Projection parameters: State Plane North,
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Figure 9. Altitude of the bedrock surface in Chimacum Creek Basin, eastern Jefferson County, Washington. Altitudes are based on topographic exposures, well data, interpreted thickness of unconsolidated deposits, and published data from Jones (1996).

Two different sets of equations were used to estimate horizontal hydraulic conductivity, depending on well construction. For wells with a screened or perforated interval, the modified Theis equation (Ferris and others, 1962) was first used to estimate transmissivity of the pumped interval. Transmissivity is the product of horizontal hydraulic conductivity and thickness of the portion of the hydrogeologic unit supplying water to the well. The modified equation is

$$s = \frac{Q}{4\pi T}\ln\frac{2.25Tt}{r^2S} , \qquad (3)$$

where

s = drawdown in the well, in feet;

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

T = transmissivity of the hydrogeologic unit, in ft^2/d;

t = length of time the well was pumped, in days;

r = radius of the well, in feet; and

S = storage coefficient, a dimensionless number, assumed to be 0.0001 for confined units and 0.1 for unconfined units.

The following assumptions are made when using equation 3: (1) Aquifers are homogeneous, isotropic, and infinite in extent; (2) wells are fully penetrating; (3) flow to the well is horizontal; and (4) water is released from storage instantaneously. Additionally, for unconfined aquifers, it is assumed that drawdown is small relative to the saturated thickness of the aquifer. A computer program was used to solve equation 3 for transmissivity (T) using Newton's iterative method (Carnahan and others, 1969). The difference in computed transmissivity between using 0.1 and 0.0001 for the storage coefficient is a factor of only about 2. Next, horizontal hydraulic conductivity is calculated using equation 4:

$$K_h = \frac{T}{b} , \qquad (4)$$

where

K_h = horizontal hydraulic conductivity of the geologic material in the vicinity of the well opening, in feet per day;

T = transmissivity of the hydrogeologic unit, in ft^2/d; and

b = thickness, in feet, approximated using the length of the open interval as reported in the drillers' report.

The use of the length of a well's open interval for b may overestimate values of K_h because the equations assume that all the water flows horizontally within a layer of this thickness. Although some of the flow will be outside this region, the amount can be expected to be small because in most sedimentary deposits, vertical flow is inhibited by horizontal layering of fine-grained materials like clay or silt. Another source of error in equation 4 is the level of accuracy for drawdown, pumping rate, and length of time the well was pumped reported by the driller. Although there are uncertainties and some of the assumptions may not be precisely met, the calculated hydraulic conductivities are within the expected range of values and appear to be reasonable estimates.

A few wells did not have screened intervals but were installed with an open end at the bottom of the casing. For these wells, Bear (1979) provides an equation for hemispherical flow to an open-ended well just penetrating a hydrogeologic unit. When modified for spherical flow to an open-ended well within a unit, the equation becomes:

$$K_h = \frac{Q}{4\pi sr} , \qquad (5)$$

where

K_h = horizontal hydraulic conductivity of the geologic material in the vicinity of the well opening, in feet per day;

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.

Equation 5 is based on the assumption that horizontal and vertical hydraulic conductivities are equal, which is not likely for the deposits within the study area. Violation of this assumption results in an underestimate of K_h by an unknown amount. Horizontal hydraulic conductivities computed for wells without screens using equation 5 were much lower than expected, and therefore were not used to calculate median K_h values for a particular hydrogeologic unit.

Median values for horizontal hydraulic conductivity were calculated using available data for each hydrogeologic unit (table 3). The estimates of horizontal hydraulic conductivity are considered reasonable for the Qgo and Qva because most of the wells are screened in either of these two aquifers. The available data are sparse for wells screened in bedrock and Qvr. None of the inventoried wells had screens in Qvt or Qa. The median horizontal hydraulic conductivities (K_h) for Qvr (10 ft/d), Qva (130 ft/d), Qgo (22 ft/d), and bedrock (0.53 ft/d) are similar in magnitude to values reported by Freeze and Cherry (1979) for similar materials. Two of the PUD public-supply wells, the Sparling well (29N/01W-3K02) and the Kively well (29N/01W-2R02), derive water from a very coarse-grained part of the Qva locally known as the Sparling Aquifer. Pump tests conducted in 1996 on the Sparling Aquifer indicated an effective transmissivity of about 111,600 ft^2/d (CH2M Hill, 1996). Such a high transmissivity may be due to the fact that production wells are constructed with large-screened intervals or have screens in multiple water-bearing units. For these reasons, wells that were developed specifically to maximize water production were not used to calculate median K_h values for the Qva.

Table 3. Estimated horizontal hydraulic conductivities for the hydrogeologic units in the Chimacum Creek Basin, eastern Jefferson County, Washington

[**Hydraulic conductivities** were based on data from selected wells in the Chimacum Creek Basin that derive water from a single hydrogeologic unit. –, not determined]

Hydrogeologic unit	Hydraulic conductivity (feet per day)			
	Number of wells	Minimum	Median	Maximum
Quaternary Alluvium (Qa)	0	–	–	–
Vashon Recessional Outwash (Qvr)	2	10	10	11
Vashon Lodgement Till (Qvt)	0	–	–	–
Vashon Advance Outwash (Qva)	[1]32	3.2	130	13,000
Older Glacial deposits (Qgo)	31	.22	22	830
Bedrock undivided (OEm, Em, Evcf)	8	.07	.53	4.9

[1] PUD public-supply wells that have been developed and optimized to achieve maximum water production (CH2M Hill, 1996) were not included.

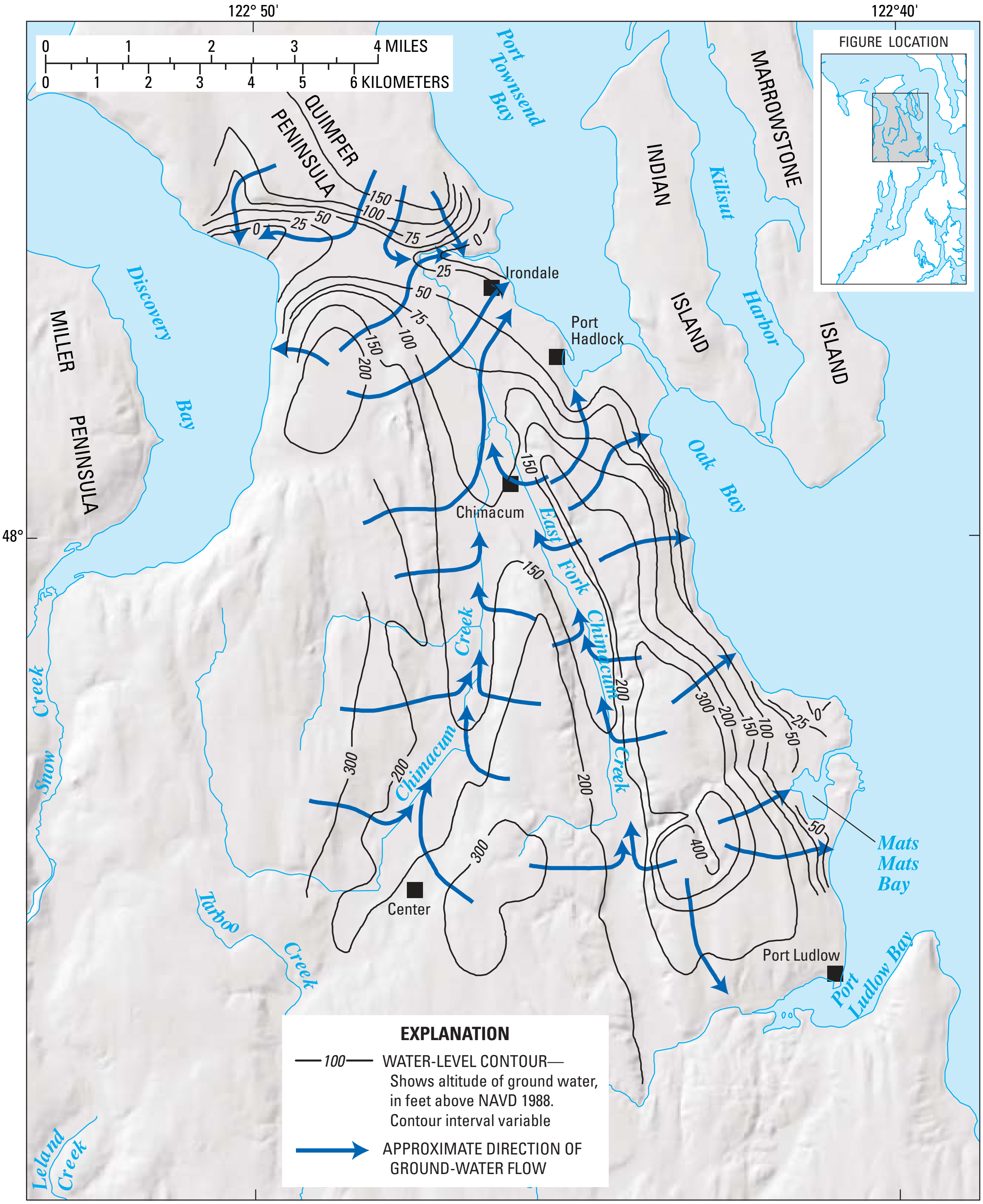
Ground-Water System

The main hydrogeologic units that produce ground water for domestic residential or agricultural use in eastern Jefferson County are Qva, Qgo, and to a much lesser extent Qvr. These hydrogeologic units make up the bulk of unconsolidated materials overlying bedrock (pl. 1). The Vashon Lodgement Till (Qvt) is not an important water-bearing unit, but it does control the rate of infiltration and therefore acts as a semi-confining layer. These main hydrogeologic units is composed of similar materials; water-bearing layers composed of silty sand to sandy gravel are interbedded with lenses of lower-conductivity clays, peat, and silt, as well as older lodgement tills. Layers dominated by fine-grained materials are distinguished from coarse-grained materials where possible on hydrogeologic sections (pl. 1). Correlation of these layers is based on drillers' logs and geologic interpolation between wells. The fine-grained and coarse-grained layers depicted on hydrogeologic sections (pl. 1) are oversimplified because of the lack of detailed well information and the lack of deep wells in particular. However, no extensive, laterally continuous layers of significantly low-conductivity material (confining layers) were identified in this study. Confining layers may be present at depth, but none of the wells inventoried in this study penetrated to such depths.

Little is known about the lower parts of Qgo, thus the unit is conservatively estimated to consist of fine-grained material. The lack of substantial confining layers in Qva and the upper parts of Qgo suggests that vertical ground-water movement between hydrogeologic units is relatively uninhibited. It may be more accurate to consider the entire sequence of unconsolidated material as a single hydrogeologic unit in which ground-water movement is inferred to occur preferentially in coarse-grained layers of high hydraulic conductivity.

Ground-Water Levels

The direction of ground-water movement can be inferred as from areas of higher ground-water altitudes to areas of lower ground-water altitudes. Depth-to-water measurements made during the well inventory in spring 2002 were subtracted from LIDAR land-surface altitudes to obtain a water-level altitude (relative to the North American Vertical Datum of 1988 [NAVD 88]). These altitudes were used to produce a water-level contour map of the Chimacum Creek Basin (fig. 10).



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
Universal Transverse Mercator projection, Zone 10, Datum NAD 83
Hillshade-modified from 6-foot Digital Elevation Model data, 1:24,000, 1992
Puget Sound LIDAR Consortium. Projection parameters: State Plane North,
horizontal datum NAD 83 and vertical datum NAVD 88.

Figure 10. Water-level contours and approximate directions of ground-water flow in aquifers in the Qva and Qgo units in the Chimacum Creek Basin, eastern Jefferson County, Washington.

Water-level contours were drawn only where aquifers were interpreted to be in lateral continuity. Measurements from both Qva and Qgo were used for the map, because there were no significant differences in water-level altitudes when the two units were mapped separately. The similarity of water-level altitudes indicates that vertical head gradients between Qva and Qgo are small or non-existent and that there is no laterally continuous confining unit acting as a barrier to ground-water flow. However, additional examination of adjacent wells screened at different depths would be needed to confirm the existence (or lack of) vertical gradients.

The water-level contours (fig. 10) were based on water-level altitudes measured during the May 2002 well inventory. Water-level altitudes measured during the October 2002 synoptic water-level measurement were within a few feet of the May 2002 measurements and did not affect the positions of the water-level contours. The contours shown on figure 10 were adjusted to match the available data including land-surface topographic information, the altitude of ephemeral streams, springs, and flowing wells, and the distribution of gaining and losing reaches of Chimacum Creek (water-level altitudes are slighter higher than creek altitudes in gaining reaches and slightly lower than creek altitudes in losing reaches). The water-level altitudes generally ranged from 300 to 400 ft above NAVD 88 in the southern part of the basin to 0 near the mouth of Chimacum Creek.

Ground-Water-Flow Directions

The ground water in the Chimacum Creek Basin generally flows from areas of recharge toward areas of discharge in a direction perpendicular to the water-level contours. Thus, lateral ground-water flow generally parallels the land surface as it moves from topographically high areas toward the axis of major valleys (fig. 10). Shallow ground water appears to move parallel to surface-water flow while deeper ground water probably flows in a general direction from south to north. This conceptual model of ground-water flow indicates a major area of ground-water discharge beneath the south end of Port Townsend Bay near the mouth of Chimacum Creek. Ground water on the margins of the Chimacum Creek Basin flows eastward toward the western coast of Puget Sound or westward toward the coastline of Discovery Bay to emerge as springs and seeps near the coastline or offshore.

Movement of water within Qvr begins as direct precipitation infiltrates from the surface, as water leaks from Chimacum Creek, and other possible hydrologic connections with Qva or Qgo. One prominent recharge area is along a losing reach of Chimacum Creek located near the community of Chimacum. Water moves preferentially within coarse-grained layers parallel to Chimacum Creek and the East Fork of Chimacum Creek. Some ground water flows back into Chimacum Creek near the mouth, where the streambed is incised into Qvr but the majority appears to flow towards Port Townsend Bay (fig. 10). The movement of water into and out of Chimacum Creek is particularly important and was the focus of the second part of this study.

Movement of water within Qva begins as direct precipitation and infiltration of water through the overlying Qvt on the west side of the study area. Although Qvt generally is assumed to be poorly transmissive, the absence of ponded water on the till surface suggests that water is able to percolate through the till and recharge the underlying units. Some ground water emerges from the west side of Chimacum Creek where water-bearing layers within Qva are exposed at the surface. However, the majority of ground-water flows within coarse-grained layers and follows a deeper flow path that trends more generally towards Port Townsend Bay near the mouth of Chimacum Creek.

Movement of water within Qgo begins as direct precipitation and infiltration of water through the overlying Qvt on the east side of the study area. Little is known about the occurrence and movement of ground water in Qgo on the west side of the study area because few wells penetrate deeper than Qva. It is likely that some recharge occurs through infiltration from overlying Qva. On the east side of the study area, ground water moves within coarse-grained layers from topographically high areas towards springs, seeps, and flowing wells in the upper reaches of Chimacum Creek where the unit is exposed (pl. 1).

Seasonal Variations

Water-level altitudes measured during the well inventory in spring 2002 generally were a few feet higher than those measured during the synoptic measurements in autumn 2002. This seasonal variation in water-level altitudes was well documented by the monitoring-well network where monthly depth-to-water measurements were made from March 2002 to July 2003 (fig. 11). The network consisted of nine private wells selected because of their distribution throughout the Chimacum Creek Basin. When non-static conditions caused by pumping from the well or nearby wells are discounted, seasonal variations generally were less than 2.5 ft. (Well 29N/01W-23F01 had repeated non-static conditions, sometimes as much as 8 ft of drawdown after the pump had operated.) Hydrographs for two wells on the east side of Chimacum Creek Basin (29N/01W-13M01 and 29N/01W-24K03, both screened in Qgo) were similar, with water levels that responded relatively quickly to precipitation events in December 2002 and March 2003 (fig. 11). Hydrographs for two wells located on the ridge separating Chimacum Creek and the East Fork of Chimacum Creek (29N/01W-23F01 and 29N/01W-35J01, also screened in Qgo) also were similar, in that water levels did not respond to precipitation events but remained relatively steady, with a slight decline over the period of observation. Hydrographs for the four wells on the west side of the Chimacum Creek Basin differed, depending on their location in the valley.

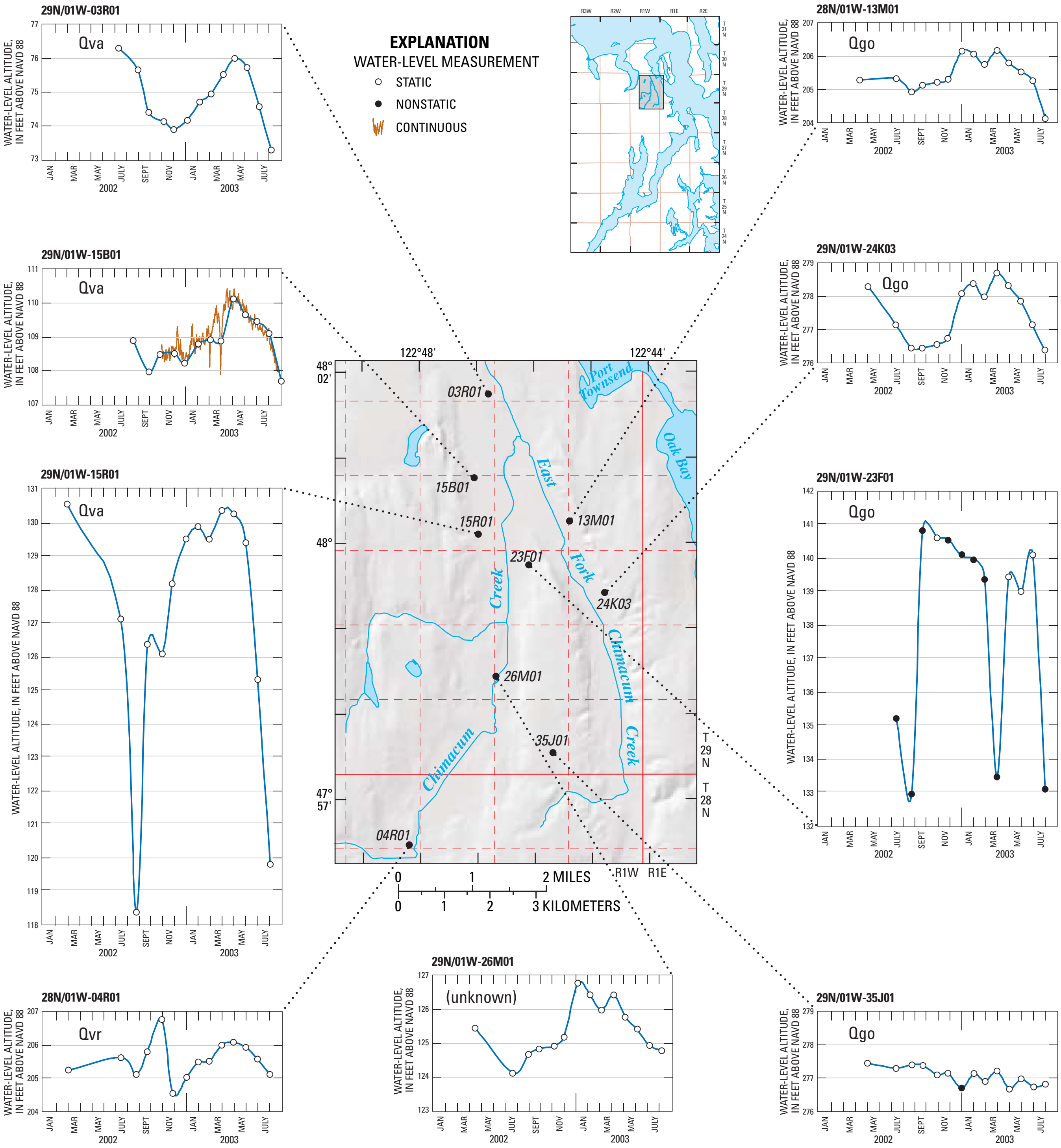


Figure 11. Seasonal variation in water levels measured in nine monitoring wells screened in water-bearing units (upper left corner of each graph) in the Chimacum Creek Basin, eastern Jefferson County, Washington, March 2002-July 2003.

The pattern for the most upgradient well (28N/01W-04R01, screened in Qvr) was similar to that of the wells on the east side of the basin, except for an unexpected peak in October 2002 that is not entirely understood. Hydrographs for wells 29N/01W-26M01 (unknown screened interval) and 29N/01W-15R01 (screened in Qva) also were similar to wells screened in Qgo on the east side of the basin where winter peak water-level altitudes in December 2002 and March 2003 closely correspond to precipitation events. The hydrograph for well 29N/01W-15R01 displays a prominent recurring water-level decline caused by upgradient irrigation withdrawals in the late summer.

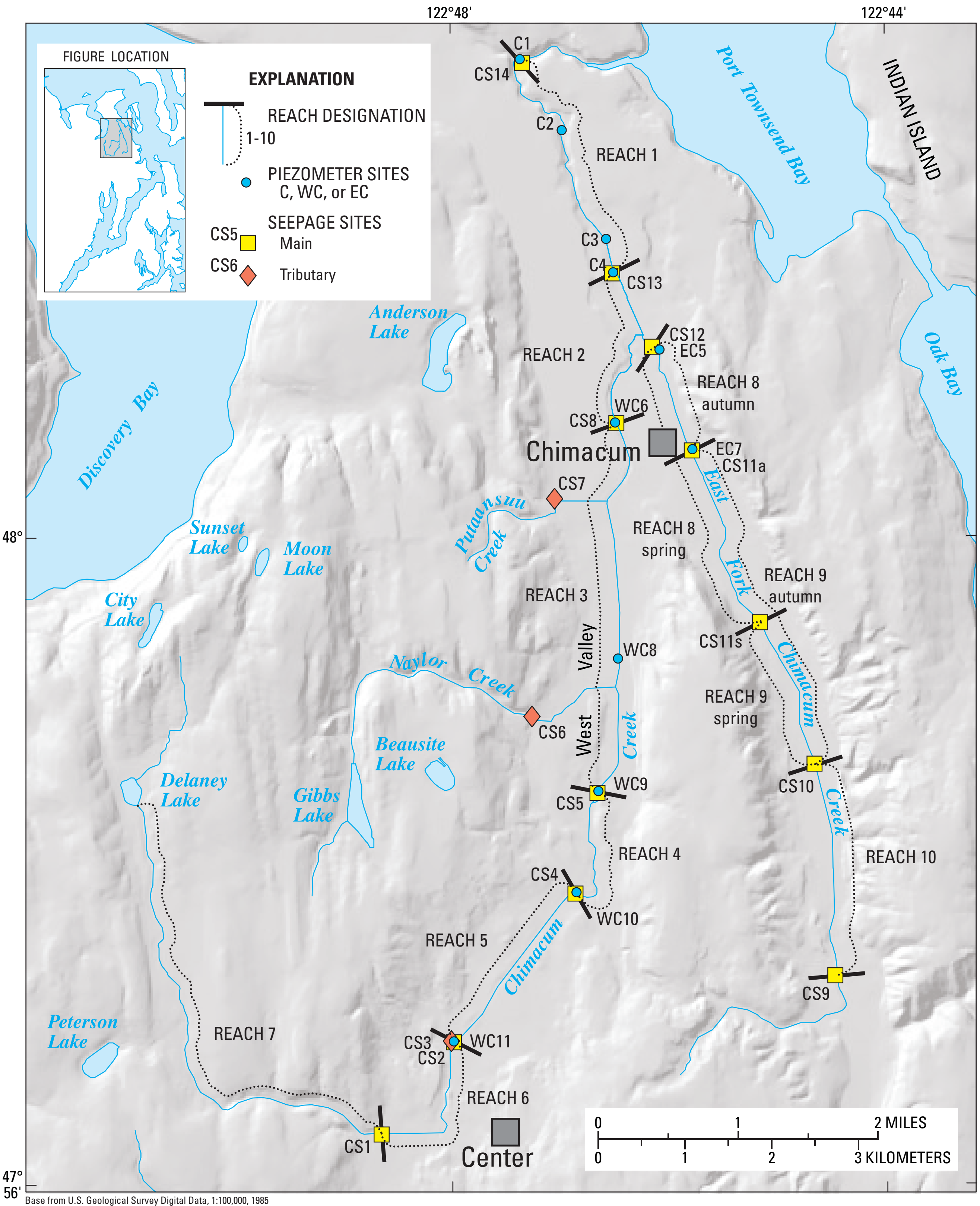
In addition to monthly monitoring, one unused well 29N/01W-15B01 (screened in Qva) also was instrumented with a water-level data recorder set to record water levels every 2 hours from September 29, 2002, to July 26, 2003 (fig. 11). The continuous data were confirmed by monthly measurements, but show that water-level changes also occur on a much shorter time scale. The short-term flucuations in water-level altitudes may be related to precipitation events or to the effect of nearby pumping wells. The most downgradient well (29N/01W-03R01) is near Chimacum Creek about 1.5 mi from the mouth. This well is believed to be screened in the highly transmissive layer within Qva known as the Sparling Aquifer. The hydrograph for this well was unique, in that it did not show a direct response to precipitation events but rather a distinct time lag in which the winter peak water-level altitude occurred in April, about 1 month later than the highest water-level altitudes seen in other wells. In addition, the lowest water-level altitude occurred in November, about 3 months later than the lowest water-level altitudes seen in other wells. This time lag may indicate the travel time for seasonal precipitation pulses to reach the lower part of the flow system.

Surface Water/Ground Water Interactions

In order to understand how exchanges occur between surface water and ground water, four drainage basins were studied in detail: Chimacum Creek, Tarboo Creek, the Big Quilcene River, and the Little Quilcene River. Because no single technique can quantify definitively how exchanges occur, this study used a combination of methods to define the spatial distribution, the seasonal variations, and the quantity of water being exchanged in each drainage basin. Seepage runs provided information about the quantity of water being exchanged, and the combination of seepage runs and instream mini-piezometers provided data to define the spatial distribution of gaining and losing reaches. These data provide the basis for dividing each stream into reaches with similar hydrologic characteristics. Multiple seepage runs and periodic mini-piezometer surveys, combined with continuous vertical temperature profiles, provided temporal information to assess seasonal variations within each reach. The use of multiple techniques provides a more complete picture of the exchanges between surface water and ground water that occur within a given drainage than using a single technique.

Chimacum Creek

Chimacum Creek originates from Delaney Lake and flows south past Peterson Lake, turns east, and cuts through a small canyon before entering West Valley just west of the community of Center (fig. 12). Here, the creek has incised all the way through Qvt and Qva and exposes Eocene marine sedimentary sandstone (Em) at the bottom of the canyon (pl. 1). During the dry summer months, the outlet from Delaney Lake is dry and 100 percent of the surface-water flow in Chimacum Creek is derived from base flow, augmented by springs and seeps in the canyon (reach 7; fig. 12). Both seepage data (table 4) and mini-piezometer data (fig. 13) confirm that the creek gains water from the ground-water system as it flows through the upper portion of West Valley, particularly in reach 6 where the creek gains more than 50 percent of its flow and in reach 4 where the creek gains about 30 percent of its flow. Downstream of reach 4, the creek flows across peat deposits (Qa) where only a small amount of exchange occurs (slightly losing during wet periods and slightly gaining during dry periods). A similar pattern can be seen in the East Fork of Chimacum Creek, where the upper reaches 9 and 10 gain water from the ground-water system (table 4) while the lower reach 8 loses water (fig. 13). Although the seepage data for the main stem of Chimacum Creek show a net gain in reach 2, mini-piezometer data EC7, WC6, and EC5 (fig. 13), and vertical temperature profiles (fig. 14*A*) indicate losing conditions near the community of Chimacum. Downstream of the confluence, Chimacum Creek incises into Qvr and conditions change to gaining. Seepage data indicate gaining conditions in reaches 1 and 2, however, mini-piezometer data and vertical temperature profile at site C4 (fig. 14*B*) indicate that ground-water exchanges are affected by seasonal variations and may change to losing conditions during winter months.



Base from U.S. Geological Survey Digital Data, 1:100,000, 1985
Universal Transverse Mercator projection, Zone 10, Datum NAD 83
Hillshade-modified from 6-foot Digital Elevation Model data, 1:24,000, 1992
Puget Sound LIDAR Consortium. Projection parameters: State Plane North, horizontal datum NAD 83 and vertical datum NAVD 88.

Figure 12. Locations of mini-piezometers and seepage-run measurement sites in the study reaches of the Chimacum Creek drainage basin, eastern Jefferson County, Washington.

Table 4. Surface-water budget based on discharge measured in the Chimacum Creek drainage basin, eastern Jefferson County, Washington, June 26 and October 22, 2002

[**Map ID**: Location of measuring sites are shown in figure 12. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre–foot. –, no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage*	*Reach*
	June 26, 2002						
	Point at which surface water flow begins in the channel			0.84	100	–	*7*
CS1	**Chimacum Creek** at Lat 47°56'20", long 122°48'34", in NW¼NE¼ sec.9, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 20 ft upstream from sediment basin, and 0.8 mi west of Center.	**0.84**	0.17	1.37	57.6	–	*6*
CS2	Unnamed Tributary at Lat 47°56'54", long 122°47'56", in SE¼NE¼ sec.4, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at West Valley Road, 0.6 mi northwest of Center, and 5 ft upstream from mouth.	.17	–	–	–	–	
CS3	**Chimacum Creek** at Lat 47°56'54", long 122°47'54", in SW¼NW¼ sec.3, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 50 ft downstream from West Valley Road, and 0.6 mi northwest of Center.	**2.38**	0	.38	8.7	–	*5*
CS4	**Chimacum Creek** at Lat 47°57'49", long 122°46'47", in SE¼NE¼ sec.34, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at Center Road bridge, and 1.7 mi north of Center.	**2.76**	0	1.61	36.8	–	*4*
CS5	**Chimacum Creek** at Lat 47°58'26", long 122°46'35", in NW¼SW¼ sec.26, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 100 ft downstream from road bridge, and 2.4 mi north of Center.	**4.37**	.46	-.93	11.8	–	*3*
CS6	Naylor Creek at Lat 47°58'54", long 122°47'11", in NW¼NE¼ sec.27, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 10 ft upstream from weir, 50 ft downstream from West Valley Road, and 2.8 mi north of Center.	.32	–	–	–	–	
CS7	Putaansuu Creek at Lat 48°00'16", long 122°46'59", in NW¼SE¼ sec.15, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 10 ft downstream from West Valley Road, and 0.9 mi southwest of Chimacum.	.14	–	–	–	–	
CS8	**Chimacum Creek** at Lat 48°00'43", long 122°46'24", in NW¼NW¼ sec.14, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at Rhody Drive bridge, and 0.3 mi west of Chimacum.	**3.90**	1.38	1.02	26.2	–	*2*
CS9	East Fork Chimacum Creek at Lat 47°57'18", long 122°44'24", in NE¼NE¼ sec.1, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 30 ft upstream from Egg and I Road, and 2.0 mi north of Beaver Valley.	.62	0	.85	57.8	*10*	
CS10	East Fork Chimacum Creek at Lat 47°58'37", long 122°44'40", in NW¼SE¼ sec.25, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, upstream from culvert, and 3.2 mi south of Chimacum.	1.47	0	.13	8.1	*9*	
CS11s	East Fork Chimacum Creek at Lat 47°59'29", long 122°45'10", in NW¼SW¼ sec.24, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, Lamberton site, and 1.7 mi southeast of Chimacum.	1.60	0	-.22	-15.9	*8*	
CS12	East Fork Chimacum Creek at Lat 48°01'11", long 122°46'12", in NE¼SW¼ sec.11, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 20 ft downstream from Chimacum Road, and 0.6 mi north of Chimacum.	1.38	–	–	–		
CS13	**Chimacum Creek** at Lat 48°01'39", long 122°46'26", in NW¼NW¼ sec.11, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at PUD gage, 50 ft upstream from footbridge, 300 ft east of end of Hilda Road, 1.2 mi north of Chimacum, and at mile 2.3.	**6.30**	0	.80	11.3	–	*1*
CS14	**Chimacum Creek** at Lat 48°02'57", long 122°47'16", in NE¼SW¼ sec.34, T. 30 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, and 0.7 mi upstream from mouth.	**7.10**	–	–	–	–	

NET gain or loss 5.01 ft^3/s, or
3,627 acre-ft per year

October 22, 2002

Table 4. Surface-water budget based on discharge measured in the Chimacum Creek drainage basin, eastern Jefferson County, Washington, June 26 and October 22, 2002 *(Continued)*

[**Map ID**: Location of measuring sites are shown in figure 12. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre–foot. –, no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage*	*Reach*
	Point at which surface water flow begins in the channel			0.79	100	–	*7*
CS1	**Chimacum Creek** at Lat 47º56'20", long 122º48'34", in NW¼NE¼ sec.9, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 20 ft upstream from sediment basin, and 0.8 mi west of Center.	**0.79**	0.13	1.93	67.7	–	*6*
CS2	Unnamed Tributary at Lat 47º56'54", long 122º47'56", in SE¼NE¼ sec.4, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at West Valley Road, 0.6 mi northwest of Center, and 5 ft upstream from mouth.	.13	–	–	–	–	
CS3	**Chimacum Creek** at Lat 47º56'54", long 122º47'54", in SW¼NW¼ sec.3, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 50 ft downstream from West Valley Road, and 0.6 mi northwest of Center.	**2.85**	0	.24	5.6	–	*5*
CS4	**Chimacum Creek** at Lat 47º57'49", long 122º46'47", in SE¼NE¼ sec.34, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at Center Road bridge, and 1.7 mi north of Center.	**3.09**	0	1.23	28.5	–	*4*
CS5	**Chimacum Creek** at Lat 47º58'26", long 122º46'35", in NW¼SW¼ sec.26, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 100 ft downstream from road bridge, and 2.4 mi north of Center.	**4.32**	.50	-.13	10.7	–	*3*
CS6	Naylor Creek at Lat 47º58'54", long 122º47'11", in NW¼NE¼ sec.27, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 10 ft upstream from weir, 50 ft downstream from West Valley Road, and 2.8 mi north of Center.	.36	–	–	–	–	
CS7	Putaansuu Creek at Lat 48º00'16", long 122º46'59", in NW¼SE¼ sec.15, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 10 ft downstream from West Valley Road, and 0.9 mi southwest of Chimacum.	.14	–	–	–	–	
CS8	**Chimacum Creek** at Lat 48º00'43", long 122º46'24", in NW¼NW¼ sec.14, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at Rhody Drive bridge, and 0.3 mi west of Chimacum.	**4.69**	1.45	1.08	23.0	–	*2*
CS9	East Fork Chimacum Creek at Lat 47º57'18", long 122º44'24", in NE¼NE¼ sec.1, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 30 ft upstream from Egg and I Road, and 2.0 mi north of Beaver Valley.	.74	0	.97	56.7	*10*	
CS10	East Fork Chimacum Creek at Lat 47º58'37", long 122º44'40", in NW¼SE¼ sec.25, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, upstream from culvert, and 3.2 mi south of Chimacum.	1.71	0	.01	.6	*9*	
CS11f	East Fork Chimacum Creek at Lat 48º00'33", long 122º45'42", in SW¼NE¼ sec.14, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, Beaver Valley Road, and 0.3 mi southeast of Chimacum.	1.72	0	-.27	-18.6	*8*	
CS12	East Fork Chimacum Creek at Lat 48º01'11", long 122º46'12", in NE¼SW¼ sec.11, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, 20 ft downstream from Chimacum Road, and 0.6 mi north of Chimacum.	1.45	–	–	–		
CS13	**Chimacum Creek** at Lat 48º01'39", long 122º46'26", in NW¼NW¼ sec.11, T. 29 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, at PUD gage, 50 ft upstream from footbridge, 300 ft east of end of Hilda Road, 1.2 mi north of Chimacum, and at mile 2.3.	**7.22**	0	1.67	18.8	–	*1*
CS14	**Chimacum Creek** at Lat 48º02'57", long 122º47'16", in NE¼SW¼ sec.34, T. 30 N., R. 1 W., Jefferson County, Hydrologic Unit 17110019, and 0.7 mi upstream from mouth.	**8.89**	–	–	–	–	

NET gain or loss 6.73 ft^3/s, or 4,873 acre-ft per year

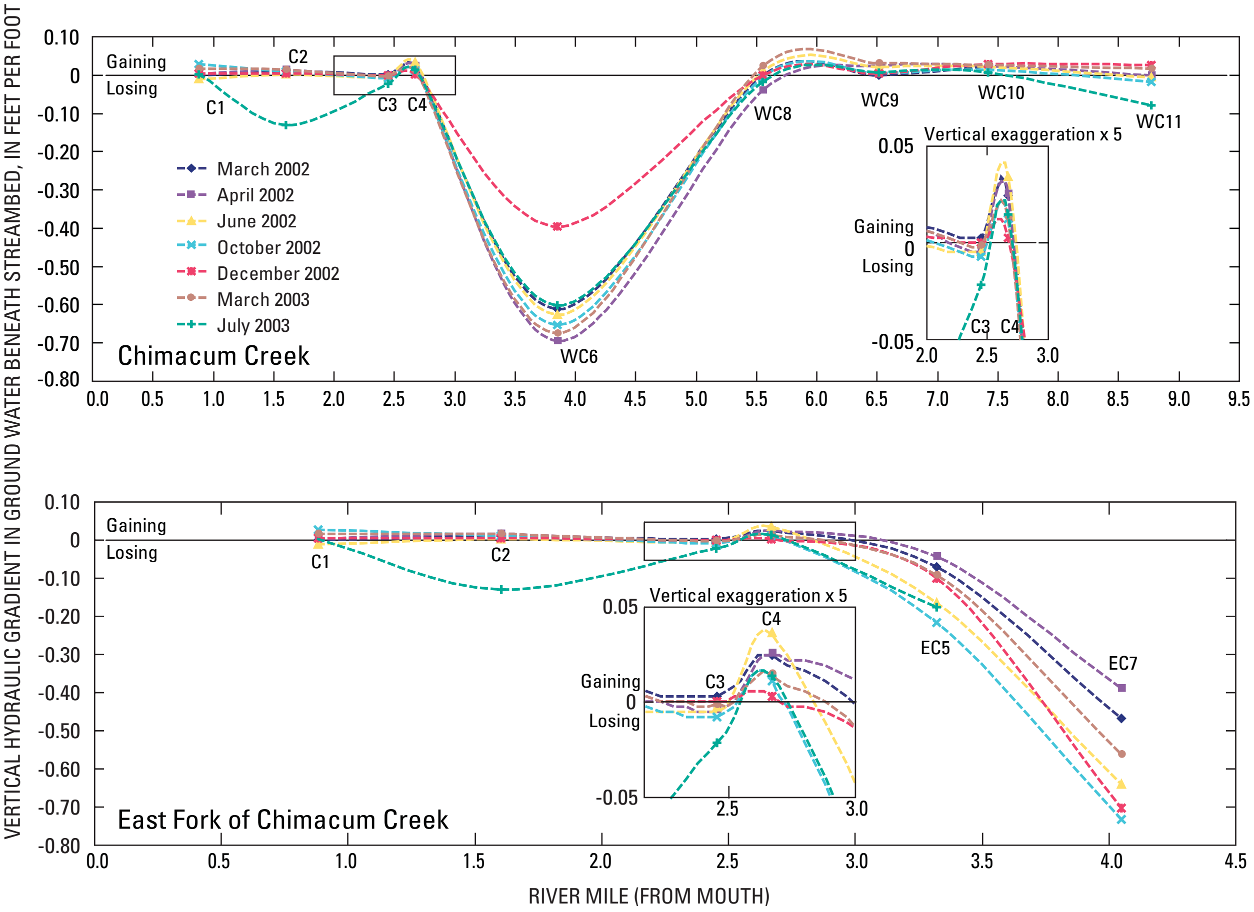
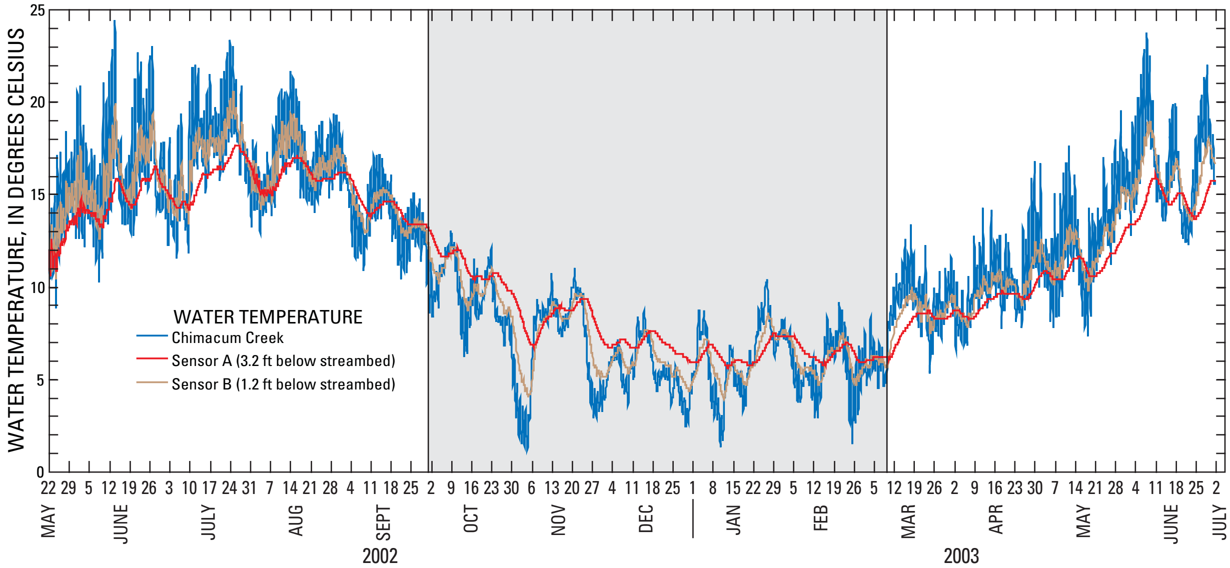


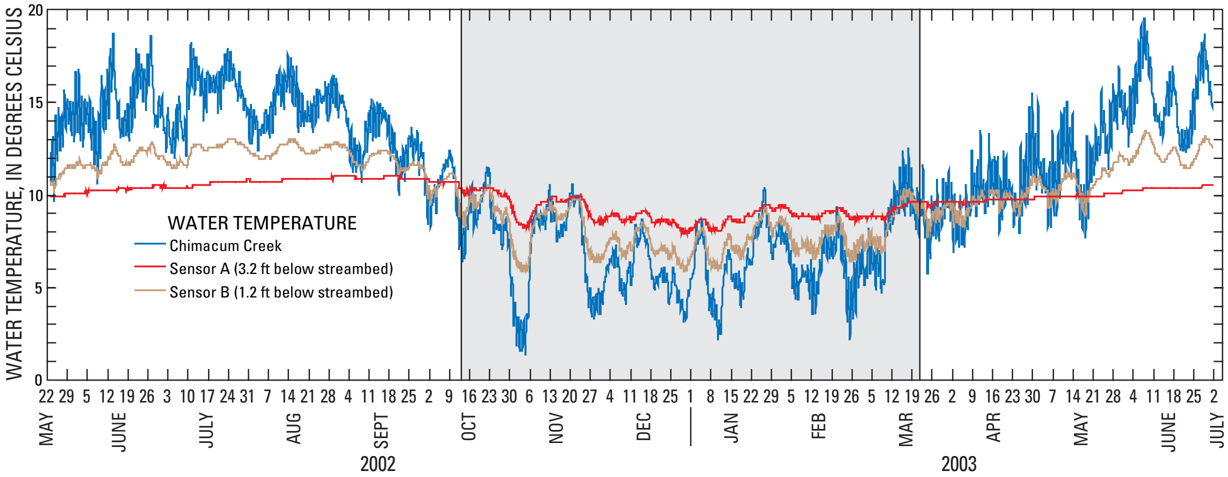
Figure 13. Vertical hydraulic gradient in ground water beneath the streambed measured at mini-piezometers in Chimacum Creek and East Fork Chimacum Creek, eastern Jefferson County, Washington, March 2002-July 2003.

Locations of mini-piezometers and seepage-run measurement sites are shown in figure 12.



A. Chimacum Creek at site WC6

Unshaded areas show the periods when ground-water temperatures generally are colder than surface-water temperatures, and shaded areas show the period when ground-water temperatures generally are warmer. Losing conditions are indicated at this site because ground-water temperatures are affected by surface-water temperatures as water moves downward.



B. Chimacum Creek at site C4

Unshaded areas show the periods when ground-water temperatures generally are unaffected by surface-water temperatures and gaining conditions are indicated. Shaded areas show the period when ground-water temperatures are affected by surface-water temperatures and losing conditions are indicated.

Figure 14. Vertical temperature profiles at sites WC6 and C4 in Chimacum Creek, eastern Jefferson County, Washington, May 2002-July 2003.

Seasonal variations between seepage runs conducted in June and October 2002 were relatively small. Both seepage runs showed identical spatial patterns and similar magnitudes of gains and losses for each stream reach (table 4). Although seepage data represent net exchanges on a reach scale and mini-piezometer data represent magnitude and direction of exchange at a point, the spatial pattern and magnitude of gains and losses were consistent between both data sets. The measured vertical hydraulic gradients (fig. 13) did show some seasonal variation that probably oversimplifies the complex and constantly changing balance between ground-water head and surface-water head. This is evident in the vertical temperature profile at site C4 (fig. 14*B*). The thermograph for this site indicates that the stream gained water throughout the summer months but switched to losing during the wet winter months between October 2002 and March 2003. The transition from gaining to losing conditions at site C4 also is indicated by a decrease in measured vertical hydraulic gradient, which was very close to zero in December 2002. The onset of winter precipitation and generally higher river stage relative to ground-water altitude may explain the apparent reversal. In contrast, the thermograph at site WC6 indicates that losing conditions predominate throughout the year (fig. 14*A*). At no time during the study did the ground-water altitudes exceed river stage at the site (fig. 13), although the apparent magnitude of loss did decrease after substantial precipitation in December 2002. Whether losing conditions always exist at site WC6 is uncertain. Historical precipitation data (fig. 2) and a comparison of 2002 mini-piezometer data with 2003 data indicate that overall conditions may have been somewhat drier during the period of this study.

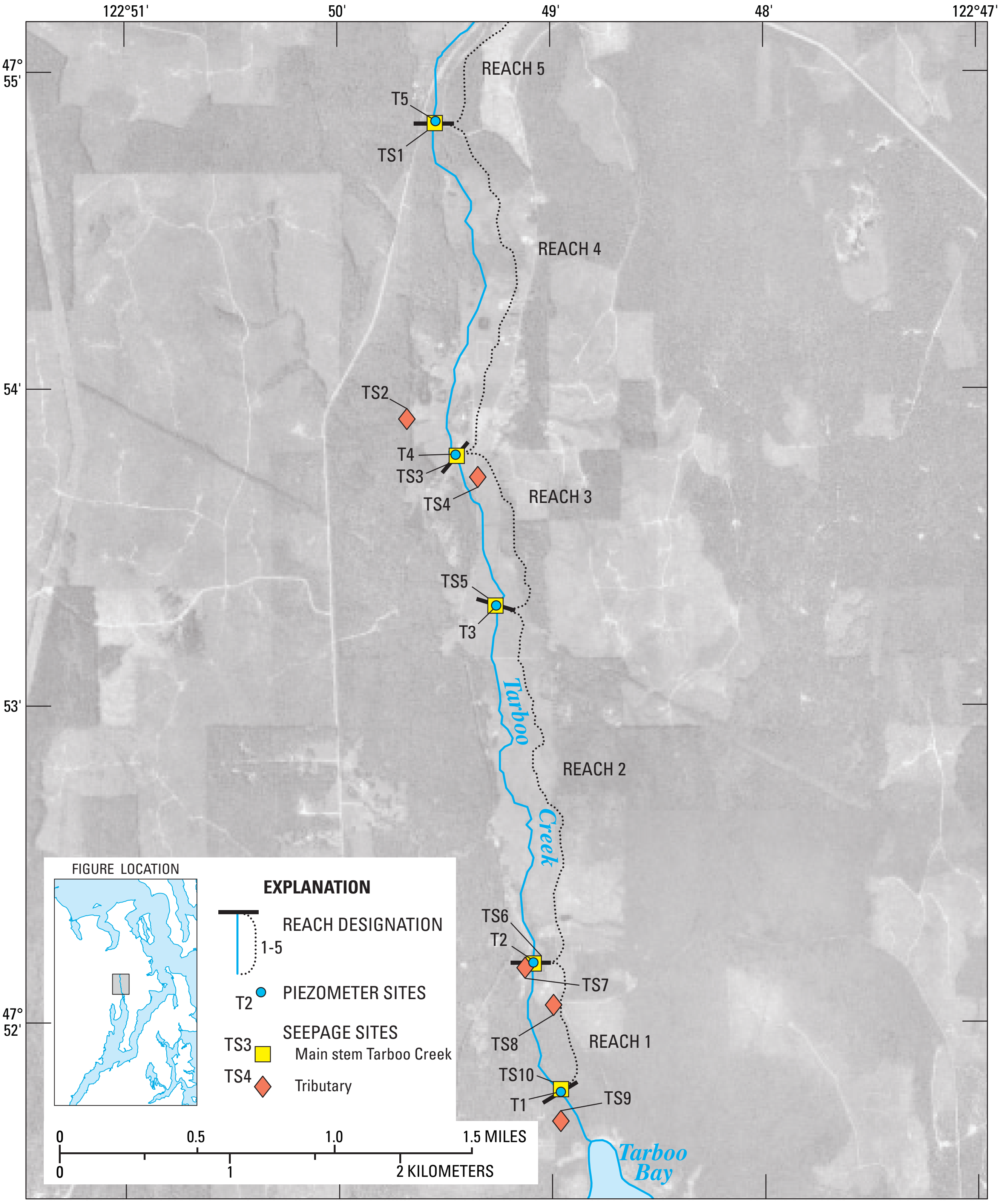
Seepage data indicate that Chimacum Creek receives a net gain of about 5 ft^3/s of ground water over its entire length in the spring and about 7 ft^3/s in the autumn (table 4). Although local gains and losses appear to vary in magnitude throughout the year, an average net discharge from ground water into Chimacum Creek of 6 ft^3/s would represent approximately 4,300 acre-ft/yr (see table 4).

Tarboo Creek

Tarboo Creek originates from two small valleys incised into Qva just east and north of Tarboo Lake (pl. 1). There is no direct connection with Tarboo Lake. For much of the year, flow in the creek is derived from ground water within reach 5, except during the winter, when surface runoff can be significant (fig. 15). As the creek flows southward toward Dabob Bay, it gains nearly 60 percent of its flow within reach 4, where the streambed crosses Qvr (table 5; fig. 15; pl. 1). Downstream of reach 4, the creek flows through pasture land and forest. Both seepage-run and mini-piezometer data indicate that the creek continues to gain water as it flows through reaches 1, 2, and 3 towards Dabob Bay, although magnitudes of measured gains were small and vertical hydraulic gradients were near neutral (table 5; fig. 16).

There was not much difference between seepage runs conducted in July and October 2002 (table 5). Spatial patterns and magnitudes of gains and losses were similar during both seepage runs except in reach 3, for which the July seepage run showed a small loss (table 5). The seasonal variations in successive mini-piezometer surveys were also very small. Vertical hydraulic gradients generally oscillated around a neutral gradient of zero (fig. 16). Vertical hydraulic gradients measured in March 2003 were discarded because the mini-piezometers were suspected of being out of equilibrium after high-water damage.

Seepage data indicate that Tarboo Creek receives a net gain of about 1.81 ft^3/s of ground water over its entire length in the spring and 1.75 ft^3/s in the autumn (table 5). Although local gains may vary in magnitude throughout the year, an average net discharge from ground water into Tarboo Creek of 1.75 ft^3/s would represent approximately 1,300 acre-ft/yr.



Base from U.S. Geological Survey Western Mapping Center
Digital Orthophoto Quarter Quad; Center and Quilcene, 1990
Universal Transverse Mercator projection, Zone 10, Datum NAD 27

Figure 15. Locations of mini-piezometers and seepage-run measurement sites in the study reaches of the Tarboo Creek drainage basin, eastern Jefferson County, Washington.

Table 5. Surface-water budget based on discharge measured in the Tarboo Creek drainage basin, eastern Jefferson County, Washington, July 2 and October 25, 2002

[**Map ID**: Location of measuring sites are shown in figure 15. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre-foot. –, no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage Reach*
	July 2, 2002					
	Point at which surface water flow begins in the channel			0.70	100	***5***
TS1	**Tarboo Creek** at Lat 47°54'51", long 122°49'28", in SE¼SE¼ sec.17, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 20 ft upstream from culvert under Dabob Road, and 2.4 mi southwest of Center.	**0.70**	0.18	1.23	58.3	***4***
TS2	Unnamed Tributary at Lat 47°53'55", long 122°49'36", in SE¼SE¼ sec.20, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, upstream from Old Tarboo Road, 3.3 mi southwest of Center, and 0.1 mi upstream from mouth.	.18	–	–	–	
TS3	**Tarboo Creek** at Lat 47°53'48", long 122°49'22", in SE¼SE¼ sec.20, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 40 ft upstream from Old Tarboo Road, and 3.3 mi southwest of Center.	**2.11**	.03	-.14	-7.0	***3***
TS4	Unnamed Tributary at Lat 47°53'44", long 122°49'16", in NW¼NW¼ sec.28, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, at ditch next to Dabob Road, 0.2 mi south of Old Tarboo Road, and 3.4 mi southwest of Center.	.03	–	–	–	
TS5	**Tarboo Creek** at Lat 47°53'20", long 122°49'11", in NW¼SW¼ sec.28, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 0.6 mi south of intersection of Old Tarboo Road and Dabob Road, and 3.8 mi southwest of Center.	**2.00**	0	.40	16.7	***2***
TS6	**Tarboo Creek** at Lat 47°52'12", long 122°49'01", in SW¼SW¼ sec.33, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 100 ft downstream from Dabob P.O. Road, and 1.6 mi north of Dabob.	**2.40**	.68	.32	9.4	***1***
TS7	Unnamed Tributary at Lat 47°52'11", long 122°49'03", in SW¼SW¼ sec.33, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, near intersection of Carl Johnson Road and Dabob P.O. Road, and 1.6 mi north of Dabob.	.02	–	–	–	
TS8	Unnamed Tributary at Lat 47°52'04", long 122°48'55", in NW¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 100 ft downstream from intersection of Dabob P.O. Road and Coyle Road, and 1.5 mi north of Dabob.	.44	–	–	–	
TS9	Unnamed Tributary at Lat 47°51'42", long 122°48'53", in SE¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, at weir 30 ft downstream from Carl Johnson Road, and 2.4 mi northwest of Dabob.	.22	–	–	–	
TS10	**Tarboo Creek** at Lat 47°51'48", long 122°48'53", in SE¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, and 0.1 mi upstream from mouth.	**3.40**	–	–	–	

NET gain or loss 1.81 ft^3/s, or 1,310 acre-ft per year

Table 5. Surface-water budget based on discharge measured in the Tarboo Creek drainage basin, eastern Jefferson County, Washington, July 2 and October 25, 2002 *(Continued)*

[**Map ID**: Location of measuring sites are shown in figure 15. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre-foot. –, no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage Reach*
	October 25, 2002					
	Point at which surface water flow begins in the channel			0.63	100	***5***
TS1	**Tarboo Creek** at Lat 47°54'51", long 122°49'28", in SE¼SE¼ sec.17, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 20 ft upstream from culvert under Dabob Road, and 2.4 mi southwest of Center.	**0.63**	0.15	1.12	58.9	***4***
TS2	Unnamed Tributary at Lat 47°53'55", long 122°49'36", in SE¼SE¼ sec.20, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, upstream from Old Tarboo Road, 3.3 mi southwest of Center, and 0.1 mi upstream from mouth.	.15	–	–	–	
TS3	**Tarboo Creek** at Lat 47°53'48", long 122°49'22", in SE¼SE¼ sec.20, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 40 ft upstream from Old Tarboo Road, and 3.3 mi southwest of Center.	**1.90**	.02	.18	8.6	***3***
TS4	Unnamed Tributary at Lat 47°53'44", long 122°49'16", in NW¼NW¼ sec.28, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, at ditch next to Dabob Road, 0.2 mi south of Old Tarboo Road, and 3.4 mi southwest of Center.	.02	–	–	–	
TS5	**Tarboo Creek** at Lat 47°53'20", long 122°49'11", in NW¼SW¼ sec.28, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 0.6 mi south of intersection of Old Tarboo Road and Dabob Road, and 3.8 mi southwest of Center.	**2.10**	0	.10	4.5	***2***
TS6	**Tarboo Creek** at Lat 47°52'12", long 122°49'01", in SW¼SW¼ sec.33, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 100 ft downstream from Dabob P.O. Road, and 1.6 mi north of Dabob.	**2.20**	.65	.35	10.9	***1***
TS7	Unnamed Tributary at Lat 47°52'11", long 122°49'03", in SW¼SW¼ sec.33, T. 28 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, near intersection of Carl Johnson Road and Dabob P.O. Road, and 1.6 mi north of Dabob.	.02	–	–	–	
TS8	Unnamed Tributary at Lat 47°52'04", long 122°48'55", in NW¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, 100 ft downstream from intersection of Dabob P.O. Road and Coyle Road, and 1.5 mi north of Dabob.	.46	–	–	–	
TS9	Unnamed Tributary at Lat 47°51'42", long 122°48'53", in SE¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, at weir 30 ft downstream from Carl Johnson Road, and 2.4 mi northwest of Dabob.	.17	–	–	–	
TS10	**Tarboo Creek** at Lat 47°51'48", long 122°48'53", in SE¼NW¼ sec.4, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, and 0.1 mi upstream from mouth.	**3.20**	–	–	–	

NET gain or loss 1.75 ft^3/s, or 1,267 acre-ft per year

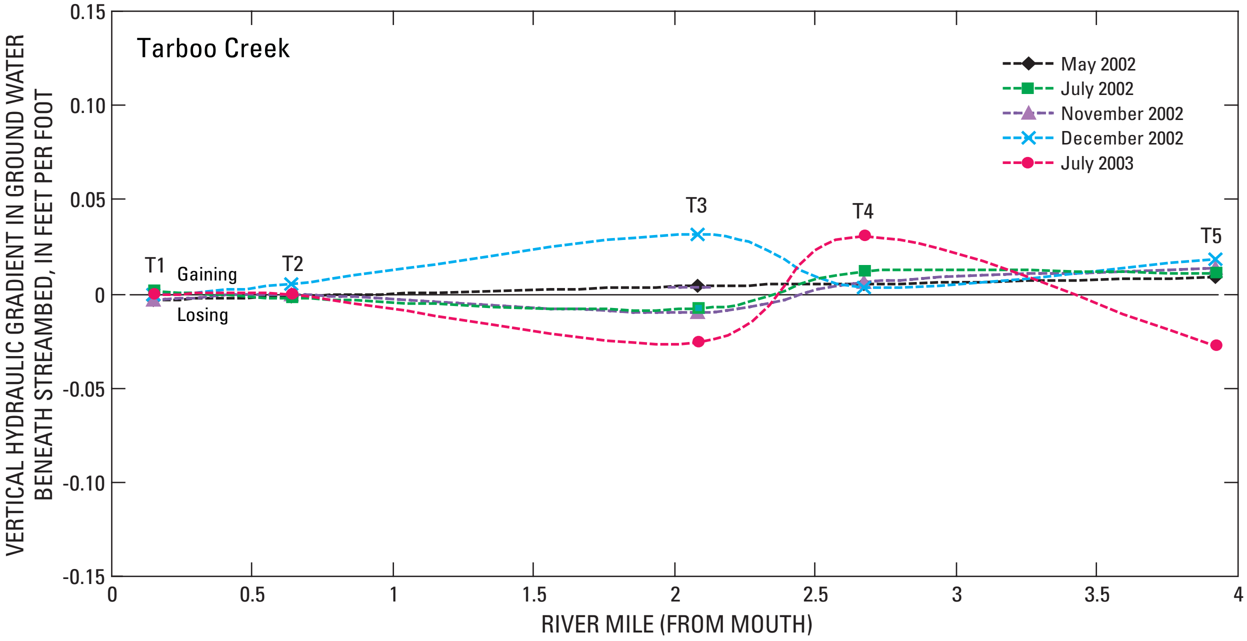


Figure 16. Vertical hydraulic gradient in ground water beneath the streambed measured at mini-piezometers in Tarboo Creek, eastern Jefferson County, Washington, May 2002-July 2003.

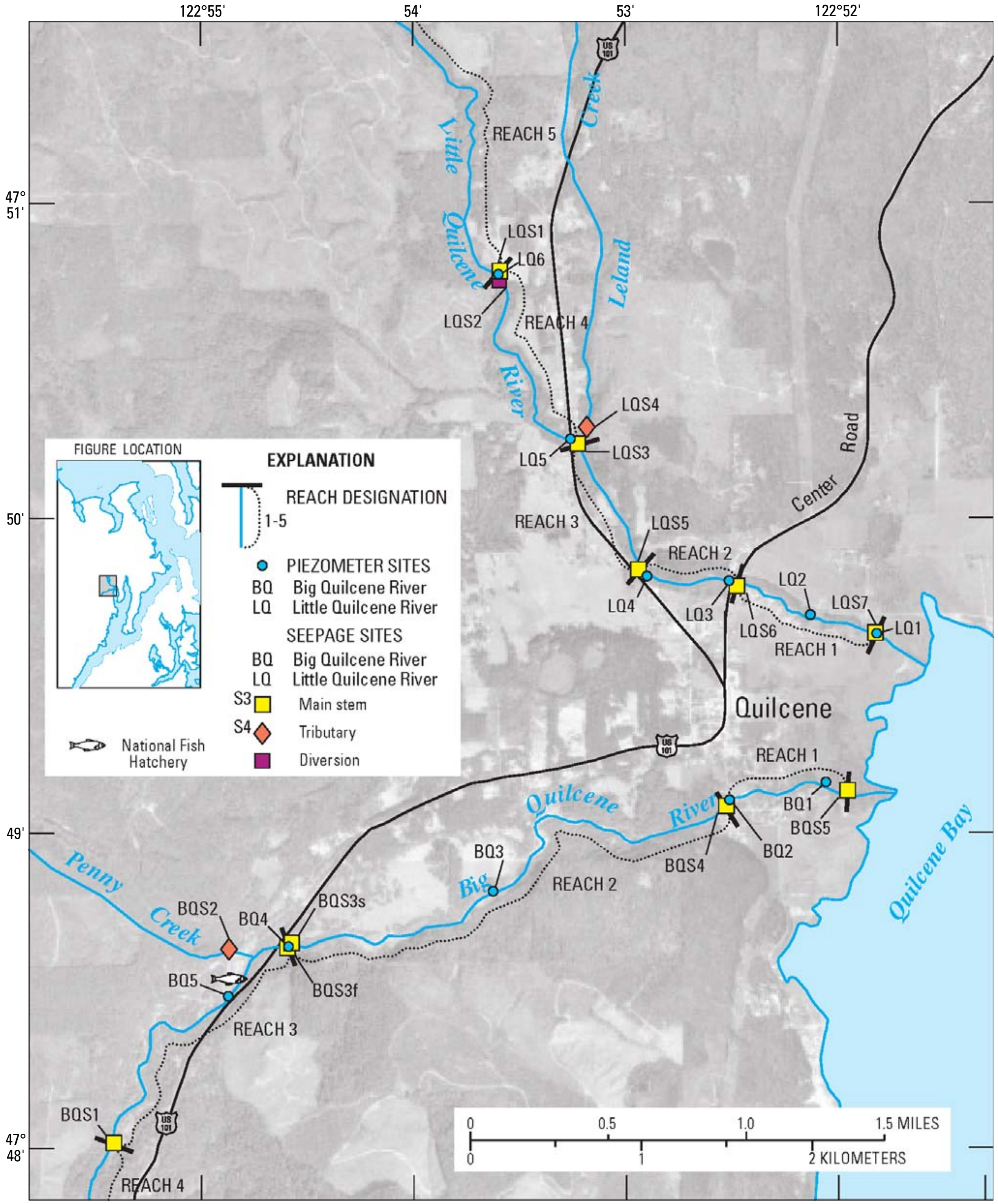
Locations of mini-piezometers and seepage-run measurement sites are shown in figure 15.

Big Quilcene River

The Big Quilcene River originates high in the Olympic Mountains and flows generally eastward toward the community of Quilcene, near the head of Quilcene Bay (fig. 1). The river cascades through a deep and narrow bedrock canyon before turning abruptly northward around the northwest flank of Mount Walker. Where the river leaves its bedrock channel at about river mile 4, the streambed is composed of large boulders and cobbles that grade into gravels and sands as it approaches the mouth at Quilcene Bay. Data from this study indicate that the Big Quilcene River appears to gain water in the vicinity of Penny Creek (reach 3; fig. 17). Accounting for the inflow of Penny Creek and the flow being diverted through the National Fish Hatchery, the seepage runs indicate gaining conditions in reach 3 (table 6). Data from reaches 2 and 3 were combined during the June 2002 seepage run because the discharge measurement at BQS3s was rated poor due to the rough channel cross section. Vertical gradients in mini-piezometers BQ5 and BQ4, located above and below Penny Creek, consistently indicated gaining conditions (fig. 18). The vertical hydraulic gradients in the next mini-piezometer downstream (BQ3) were near zero, suggesting little or no exchange (fig. 18). Most of the surface-water and ground-water exchanges occur downstream from BQ3 in reach 1 and the lower portion of reach 2 (fig. 17). Both seepage data and mini-piezometer data indicated consistent losing conditions where the Big Quilcene River flows across Quaternary alluvial deposits (Qal of Grimstad and Carson, 1981) overlying Qvr near the mouth of the river. Losing conditions may be the result of sediment deposition in the lower Big Quilcene River that has elevated the streambed above the adjacent water table, similar to conditions on the lower Dungeness River in Clallam County (Simonds and Sinclair, 2002).

The seasonal variation between seepage runs conducted in June and October 2002 was very large (table 6). The difference is due in part to large differences in streamflow between seepage runs (184 ft^3/s in June and 25.4 ft^3/s in October). The higher streamflow also increases the chance of error when measuring discharge. Losses in reach 1 were nearly identical in June and October 2002. The vertical-temperature profile at site BQ1 confirms that the river is losing water throughout the year, even though some of the surface-water data were lost (fig. 19). At BQ1, the temperature of the ground water closely follows the seasonal temperature pattern of the river, with a temporal lag of several weeks. Diurnal temperature cycles in the river were not seen, in even the shallowest temperature sensor, indicating that ground water has a thermal signature affected not by daily cycles but by seasonal cycles.

Seepage data indicate that net gains exceed net losses during high-flow periods (winter and spring) and net losses exceed net gains during low-flow periods (summer and autumn). Net gains or losses, therefore, vary with time of year. Data from this study indicate that the river has a net gain of 11.40 ft^3/s or about 8,300 acre-ft/yr during the spring and a net loss of 8.70 ft^3/s or about 6,300 acre-ft/yr during autumn. Additional monitoring would be required to calculate the net gain or loss on an annual basis.



Base from U.S. Geological Survey Western Mapping Center
Digital Orthophoto Quarter Quad; Mount Walker and Quilcene, 1990
Universal Transverse Mercator projection, Zone 10, Datum NAD 27

Figure 17. Locations of mini-piezometers and seepage-run measurement sites in the study reaches of the lower Big Quilcene River, eastern Jefferson County, Washington.

Table 6. Surface-water budget based on discharge measured in the lower Big Quilcene River, eastern Jefferson County, Washington, June 17 and October 23, 2002

[**Map ID**: Location of measuring sites are shown in figure 17. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre- foot. – no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage Reach*
	June 17, 2002					
	Point at which surface water leaves bedrock channel	–	–	assumed 0	100	***4***
BQS1	**Big Quilcene River** at Lat 47°48'02", long 122°55'20", in NW¼SW¼ sec.27, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Hiddendale Community Park, 0.9 mi southwest of Hwy 101 bridge, and 2.8 mi southwest of Quilcene.	**166.50**	5.70	14.80	7.9	***3***
BQS2	Penny Creek at Lat 47°48'39", long 122°54'48", in SW¼SE¼ sec.22, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, upstream from hatchery, upstream from diversion, and 2.1 mi southwest of Quilcene.	5.70	–	–	–	
BQS3s	**Big Quilcene River** at Lat 47°48'39", long 122°54'31", in SE¼SE¼ sec.22, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, below hwy 101, 1.8 mi southwest of Quilcene, and at mile 2.5.	[1]**218.40**	0	–	–	***2***
BQS4	**Big Quilcene River** at Lat 47°49'06", long 122°52'27", in SW¼NE¼ sec.24, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Rodgers Road, and 0.4 mi south of Quilcene.	**187.00**	0	-3.40	-1.9	***1***
BQS5	**Big Quilcene River** at Lat 47°49'09", long 122°51'53", in SE¼NE¼ sec.24, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 0.3 mi downstream from Linger Longer Road, and near mouth.	**183.60**	–	–	–	
			NET gain or loss 11.40 ft^3/s or 8,253 acre-ft per year			
	October 23, 2002					
	Point at which surface water leaves bedrock channel	–	–	assumed 0	100	***4***
BQS1	**Big Quilcene River** at Lat 47°48'02", long 122°55'20", in NW¼SW¼ sec.27, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Hiddendale Community Park, 0.9 mi southwest of Hwy 101 bridge, and 2.8 mi southwest of Quilcene.	**32.00**	2.10	0.50	1.7	***3***
BQS2	Penny Creek at Lat 47°48'39", long 122°54'48", in SW¼SE¼ sec.22, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, upstream from hatchery, upstream from diversion, and 2.1 mi southwest of Quilcene.	2.10	–	–	–	
BQS3f	**Big Quilcene River** at Lat 47°48'40", long 122°54'30", in SE¼SE¼ sec.22, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, below hwy 101, 1.8 mi southwest of Quilcene, and at mile 2.4.	**34.60**	0	-6.00	-21.0	***2***
BQS4	**Big Quilcene River** at Lat 47°49'06", long 122°52'27", in SW¼NE¼ sec.24, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Rodgers Road, and 0.4 mi south of Quilcene.	**28.60**	0	-3.20	-12.6	***1***
BQS5	**Big Quilcene River** at Lat 47°49'09", long 122°51'53", in SE¼NE¼ sec.24, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 0.3 mi downstream from Linger Longer Road, and near mouth.	**25.40**	–	–	–	
			NET gain or loss -8.70 ft^3/s, -6,299 acre-ft per year			

[1] Measurement rated poor; not used in the seepage calculation; reaches 2 and 3 were combined for this seepage run.

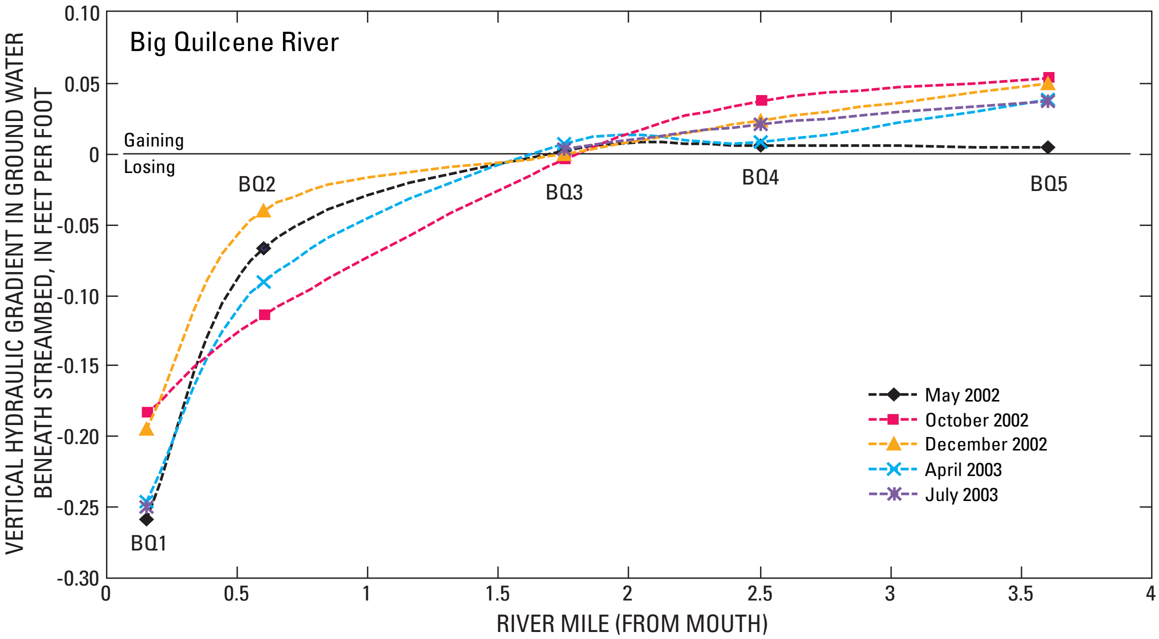


Figure 18. Vertical hydraulic gradient in ground water beneath the streambed measured at mini-piezometers in the lower Big Quilcene River, eastern Jefferson County, Washington, May 2002-July 2003.

Locations of mini-piezometers and seepage-run measurement sites are shown in figure 17.

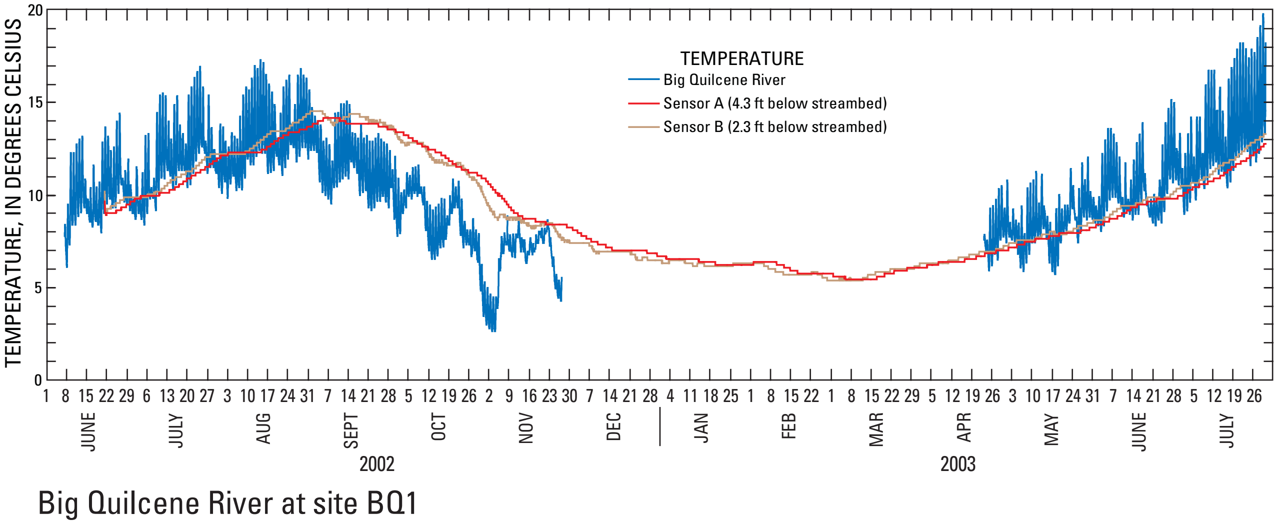


Figure 19. Vertical temperature profiles at site BQ1 in the lower Big Quilcene River, eastern Jefferson County, Washington, June 2002-July 2003.

Surface-water-temperature data from June 7-November 8, 2002 were provided by the City of Port Townsend at river mile 0.4. Data from November 8-27, 2002, and April 23-July 30, 2003 were collected by the U.S. Geological Survey at river mile 0.15. Temperature differences between the two sites are assumed to be less than 1°C.

Little Quilcene River

The Little Quilcene River originates high in the Olympic Mountains and flows east through a deep bedrock canyon before turning southeast toward the community of Quilcene at the head of Quilcene Bay (fig. 1). The river leaves its bedrock channel at about river mile 3, where the streambed is composed of boulders and cobbles grading into gravels and sands as it approaches the mouth at Quilcene Bay. As soon as the Little Quilcene River encounters the alluvial streambed (reach 4), it begins to lose water to the ground-water system (fig. 17). Seepage data indicate that the river maintains a net loss of water within reaches 3 and 4 or until about river mile 1.1 (table 7). Mini-piezometer data were consistent with seepage data except in the vicinity of Leland Creek, where a positive vertical gradient at site LQ5 indicated a gaining condition (fig. 20). Reach 2 has both a net seepage gain and a positive vertical hydraulic gradient at mini-piezometer site LQ3. Gaining conditions on the Little Quilcene River appear to be localized and could be related to the confluence with Leland Creek (LQ5) or to other ground-water inflow (LQ3). Losing conditions were observed within reach 1, where the Little Quilcene River flows across Quaternary alluvial deposits (Qal of Grimstad and Carson, 1981) overlying Qvr. As in the Big Quilcene River, sediment deposition may have elevated the streambed above the adjacent water table to produce losing conditions (Simonds and Sinclair, 2002).

Seasonal variations between seepage runs conducted in June and October 2002 were small. Spatial patterns of gains and losses for each stream reach were identical for both seepage runs, with magnitudes proportional to streamflow (table 7). Mini-piezometer data also indicated a consistent spatial pattern that varied only in the magnitude of gains and losses (fig. 20). The vertical temperature profile at site LQ2 also indicated losing conditions throughout the year (fig. 21). A pumping well close to site LQ2 that supplies a group of homes just north of Quilcene likely does not withdraw enough water to explain the large negative vertical hydraulic gradients observed at mini-piezometer site LQ2. The pattern of ground-water temperatures recorded by the shallow sensor matched the patterns of weekly river fluctuations. The pattern of temperatures recorded by the deeper sensor matched the seasonal temperature pattern of the river, with a lag of about 2 weeks (fig. 21).

Seepage data indicate that net losses exceed net gains along the lower 3 mi of the Little Quilcene River. Data from this study suggest that the river has a net loss of 5 ft^3/s, or about 3,600 acre-ft/yr in the spring and 0.35 ft^3/s, or about 250 acre-ft/yr in the autumn. Because the quantity of surface-water loss is proportional to streamflow, additional monitoring would be required to determine the annual net loss.

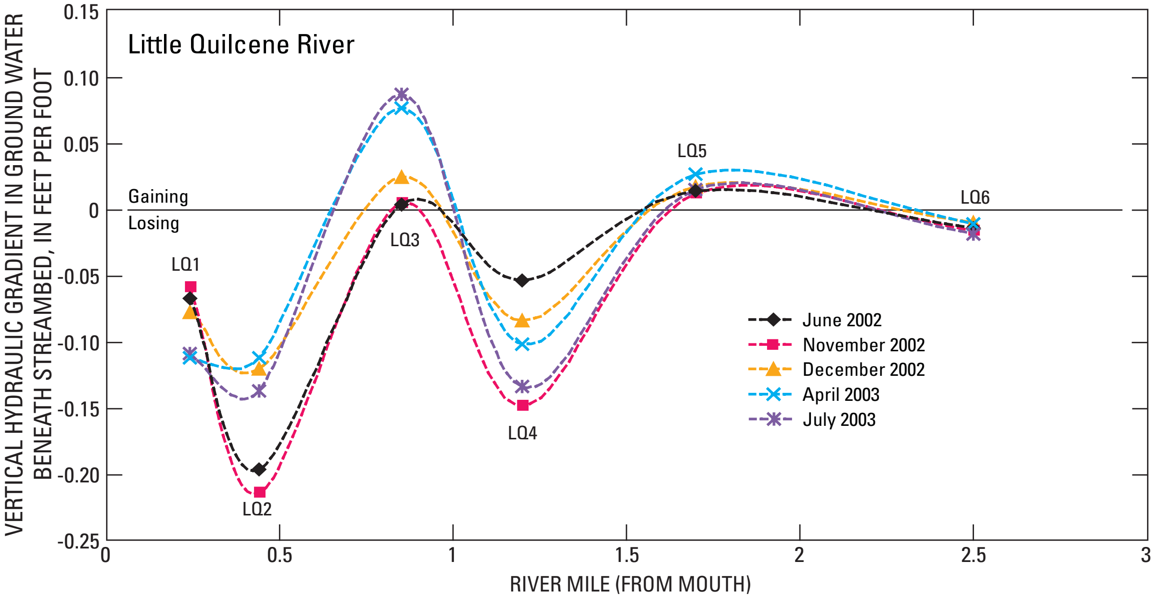


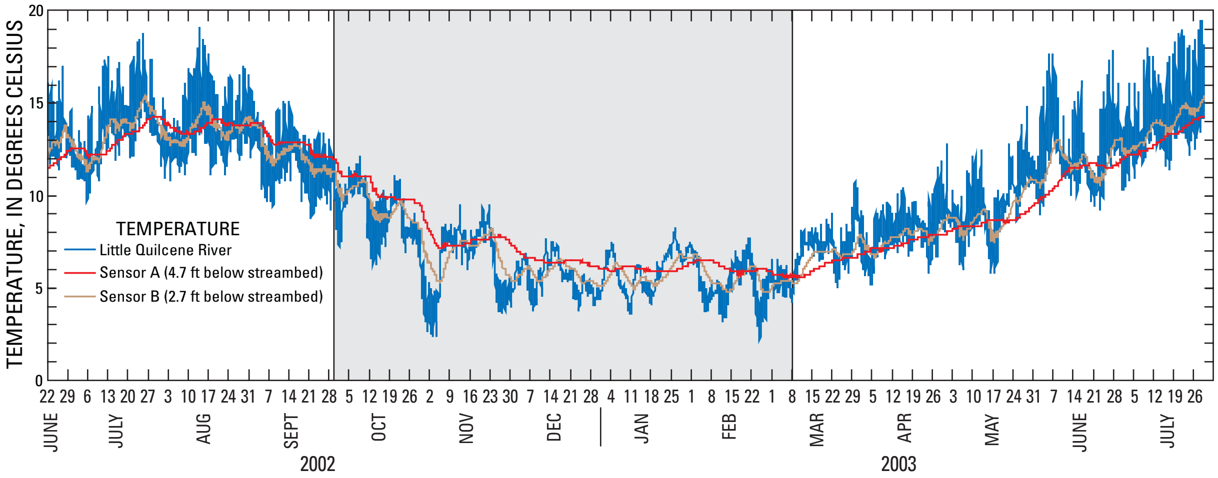
Figure 20. Vertical hydraulic gradient in ground water beneath the streambed measured at mini-piezometers in the lower Little Quilcene River, eastern Jefferson County, Washington, June 2002-July 2003.

Locations of mini-piezometers and seepage-run measurement sites are shown in figure 17.

Table 7. Surface-water budget based on discharge measured in the lower Little Quilcene River, eastern Jefferson County, Washington, June 18 and October 24, 2002

[**Map ID**: Location of measuring sites are shown in figure 17. **Site location**: Site names in bold are measurement sites located on the main stem of the river. All other sites are located on tributary streams. **Cumulative tributary inflow and net gain or loss** are computed between consecutive river measurement locations. **Percentage of flow** is relative to discharge at downstream end of reach. **Abbreviations:** ft, foot; mi, mile; ft^3/s, cubic foot per second; acre-ft, acre-foot. –, no data]

Map ID	Site location	Discharge (ft^3/s)	Cumulative tributary inflow (ft^3/s)	Net gain or loss (ft^3/s)	Percentage of flow	*Seepage Reach*
	June 18, 2002					
	Point at which surface water leaves bedrock channel	–	–	assumed 0	100	*5*
LQS1	**Little Quilcene River** at Lat 47°50'48", long 122°53'31", in SW¼NE¼ sec.11, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 400 ft upstream from small diversion, and 1.8 mi northwest of Quilcene.	**38.70**	-1.76	-3.04	-9.0	*4*
LQS2	Unnamed Diversion at Lat 47°50'46", long 122°53'31", in SE¼NE¼ sec.11, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 20 ft downstream from diversion of Little Quilcene River, and 1.8 mi northwest of Quilcene.	-1.76	–	–	–	
LQS3	**Little Quilcene River** at Lat 47°50'15", long 122°53'09", in NE¼NE¼ sec.14, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Hwy 101 bridge, and 1.0 mi northwest of Quilcene.	**33.90**	3.00	-.70	-1.9	*3*
LQS4	Leland Creek at Lat 47°50'18", long 122°53'08", in NE¼NE¼ sec.14, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 1.0 mi northwest of Quilcene, and 100 ft upstream from mouth.	3.00	–	–	–	
LQS5	**Little Quilcene River** at Lat 47°49'51", long 122°52'52", in NW¼SW¼ sec.13, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, and 0.6 mi northwest of Quilcene.	**36.20**	0	4.80	11.7	*2*
LQS6	**Little Quilcene River** at Lat 47°49'48", long 122°52'24", in NW¼SE¼ sec.13, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Center Road, and 0.4 mi north of Quilcene.	**41.00**	0	-6.10	-17.5	*1*
LQS7	**Little Quilcene River** at Lat 47°49'39", long 122°51'45", in SW¼SW¼ sec.18, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, south of intersection of McInnes Road and East Quilcene Road, 0.6 mi northeast of Quilcene, and near mouth.	**34.90**	–	–	–	
			NET gain or loss -5.04 ft^3/s, or 3,648 acre-ft per year			
	October 24, 2002					
	Point at which surface water leaves bedrock channel	–	–	assumed 0	100	*5*
LQS1	**Little Quilcene River** at Lat 47°50'48", long 122°53'31", in SW¼NE¼ sec.11, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 400 ft upstream from small diversion, and 1.8 mi northwest of Quilcene.	**8.10**	-1.18	-0.05	-0.7	*4*
LQS2	Unnamed Diversion at Lat 47°50'46", long 122°53'31", in SE¼NE¼ sec.11, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 20 ft downstream from diversion of Little Quilcene River, and 1.8 mi northwest of Quilcene.	-1.18	–	–	–	
LQS3	**Little Quilcene River** at Lat 47°50'15", long 122°53'09", in NE¼NE¼ sec.14, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Hwy 101 bridge, and 1.0 mi northwest of Quilcene.	**6.87**	1.63	-.54	-6.8	*3*
LQS4	Leland Creek at Lat 47°50'18", long 122°53'08", in NE¼NE¼ sec.14, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, 1.0 mi northwest of Quilcene, and 100 ft upstream from mouth.	1.63	–	–	–	
LQS5	**Little Quilcene River** at Lat 47°49'51", long 122°52'52", in NW¼SW¼ sec.13, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, and 0.6 mi northwest of Quilcene.	**7.96**	0	1.24	13.5	*2*
LQS6	**Little Quilcene River** at Lat 47°49'48", long 122°52'24", in NW¼SE¼ sec.13, T. 27 N., R. 2 W., Jefferson County, Hydrologic Unit 17110018, at Center Road, and 0.4 mi north of Quilcene.	**9.20**	0	-1.00	-12.2	*1*
LQS7	**Little Quilcene River** at Lat 47°49'39", long 122°51'45", in SW¼SW¼ sec.18, T. 27 N., R. 1 W., Jefferson County, Hydrologic Unit 17110018, south of intersection of McInnes Road and East Quilcene Road, 0.6 mi northeast of Quilcene, and near mouth.	**8.20**	–	–	–	
			NET gain or loss -0.35 ft^3/s, or -253 acre-ft per year			



Little Quilcene River at site LQ2

Figure 21. Vertical temperature profiles at site LQ2 in the lower Little Quilcene River, eastern Jefferson County, Washington, June 2002-July 2003.

Unshaded areas show the periods when ground-water temperatures generally are colder than surface-water temperatures, and shaded areas show the period when ground-water temperatures generally are warmer. Losing conditions are indicated at this site because ground-water temperatures are affected by surface-water temperatures as water moves downward.

Comparison Between Drainage Basins

Each of the drainage basins evaluated in this study had a distinctive and unique pattern of surface-water and ground-water exchanges. The patterns of gains and losses generally were consistent throughout the period of study, although the magnitudes varied in response to seasonal precipitation patterns. Gaining or losing conditions reversed where vertical hydraulic gradients generally were small or where changes in stream stage or discharge generally were large. Surface-water and ground-water exchanges in bedrock channels were not evaluated in this study. However, all streams with upper reaches underlain by unconsolidated materials gained water in those reaches except the Little Quilcene River. Streams generally gain water where the streambed comes into contact with water-bearing layers and springs or seeps contribute to surface-water flow. There was substantial loss to ground water in the lower reaches of the Big and Little Quilcene Rivers on the alluvial plain at the head of Quilcene Bay, where the river is channelized by levees and the streambed is aggrading. Chimacum Creek loses a substantial quantity of water in the vicinity of Chimacum, most likely because the streambed there is highly permeable Vashon Recessional Outwash deposits and ground-water altitudes are well below the local streambed. The lower-most reaches of Chimacum Creek gained water where the streambed has incised below the level of the adjacent water table. In this area, however, high stream flows were sufficient to reverse the hydraulic gradients and cause losing conditions during the winter months.

The primary control governing the pattern of gaining and losing reaches is the hydraulic conductivity of the streambed, which is a function of the local geology. Precipitation events control the magnitudes of gains and losses by changing the elevation of stream stage relative to the adjacent water table. Where magnitudes of gains and losses are small, reversals can occur more readily. These factors combine to make each drainage basin unique.

Additional Studies

One outcome of this study was the recognition of several areas wherein additional data would facilitate a more thorough understanding of the water resources of the Chimacum Creek Basin and associated surface water/ground water interactions.

Continued long-term water-level monitoring in the Chimacum Creek Basin can provide more detail about annual variations within the ground-water system. Monthly water-level data collected over many years of record would improve the ability to detect seasonal fluctuations and long-term trends in ground-water levels. The many recent advances in water-level-monitoring technology make it easy to install an array of water-level data loggers programmed to record water levels at set intervals for long periods.

The depth to bedrock and the thickness and stratigraphy of the Older Glacial Deposits is largely unknown. Test drilling of deep boreholes and extraction of drill core would greatly enhance knowledge of the glacial stratigraphy and the geometry of water-bearing layers. Geophysical surveys generally also would help determine the geometry of the bedrock surface.

An increased understanding of ground-water recharge would help quantify how much precipitation is able to infiltrate the till to the underlying aquifers. Because till covers most of the surface area in the Chimacum Creek Basin and surrounding region, the degree to which till acts as a barrier to infiltration affects recharge estimates and therefore predictions of water-resource availability.

A more detailed examination of the potential for vertical ground-water flow between Qgo and Qva would be useful. If additional wells screened in Qgo were located, the information from those wells could be compared with that of adjacent wells screened in Qva to determine vertical hydraulic gradients and possible areas of upwelling ground water.

Although the two seepage studies of the Big and Little Quilcene Rivers that were part of this study provided some information, additional seepage studies would be needed to fully characterize net gains and losses for these two rivers. Continued monitoring would be needed to calculate net gains or losses on an annual basis.

Further analysis of the vertical-temperature-profile data would help quantify streambed hydraulic-conductivity values and facilitate calculation of rates of loss through the streambed.

Finally, the data provided in this report could be used to develop a three-dimensional ground-water-flow model for the Chimacum Creek Basin. Such a model can be used to simulate the effects of development or other scenarios on the ground-water system.

Summary

The Washington State Watershed Management Act of 1998 provides a mechanism for local governments to assess the status of their water resources and initiate planning processes for managing those water resources. The planning unit for Water Resource Inventory Area 17 in eastern Jefferson County recognized the need to investigate the ground-water system in the unconsolidated glacial deposits of the Chimacum Creek Basin and to better understand the interactions between surface water and the ground-water system in the WRIA 17 area. They initiated a 3-year cooperative study with the U.S. Geological Survey in 2002 with the following objectives.

1. Define the hydrogeologic framework, including the geometry of aquifers and confining units in the unconsolidated glacial deposits of the Chimacum Creek Basin;
2. Define the movement of ground water within the ground-water system of the Chimacum Creek Basin; and,
3. Better understand how ground water and surface water interact in the Chimacum Creek drainage basin, the Tarboo Creek drainage basin, and lower portions of the Big and Little Quilcene Rivers.

For the study of the ground-water system, a well inventory was conducted in the Chimacum Creek Basin and geologic data from well logs and water level information were compiled. LIDAR imagery was used to construct a new geologic map, and driller's logs were used to construct eight hydrogeologic sections across the basin. Water levels were measured throughout the basin and selected wells were monitored on a monthly basis.

The stratigraphy of the Chimacum Creek Basin includes six geologic units: Quaternary Alluvium, Vashon Recessional Outwash deposits, Vashon Lodgement Till, Vashon Advance Outwash deposits, Older Glacial Deposits, and Bedrock. Lowland areas and small depressions contain Quaternary Alluvium, which locally consist of thick accumulations of peat. Vashon Recessional Outwash deposits occupy glacial outwash channels that are incised into the Vashon Lodgement Till, which forms a hardened and conspicuously grooved surface over much of the area. Sands and gravels within the underlying Vashon Advance Outwash deposits are significant sources of ground water in the basin. The Older Glacial Deposits are an undifferentiated mixture of deposits related to multiple glaciations. The bedrock, including sedimentary, igneous, and intrusive igneous rocks, is exposed in scattered localities around the margins of the basin and underlies the basin at depths ranging from 0 to more than 1,000 feet below land surface.

The six geologic units correspond to hydrogeologic units, which, for the purposes of this study, were subdivided into coarse-grained layers (aquifers) and fine-grained layers. Quaternary Alluvium in flat valley bottoms is rich in organic matter and, although generally saturated, does not transmit water very well. Vashon Recessional Outwash deposits typically are less than 100 feet thick and occur primarily in the Chimacum Creek and East Fork Chimacum Creek Valleys. Some of the coarse-grained aquifer materials within the Vashon Recessional Outwash are in hydraulic continuity with Chimacum Creek. The Vashon Lodgement Till is a low-permeability unit at the land surface over much of the area. Because the base of the till is above the water table, it does not act as a true confining layer; rather, it retards the infiltration of precipitation and slows ground-water recharge. The Vashon Advance Outwash is a widely used aquifer on the west side of the Chimacum Creek Basin, where deposits are as much as 200 feet thick. Several layers, such as the Sparling Aquifer, are very productive and currently supply a growing public water-supply system. The unit is more discontinuous on the east side of the Chimacum Creek Basin and is not present beneath till between Chimacum Creek and the East Fork of Chimacum Creek. The Older Glacial Deposits are widespread in the Chimacum Creek Basin and may exceed 1,000 feet in thickness as the depth to bedrock increases to the north. Discontinuous lenses of sand and gravel within the unit contribute usable quantities of water for domestic wells, but the unit is largely buried and therefore its stratigraphy is poorly understood. Bedrock is present beneath all of the unconsolidated deposits and is exposed in isolated outcrops. All of the bedrock units have relatively low permeability; however, a small number of wells drilled in bedrock have yields sufficient for limited domestic use. The median values of horizontal hydraulic conductivity for Vashon Recessional Outwash, Vashon Advance Outwash, Older Glacial Deposits, and Bedrock, are 10, 130, 22, and 0.53 feet per day, respectively.

Lateral ground-water flow in both the Older Glacial Deposits and Vashon Advance Outwash aquifers generally follows the surface-water drainage pattern. Ground water flows from high areas towards low areas, and thus, flow paths converge on Chimacum Creek, where they turn northward and flow toward Port Townsend Bay. Flow paths on the east side of the Chimacum Creek Basin flow east toward the coast, where discharge areas can be found at or near the bedrock contact. Ground-water discharge also occurs at the south end of West Valley, providing base flow to Chimacum Creek.

A combination of methods was used to better understand surface water/ground water interactions in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers. Seepage runs were conducted on each stream in June-July 2002 and again in October 2002, instream mini-piezometers were installed and measured periodically, and temperature sensors were installed to record continuous streambed temperatures for a period of 1 year (July 2002 to July 2003).

The upper reaches of Chimacum Creek gain water from the ground-water system (probably from coarse-grained zones within Qva and Qgo). Little ground water is exchanged as the creek flows over peat deposits. Near the community of Chimacum, the creek loses water through the streambed as it flows over Qvr. Farther downstream, where the creek is incised into Qvr and the local water table is higher than the average stream stage, the stream gains water. However, winter stream stages can be higher than the local water table, causing the creek to lose water to the ground-water system. The average net exchange between ground water and Chimacum Creek observed during the course of this study was a gain of about 6 cubic feet per second (ft^3/s).

Tarboo Creek gains water from the ground-water system in its upper reaches, where the streambed is in contact with water-bearing horizons within Qva and Qvr. The middle reaches of Tarboo Creek appear to be a transition zone, where gaining or losing conditions may depend upon precipitation events that affect altitudes of stream stage relative to the adjacent water table. Although the seepage data indicate that the lower reaches of the creek may gain small amounts of water, the mini-piezometer data suggest little or no ground-water exchange. The net exchange between ground water and Tarboo Creek observed during this study was a gain of about 1.75 ft^3/s.

The Big Quilcene River gains water from the ground-water system where the streambed is in contact with very coarse boulder and gravel alluvium. Ground water enters the river in the vicinity of Penny Creek and just downstream from highway 101. Below the gaining reach, where the river flattens out and the flood plain widens, the river passes through a transition zone of little or no ground-water exchange. The lower reaches of the river are characterized by losing conditions throughout the year. The net exchange between ground water and the Big Quilcene River observed in this study depended on river flow and ranged from a gain of about 11.4 ft^3/s in the spring to a loss of about 8.7 ft^3/s in the autumn.

The Little Quilcene River loses water once the river leaves its bedrock channel and the streambed changes to alluvial deposits. As the river flows south towards the community of Quilcene, it continues to lose water, except for gains in localized areas near the mouth of Leland Creek and just upstream from Center Road. Losing conditions persist throughout the year as the river flows across the alluvial plain at the head of Quilcene Bay, similar to the lower reaches of the Big Quilcene River. The net exchange between ground water and the Little Quilcene River found in this study also depended on river flow and ranged from a loss of about 0.35 ft^3/s in the spring to a loss of about 5 ft^3/s in the autumn.

Each of the drainage basins had a unique pattern of surface-water and ground-water exchanges. The patterns of gains and losses generally remained consistent while the magnitudes varied in response to seasonal precipitation patterns. In several cases, the hydraulic gradients were near zero and the change in stream stage was sufficient to cause a change from gaining to losing.

Small streams like Chimacum and Tarboo Creeks generally gain water where the streambed comes into contact with water-bearing layers and springs or seeps contribute to surface-water flow. Chimacum Creek loses significant quantities of water when the streambed encounters highly permeable deposits with a lower water-table altitude. Substantial loss to ground water also occurs in the lower reaches of the Big and Little Quilcene Rivers where the streambed is aggrading on the alluvial plain at the head of Quilcene Bay.

The geology and hydraulic conductivity of the streambed combined with the elevation of stream stage relative to the adjacent water table is what determines the pattern of gaining and losing reaches. The combination of these factors is what makes each drainage basin unique.

Additional deep boreholes and geophysical surveys would contribute to a better understanding of the hydrogeology of the area. More water-level monitoring, a recharge study, and examination of vertical gradients between hydrogeologic units would enhance knowledge of the ground-water system. More seepage runs and analysis of vertical temperature data would help define surface water/ground water interactions. All of the data could be used to develop a three-dimensional ground-water-flow model for the Chimacum Creek Basin.

References Cited

Bear, Jacob, 1979, Hydraulics of ground water: New York, McGraw-Hill, 569 p.

Carnahan, B., Luther, H.A., and Wilkes, J.O., 1969, Applied numerical methods: New York, John Wiley and Sons, Inc., 604 p.

CH2M Hill, 1996, Tri-Area ground-water study, summary report: Port Townsend, Washington, CH2M Hill, prepared for the City of Port Townsend, September 3, 1996, 43 p. plus appendixes.

Easterbrook, D.J., 1979, The last glaciation of northwest Washington: *in* Armentrout, J.M., Cole, M.R., Ter Best, Harry Jr., eds., 1979, Cenozoic paleogeography of the western U.S., Pacific Coast Paleogeography Symposium No. 3: Society of Economic Paleontologists and Mineralogists Symposium Volume, p. 177-189.

Easterbrook, D.J., 1986, Stratigraphy and chronology of Quaternary deposits of the Puget lowland and Olympic Mountains of Washington and the Cascade Mountains of Washington and Oregon: Quaternary Science Reviews, v. 5, p. 145-159.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, 174 p.

Freeze, R.A., and Cherry, J.A., 1979, Ground water: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Grimstad, Peder, and Carson, R.J., 1981, Geology and ground-water resources of eastern Jefferson County, Washington: Washington State Department of Ecology Water Supply Bulletin no. 54, 125 p.

Jamestown S'Klallam Tribe, 1994, The Dungeness-Quilcene Water Resources Management Plan: A plan submitted to the Department of Ecology under the Chelan Agreement, June 30, 1994, various pagination.

Jefferson County, 1998, Jefferson County Comprehensive Plan, December 1998.

Jones, M. A., 1996, Thickness of unconsolidated deposits in the Puget Sound lowland, Washington and British Columbia: U.S. Geological Survey Water-Resources Investigation Report 94-4133, 1 plate, scale 1:500,000.

Parametrix, Inc., 2000, Stage 1 Technical assessment as of February 2000, Water Resource Inventory Area 17: Kirkland, Washington, Parametrix, Inc., project no. 553-1820-007, 414 p.

Rantz, S.E., and others, 1982, Volume 1, Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Ritter, Dale F., 1978, Process geomorphology: Dubuque, Iowa, William C. Brown Company Publishers, p. 414.

Simonds, F.W., and Sinclair, K.A., 2002, Surface water/ground water interactions along the lower Dungeness River and vertical hydraulic conductivity of streambed sediments, Clallam County, Washington, September 1999-July 2001: U.S. Geological Survey Water-Resources Investigations Report 02-4161, 62 p.

Tabor, R.W., and Cady, W.M., 1978, Geologic map of the Olympic Peninsula, Washington: U.S. Geological Survey Miscellaneous Investigation Series Map I-994, scale 1:125,000.

U.S. Department of Agriculture, 1975, Soil Survey of Jefferson County Area, Washington: Soil Conservation Service, 100 p., 70 pl.

Table 8. Physical and hydrologic data for inventoried wells in the Chimacum Creek Basin, eastern Jefferson County, Washington, May 2002

[**Local well No.:** See figure 4 for explanation of well-numbering system. Location of wells are shown on plate 1. **Washington Dept. of Ecology tag:** Washington Department of Ecology unique identification No. **Hydrogeologic unit:** See Plate 1 for explanation of units. **LIDAR altitude:** Land-surface altitude determined from LIDAR return signal. **Primary use of water:** H, domestic; I, irrigation; P, public supply; T, institutional; U, unused; and Z, other. **Drillers' log available:** Y, yes; N, no. **Abbreviations**: ft, foot; ft/d, foot per day. – no data]

Local well No.		Washington Dept. of Ecology tag	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Hydro-geologic unit	LIDAR altitude (ft)	Depth of hole (ft)	Depth of well (ft)	Primary use of water	Horizontal hydraulic conductivity (ft/d)	Drillers' log available
28N/01E -	04E01	ACJ 769	475653.6	1224112.0	Qgo	61	43	43	H	4.8	Y
	05L01	–	475644.5	1224221.2	Qgo	462	108	108	H	5.3	Y
	06L01	ACP 278	475643.0	1224338.0	Qgo	504	97	96	H	5.9	Y
	07N01	ACP 340	475537.1	1224403.6	Qgo	162	52	52	U	46	Y
	08F01	–	475559.7	1224216.4	Qgo	420	216	214	H	–	Y
	15K01	–	475502.2	1223922.9	Qva	159	471	471	U	–	Y
	15K02	ABA 712	475501.9	1223918.0	Qva	100	92	92	H	31	Y
	15K03	–	475458.5	1223917.8	Qva	97	101	101	H	3.2	Y
	18N01	–	475450.5	1224354.7	Qgo	156	44	44	H	[1].01	Y
28N/01W-	01C01	–	475711.9	1224459.3	Qgo	352	115	115	T	63	Y
	02A03	–	475714.0	1224523.6	Qgo	312	64	64	H	420	Y
	03H01	ACM 713	475652.8	1224640.8	Qgo	318	270	270	H	.22	Y
	03J01	–	475640.4	1224645.2	Qgo	355	238	238	H	14	Y
	03N02	ACJ 798	475636.8	1224751.1	Qva	176	67	67	U	15	Y
	04R01	ABA 530	475628.9	1224807.3	Qvr	214	36	36	H	10	Y
	05A01	ACP 257	475708.5	1224915.0	Qva	557	329	328	H	43	Y
	06H01	AAC 157	475656.1	1225045.4	Qva	511	162	161	H	–	Y
	06J01	–	475645.8	1225038.1	Qva	561	207	207	H	7,400	Y
	09H01	–	475607.8	1224759.2	Qva	234	90	89	H	–	Y
	10B01	–	475622.2	1224701.0	Qgo	316	51	51	H	[1].01	Y
	10E01	ABE 815	475607.8	1224741.6	Qgo	256	172	172	H	150	Y
	11C01	AFC 962	475615.2	1224608.0	Qgo	475	191	191	H	[1]32	Y
	12Q01	–	475537.8	1224427.2	Qgo	245	58	58	H	–	Y
29N/01E-	07M05	ACC 085	480105.6	1224400.2	Qva	60	58	58	H	–	Y
	19G02	–	475933.0	1224321.2	Qgo	162	105	105	H	9.9	Y
	19P01	ACC 063	475907.9	1224339.4	Qgo	367	244	244	H	26	Y
	28N04	–	475816.5	1224123.1	Qgo	9	51	49	H	16	Y
	29D01	–	–	–	–	110	30	30	P	–	N
	29D02	–	–	–	Em	109	200	164	P	.15	Y
	29D03	–	–	–	Qgo	124	28	28	P	81	Y
	29D04	–	475850.6	1224240.1	Em	107	90	90	U	.85	Y
	29D05	–	475851.9	1224236.6	Em	74	105	105	H	.10	Y
	29D06	WA 458 00	475851.7	1224242.6	Evcf	124	160	160	U	.07	Y
	29D07	–	–	–	Em	118	59	59	P	4.9	Y
	29R01	AFB 933	475815.3	1224132.1	Qgo	36	56	56	H	21	Y
	32P01	ABB 996	475721.3	1224151.5	Qgo	103	78	77	H	150	Y
	32R01	–	475718.2	1224130.7	Qgo	43	79	79	H	47	Y
	32R02	ABA 156	475728.1	1224146.3	Qvr	55	52	52	H	11	Y
	33C01	–	475805.1	1224051.4	Evcf	84	96	96	H	.34	Y
	33E03	–	475752.5	1224116.3	Qgo	59	75	75	H	21	Y
	33M05	–	475741.0	1224110.9	Qgo	40	73	73	H	37	N
29N/01W-	02R02	–	–	–	Qva	129	110	107	P	150	Y
	02R03	–	480142.8	1224531.5	Qva	128	110	110	U	160	Y
	02R04	–	–	–	Qva	128	133	133	P	[1]220,000	Y
	03G02	–	480211.2	1224712.7	Qva	128	67	67	Z	2,000	Y
	03H01	–	480209.1	1224654.4	Qvr	107	45	38	U	–	Y
	03K01	ABR 387	480207.6	1224658.8	Qvr	128	64	64	U	–	Y
	03K02	–	480207.5	1224659.7	Qva	126	184	184	U	–	Y
29N/01W-	03K03	–	480206.8	1224657.8	Qva	126	226	106	U	–	Y

Table 8. Physical and hydrologic data for inventoried wells in the Chimacum Creek Basin, eastern Jefferson County, Washington, May 2002—*Continued*

[**Local well No.:** See figure 4 for explanation of well-numbering system. Location of wells are shown on plate 1. **Washington Dept. of Ecology tag:** Washington Department of Ecology unique identification No. **Hydrogeologic unit:** See Plate 1 for explanation of units. **LIDAR altitude:** Land-surface altitude determined from LIDAR return signal. **Primary use of water:** H, domestic; I, irrigation; P, public supply; T, institutional; U, unused; and Z, other. **Drillers' log available:** Y, yes; N, no. **Abbreviations**: ft, foot; ft/d, foot per day. – no data]

Local well No.	Washington Dept. of Ecology tag	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Hydro-geologic unit	LIDAR altitude (ft)	Depth of hole (ft)	Depth of well (ft)	Primary use of water	Horizontal hydraulic conductivity (ft/d)	Drillers' log available
03K04	–	480206.8	1224715.0	Qva	128	130	73	U	–	Y
03K05	ACF 484	–	–	Qva	126	113	113	P	590	Y
203R01	ACC 100	480145.4	1224642.3	Qva	133	95	95	I	–	Y
05A01	ABN 404	480226.1	1224923.2	Qva	152	169	165	H	33	Y
09J01	–	–	–	Qva	291	170	49	P	17	Y
09L01	–	480110.1	1224848.6	OEm	368	66	66	H	<.01	Y
10A01	ABB 044	480128.7	1224646.8	Qva	134	64	64	I	670	Y
10Q02	AFL 952	480057.5	1224707.9	Qva	161	125	125	U	–	Y
10Q03	AGC 501	480100.3	1224707.7	Qva	144	100	98	U	–	Y
11C01	623	480136.2	1224603.3	Qva	110	48	46	H	38	Y
11L01	AGC 523	480114.6	1224557.4	Qva	116	78	78	I	–	Y
11Q01	AFC 957	480100.9	1224551.4	Qva	151	199	199	H	5.1	Y
12H01	ABA 533	480117.8	1224408.8	OEm	85	210	210	H	.87	N
12H02	AEN 317	480117.2	1224401.0	Qva	54	50	50	U	46.8	Y
13M01	ACR 059	480016.1	1224518.6	Qgo	141	81	80	H	830	Y
15B01	–	480046.9	1224657.9	Qva	127	86	86	U	160	Y
15Q01	AEA 439	480000.4	1224702.3	Qva	221	173	173	H	27	Y
15R01	–	480007.1	1224654.1	Qva	136	95	95	I	–	N
21E01	ACP 262	475941.7	1224901.2	Qvt/Evcf	632	40	38	H	–	Y
21E02	ACM 710	475938.2	1224901.0	Evcf	626	90	90	H	.72	N
21J01	AFC 959	475925.0	1224752.2	Qgo	465	258	258	U	14	Y
22F03	ACR 121	475934.9	1224725.9	Qgo	470	354	354	H	47	Y
22J01	AFL 958	475928.1	1224654.7	Qgo	224	175	175	U	–	Y
23F01	–	475945.4	1224601.6	Qgo	176	87	87	H	–	Y
23H01	ACJ 762	475931.8	1224521.0	Qgo	172	83	83	U	22	Y
23L01	–	475927.5	1224607.2	Qgo	159	157	157	H	.97	Y
24C01	160	475950.1	1224447.6	Qgo	382	321	306	H	1.9	Y
24K03	–	475925.9	1224441.4	Qgo	155	40	37	U	18.4	Y
26M01	–	475827.1	1224635.7	–	131	–	–	H	–	N
26M02	–	475838.1	1224632.6	–	122	31	23	H	–	N
26M03	–	475830.0	1224621.2	Qvr	124	41	38	I	–	N
27C01	AEK 928	475856.1	1224718.0	Qva	260	70	70	H	8.2	Y
27E01	ABP 934	475851.4	1224744.2	Qgo	471	398	398	H	[1].09	Y
27F01	–	475844.2	1224725.0	Qgo	275	195	195	H	25	Y
28R01	ACP 298	–	–	Qva	435	238	237	P	200	Y
30R01	–	475814.2	1225033.8	Em	575	117	117	H	–	Y
31B01	–	475806.3	1225101.6	Qva	605	134	134	H	[1].05	Y
31B02	–	475801.6	1225101.4	Qva	655	235	235	H	13,000	Y
32R01	–	475725.7	1224924.8	Qgo	509	350	348	H	3.6	Y
33R01	–	475727.9	1224802.6	Qva	278	58	50	H	70	Y
33R02	ABB 828	475720.1	1224804.2	Qva	256	48	46	H	9.4	Y
34C01	ACR 131	475801.0	1224725.9	Qva	279	179	179	U	180	Y
34F01	ABE 809	475757.6	1224730.3	Qva	300	88	88	H	3.5	Y
35J01	ACJ 763	475733.5	1224536.7	Qgo	362	109	109	H	430	Y
35L01	ACP 362	475733.8	1224610.7	Qgo	289	60	60	H	75	Y
35R02	ACR 101	475721.0	1224529.8	Qgo	323	73	73	H	410	Y
36A01	–	475806.8	1224417.1	Qgo	194	122	122	H	18	Y
30N/01W- 28F01	–	480400.7	1224844.0	Qva	264	141	141	T	–	Y
28F02	ABW 228	480358.3	1224835.2	Qva	246	95	95	H	–	Y
28M02	ABN 406	480350.3	1224910.3	Qva	221	242	240	U	110	Y

Table 8. Physical and hydrologic data for inventoried wells in the Chimacum Creek Basin, eastern Jefferson County, Washington, May 2002—*Continued*

[**Local well No.:** See figure 4 for explanation of well-numbering system. Location of wells are shown on plate 1. **Washington Dept. of Ecology tag:** Washington Department of Ecology unique identification No. **Hydrogeologic unit:** See Plate 1 for explanation of units. **LIDAR altitude:** Land-surface altitude determined from LIDAR return signal. **Primary use of water:** H, domestic; I, irrigation; P, public supply; T, institutional; U, unused; and Z, other. **Drillers' log available:** Y, yes; N, no. **Abbreviations**: ft, foot; ft/d, foot per day. – no data]

Local well No.	Washington Dept. of Ecology tag	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Hydro-geologic unit	LIDAR altitude (ft)	Depth of hole (ft)	Depth of well (ft)	Primary use of water	Horizontal hydraulic conductivity (ft/d)	Drillers' log available
29A01	ABE 807	480411.3	1224914.9	Qva	240	149	149	H	7.2	Y
29G01	ABW 207	480402.5	1224937.5	Qva	255	77	77	H	–	Y
32G01	ACR 108	480305.2	1224952.2	Qva	118	143	143	H	160	Y
32K01	–	480258.4	1224946.0	–	44	–	47	U	–	N
33H02	ACM 501	–	–	Qva	108	75	74	P	–	Y
33H03	ACM 502	–	–	Qva	108	120	120	P	–	Y
33M01	–	480251.1	1224854.7	Qva	135	180	153	U	150	Y
33N02	AAB 781	–	–	Qva	140	173	173	P	160	Y
34A01	ABC 314	–	–	Qva	172	217	217	P	140	Y
34E01	ACY 840	480307.5	1224727.9	Qva	133	75	75	H	350	Y
34H01	–	480306.3	1224641.7	Qva	148	200	200	H	350	Y

[1] Value not used to estimate aquifer parameters.

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