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Surface Water-Ground Water Interactions Along the Lower Dungeness River and Vertical Hydraulic Conductivity of Streambed Sediments, Clallam County, Washington, September 1999-July 2001

Water-Resources Investigations Report 02-4161
Washington State Department of Ecology Report 02-03-027

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

Oblique aerial photograph of the lower Dungeness River as it crosses the Sequim-Dungeness peninsula, Clallam County, Washington. Photograph courtesy of Dan Crowell, Soundview Aerial Photography, Arlington, Washington, March 1993.

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By F. William Simonds[1] and Kirk A. Sinclair[2]

[1] U.S. Geological Survey, Tacoma, Washington
[2] Washington State Department of Ecology

U.S. GEOLOGICAL SURVEY

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Tacoma, Washington
2002

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
1201 Pacific Avenue – Suite 600
Tacoma, Washington 98402
http://wa.water.usgs.gov

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CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter
foot (ft	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.004047	square kilometer
square feet (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow rate	
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch per year (in/yr)	25.4	millimeter per year

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:
°C = 5/9 × (°F - 32).

VERTICAL DATUM

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

Surface Water-Ground Water Interactions Along the Lower Dungeness River and Vertical Hydraulic Conductivity of Streambed Sediments, Clallam County, Washington, September 1999-July 2001

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ABSTRACT

The Dungeness River emerges from the Olympic Mountains and flows generally north toward the Strait of Juan De Fuca, crossing the broad, fertile alluvial fan of the Sequim-Dungeness peninsula in northeastern Clallam County, Washington. Increasing competition for the peninsula's ground-water resources, changing water-use patterns, and recent requirements to maintain minimum in-stream flows to enhance endangered salmon and trout populations have severely strained the peninsula's water resources and necessitated a better understanding of the interaction between surface water and ground water. Three methods were used to characterize the interchange between surface water and ground water along the lower 11.8 miles of the Dungeness River corridor between September 1999 and July 2001. In-stream mini-piezometers were used to measure vertical hydraulic gradients between the river and the water-table aquifer at 27 points along the river and helped to define the distribution of gaining and losing stream reaches. Seepage runs were used to quantify the net volume of water exchanged between the river and ground water within each of five river reaches, termed "seepage reaches." Continuous water-level and water-temperature monitoring at two off-stream well transects provided data on near-river horizontal hydraulic gradients and temporal patterns of water exchange for a representative gaining stream reach and a representative losing stream reach.

Vertical hydraulic gradients in the mini-piezometers generally were negative between river miles 11.8 and 3.6, indicating loss of water from the river to ground water. Gradients decreased in the downstream direction from an average of -0.86 at river mile 10.3 to -0.23 at river mile 3.7. Small positive gradients (+0.01 to +0.02) indicating ground-water discharge occurred in three localized reaches below river mile 3.7. Data from the seepage runs and off-stream transect wells supported and were generally consistent with the mini-piezometer findings. An exception occurred between river miles 8.1 and 5.5 where seepage results showed a small gain and the mini-piezometers showed negative gradients.

Vertical hydraulic conductivity of riverbed sediments was estimated using hydraulic gradients measured with the mini-piezometers and estimated seepage fluxes. The resulting conductivity values ranged from an average of 1 to 29 feet per day and are similar to values reported for similar river environments elsewhere.

The results of this study will be used to calibrate a transient, three-dimensional ground-water flow model of the Sequim-Dungeness peninsula. The model will be used to assess the potential effects on ground-water levels and river flows that result from future water use and land-use changes on the peninsula.

INTRODUCTION

The Dungeness River emerges from the Olympic Mountains and flows generally north toward the Strait of Juan De Fuca, crossing the broad, fertile alluvial fan of the Sequim-Dungeness peninsula, in Clallam County, Washington (fig. 1). The river is an important source of irrigation water for the area's agricultural economy. During the past 20 years, the peninsula's human population has increased by roughly 250 percent and land use has gradually shifted from irrigated agriculture to urban and rural residential development (Thomas and others, 1999).

Increasing competition for the peninsula's ground-water resources, changing water-use patterns, and recent requirements to maintain minimum in-stream flows to enhance endangered salmon and trout populations have severely strained the peninsula's water resources and necessitated a better understanding of the interaction between surface water and ground water (U.S. Forest Service, 1995: Jamestown S'Klallam Tribe, 1994). To address this need, the U.S. Geological Survey (USGS), in cooperation with Clallam County, conducted a study from September 1999 to July 2001 to assess the interaction between surface water and ground water using three methods of data collection and analysis that, combined, provide a reasonable evaluation of the distribution, timing, and volume of surface water-ground water exchange in the area. Results from the study will be useful in future water management decisions affecting the peninsula and will provide information for the development and calibration of a transient, three-dimensional ground-water-flow model of the Sequim-Dungeness peninsula. The model will be used to assess the effects of anticipated water-use changes on the peninsula and the potential ramifications of these changes on area ground-water levels and in-stream flows.

Purpose and Scope

This report summarizes a 2-year effort to evaluate and describe the hydraulic interaction between the lower Dungeness River and the water-table aquifer underlying the Sequim-Dungeness peninsula in northeastern Clallam County, Washington. The major objectives of this study were:

1. To provide annual and seasonal estimates of the distribution, direction, and volume of water exchange between the lower Dungeness River and the water table aquifer;
2. To evaluate how rainfall and snowmelt-driven river-level changes affect surface water and ground water exchange along the lower Dungeness River corridor; and
3. To estimate average vertical hydraulic conductivity of Dungeness River streambed sediments, which will aid in the calibration of a transient, three-dimensional ground-water flow model of the study area.

The approach involved using three data-collection and analysis methods to evaluate the distribution, timing, and volume of surface-water and ground-water exchange. Data were collected from 27 in-stream mini-piezometer locations, 3 stream seepage runs in which 5 river reaches or seepage reaches were evaluated, and 2 off-stream piezometer arrays termed "off-stream well transects" (fig. 2). The study was conducted from September 1999 through July 2001 and focused on the lower Dungeness River corridor from USGS streamgaging station 12048000 to Schoolhouse Bridge near the mouth of the river.

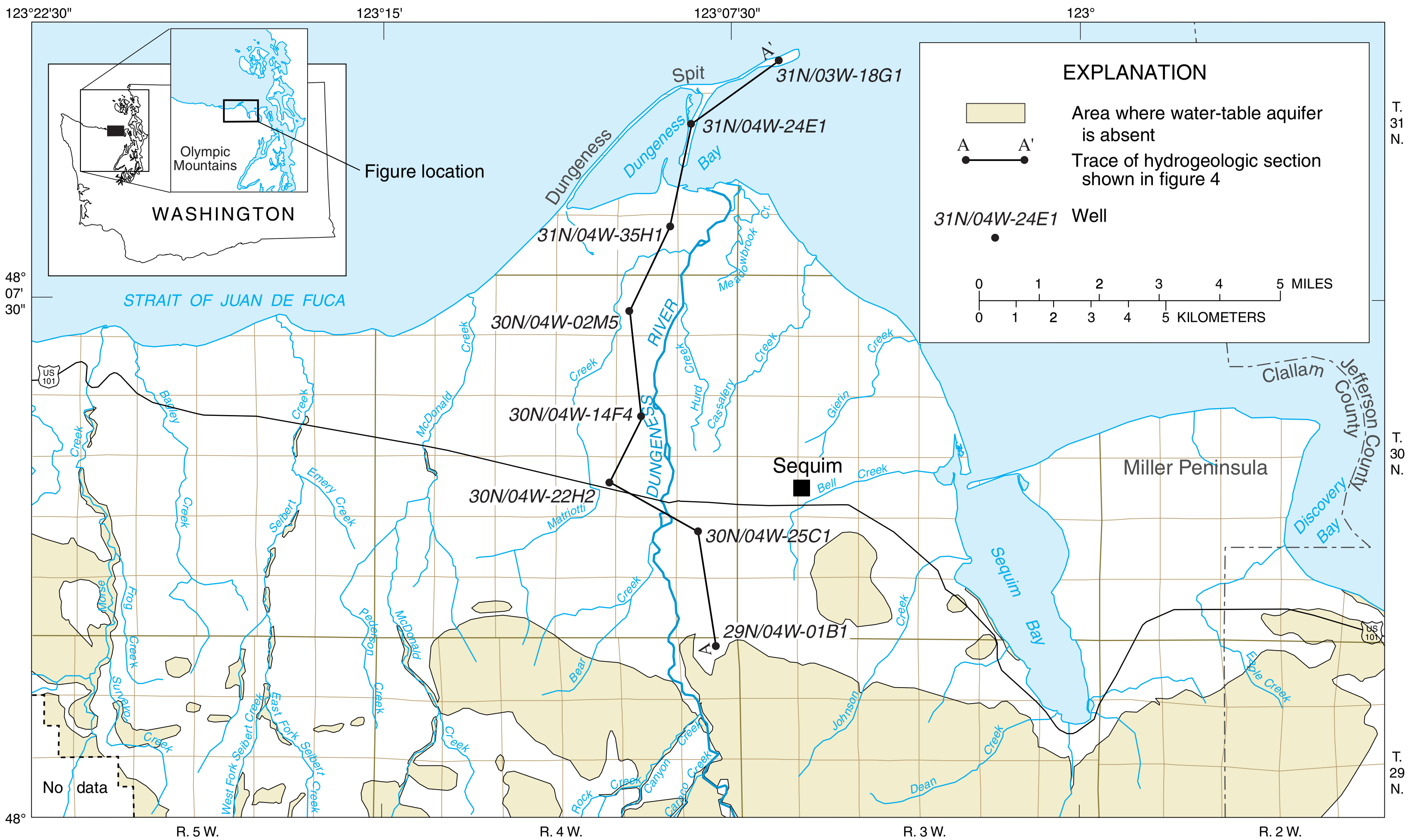


Figure 1. Location of the study area, the Dungeness River, and the trace of the hydrogeologic section on the Sequim-Dungeness peninsula, Clallam County, Washington.

The hydrogeologic section is shown in figure 4. (Modified from Thomas and others, 1999).

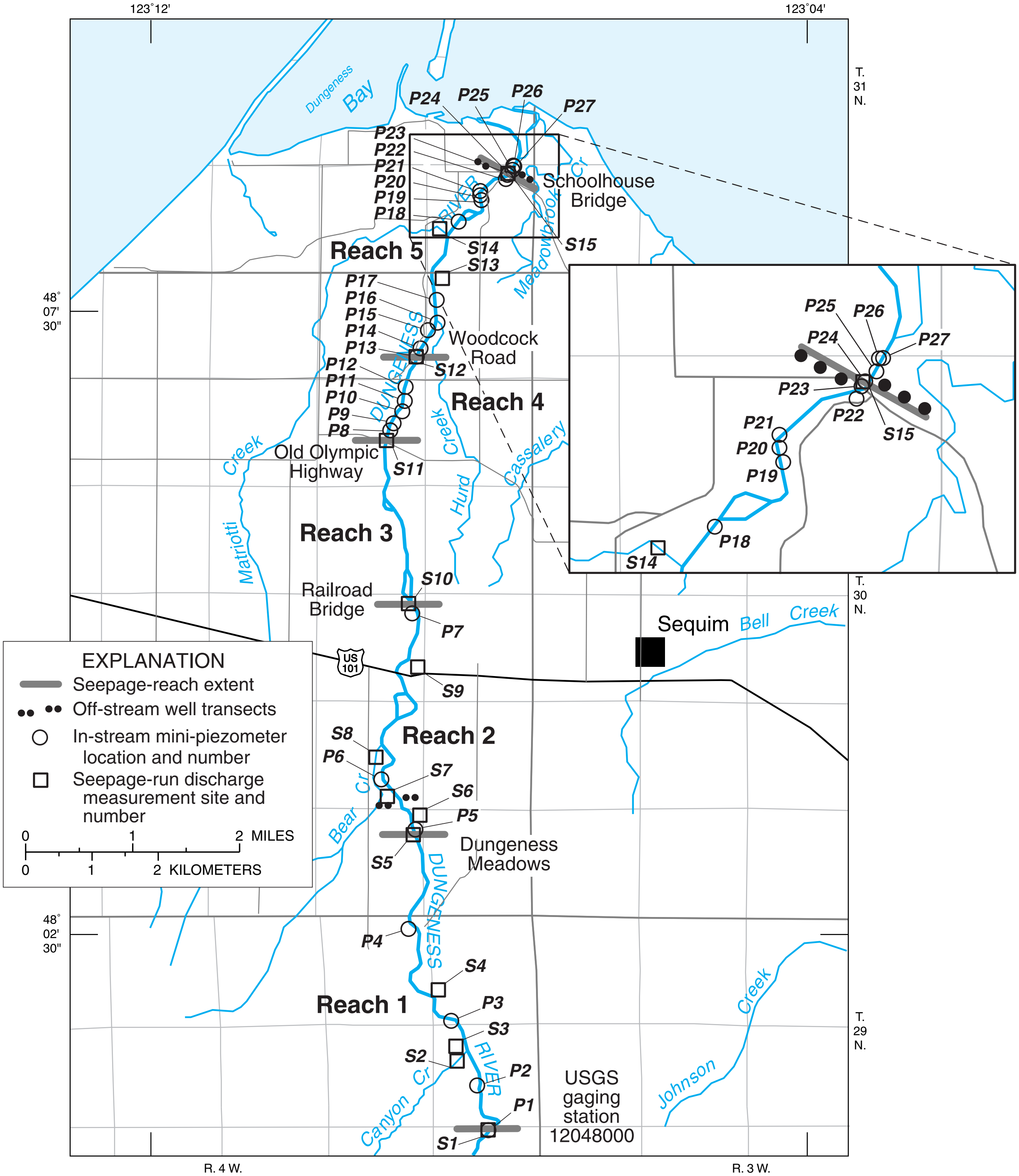


Figure 2. Locations of the sites of in-stream mini-piezometers, seepage-run discharge measurements, and off-stream well transects in the study area along the Dungeness River corridor on the Sequim-Dungeness peninsula, Clallam County, Washington.

DESCRIPTION OF STUDY AREA

The Dungeness River watershed encompasses an area of about 156 square miles, starting in the northeastern Olympic Mountains and including most of the Sequim-Dungeness Peninsula (fig. 1). The peninsula is approximately 65 square miles in area and ranges in altitude from sea level to about 600 feet above sea level. The topography of the area is mostly flat or gently sloping, with a few small hills.

The Sequim-Dungeness area has a temperate marine climate with cool, wet winters and warm, dry summers. The average annual precipitation for the study area is approximately 21 inches and ranges from approximately 30 inches near the foothills of the Olympic Mountains to about 15 inches near the mouth of the Dungeness River (National Oceanic and Atmospheric Administration, 1982). Most of the annual precipitation occurs during the winter (December through February) and falls as snow in the upper watershed and as rain in the lowlands. Air temperatures remain moderate throughout a typical year. Average monthly maximum temperatures range from 45 degrees Fahrenheit (^{o}F) in January to 72 ^{o}F in July, and average monthly minimum temperatures range from 32 ^{o}F in January to 51 ^{o}F in August (National Oceanic and Atmospheric Administration, 1982).

Land cover in the study area is mostly grassland and forest, irrigated agriculture, and rural residential or urban development. As of 1996, the study area contained approximately 200 miles of ditches that are used to divert about 75 cubic feet of water per second (ft^3/s) from the Dungeness River to supply local irrigation needs during the growing season (generally May through September). In the non-irrigation season, withdrawals range from 10 to 40 cubic feet per second (Thomas and others, 1999). Although land use is gradually changing from agricultural to residential, irrigation ditches are still used to supply river water to area crops, livestock, and residential lawns and gardens.

Previous Investigations

This study drew from a number of previous hydrologic and geologic investigations. The geology of the Sequim-Dungeness area was described by Tabor and Cady (1978), Othberg and Palmer (1980 a, b, c), and Thomas and others (1999). Three regional ground-water studies (Noble, 1960; Drost, 1983; and Sweet-Edwards/EMCON 1991a, b, c), along with other local studies, were used by the Clallam County Department of Community Development to develop a ground-water protection strategy in 1994 (Clallam County, 1994). The Dungeness-Quilcene Water Resources Management Plan summarizes many of the previous water-resource studies in eastern Clallam County and western Jefferson County (Jamestown S'Klallam Tribe, 1994). Thickness maps of unconsolidated deposits in Puget Sound and hydrogeologic sections across the Sequim-Dungeness Peninsula were provided by Jones (1996a, b). Thomas and others (1999) summarized the hydrogeology of the Sequim-Dungeness area and used available well data to describe the ground-water flow system.

Acknowledgments

The authors thank Nash Huber, Mr. and Mrs. Engle, The North Olympic Land Trust, and Lloyd Beebe for permission to access private property during data collection in 2000-2001. We also thank Ann Soule, with the Clallam County Natural Resources Division, and Linda Newberry and Ann Seite, with the Jamestown S'Klallam Tribe, for their assistance and encouragement throughout the study. We also gratefully acknowledge the many area residents who expressed interest and support for this study as fieldwork progressed, especially Roger Schmidt and Mike Jeldness, who provided helpful insights into the area's history and irrigation practices. Finally, this study would not have been successful without the support of the Washington Department of Ecology's Stream Hydrology Unit and the USGS field office personnel who provided equipment and staff support during the seepage runs.

HYDROGEOLOGIC SETTING

The river channel in the headwaters of the Dungeness River is composed of Tertiary-age volcanic and sedimentary bedrock that makes up most of the Olympic Mountains. Once the river leaves the Olympic Mountains and enters the Sequim-Dungeness peninsula, it is underlain by recent alluvium and a sequence of unconsolidated glacial and interglacial sediments of Quaternary age (fig. 3). The thickness of the unconsolidated deposits increases from a few feet near the southern bedrock contact to approximately 2,400 feet near the mouth of the Dungeness River (Jones, 1996b). Consequently, the number and thickness of hydrogeologic units beneath the river channel increases to the north.

Three aquifer units and two confining units have been identified and correlated using well logs from the Sequim-Dungeness area (Drost, 1983; Jones, 1996b; Thomas and others, 1999). In descending order, the hydrogeologic units are the water-table aquifer, the upper confining unit, the upper confined aquifer, the lower confining unit, and the lower confined aquifer (fig. 4). The aquifer units consist primarily of coarse-grained deposits of sand and gravel. The confining units generally consist of fine-grained silt and clay. Very few data are available on the undifferentiated deposits below the lower confined aquifer, however they are assumed to be a mixture of glacial and non-glacial deposits of Quaternary age (Jones, 1996b).

The materials that compose the water-table aquifer were deposited about 10,000 to 15,000 years ago during the Vashon stade of the Frasier glaciation. Modern fluvial processes have dominated the landscape since retreat of the Vashon ice sheet and have extensively reworked the Vashon outwash materials. Currently, the Dungeness River meanders from south to north across the peninsula for approximately 11 miles before emptying into the Strait of Juan De Fuca north of the town of Sequim. The river forms a braided channel that descends from the mountain front at an average gradient of 48 feet per mile. Flood-control levees, constructed to protect crop land and residential development, cut off some portions of the channel from the adjacent flood plain. Flow in the Dungeness River (fig. 5) varies seasonally, with high flows in the winter (due to rain) and in the early summer (due to snow melt). Flow in the river is consistently low in the late summer and fall.

Recharge to the study area ground-water system is highly variable and derives from several sources including precipitation (mostly in the winter), leakage from the Dungeness River and irrigation ditches, and percolation of septic-system effluent and unconsumed irrigation water. Area ground water generally flows from south to north across the peninsula toward natural points of discharge at springs and seeps, the Dungeness River, and the Strait of Juan De Fuca (fig. 6). Evapotranspiration and pumping from wells also remove water from the ground-water system.

Horizontal ground-water flow in the water-table aquifer is approximately parallel to the Dungeness River (fig. 6). Ground-water flow directions in the upper and lower confined aquifers, although not as well defined by available water-level data, are thought to be similar to those in the water-table aquifer (Thomas and others, 1999). Vertical flow between aquifers is generally downward in the southern study area (near the Olympic Mountain foothills) and upward in the northern study area (near the Strait of Juan De Fuca) (fig. 4).

Because of its low permeability, bedrock is assumed to be the lower boundary of the regional aquifer system. The upper boundary is the potentiometric surface for the water-table aquifer and was well defined in 1996 by Thomas and others (1999). Lateral boundaries of the regional aquifer system include bedrock to the south, Morse Creek to the west, and saltwater interfaces along the Strait of Juan De Fuca, Dungeness Bay to the north, and Sequim Bay to the east.

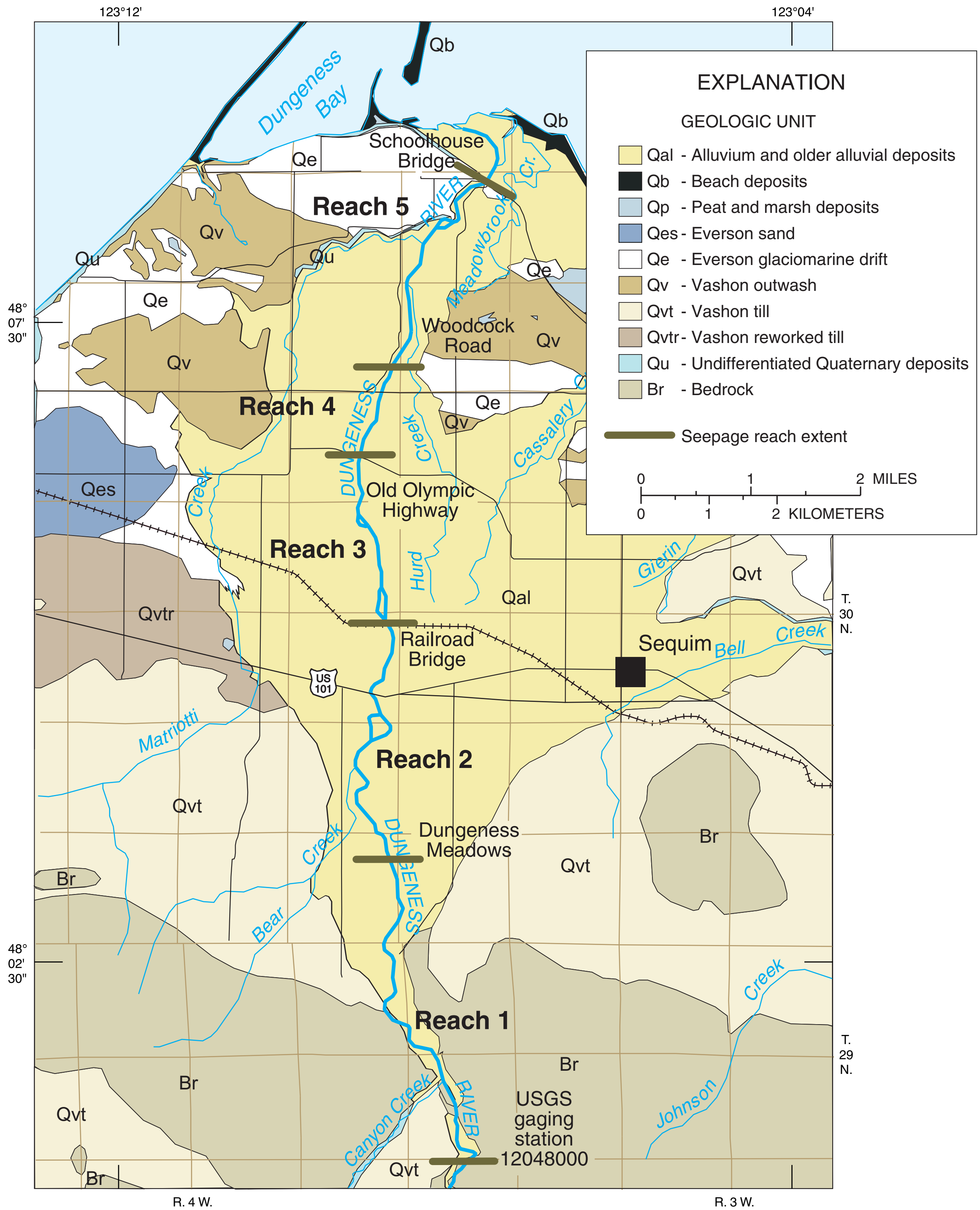


Figure 3. Surficial geology of the study area on the Sequim-Dungeness peninsula, Clallam County, Washington.

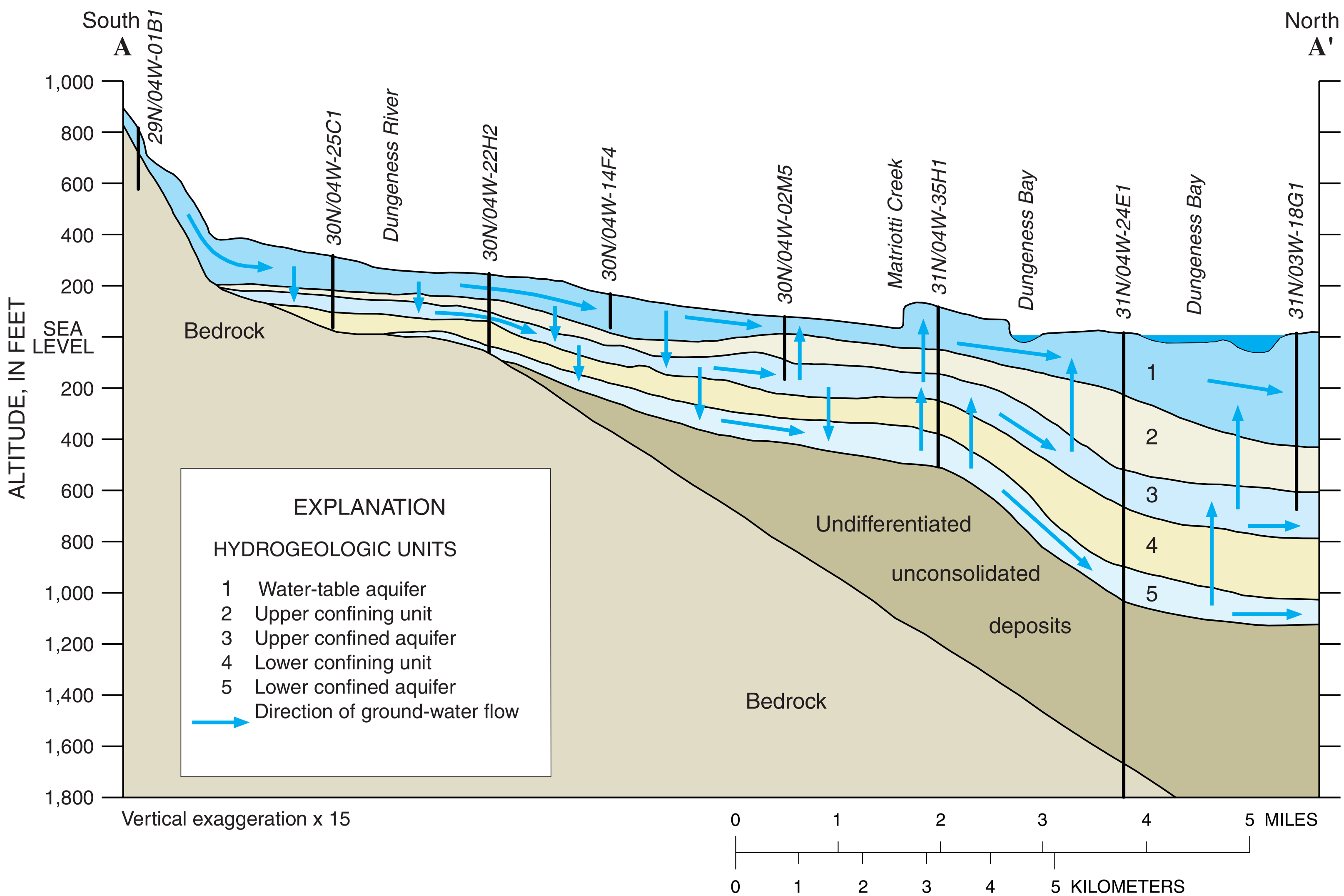


Figure 4. Hydrogeologic section showing the principal aquifer and confining units and directions of ground-water flow on the Sequim-Dungeness peninsula, Clallam County, Washington.

(Modified from Drost, 1983) See figure 1 for the trace of the section.

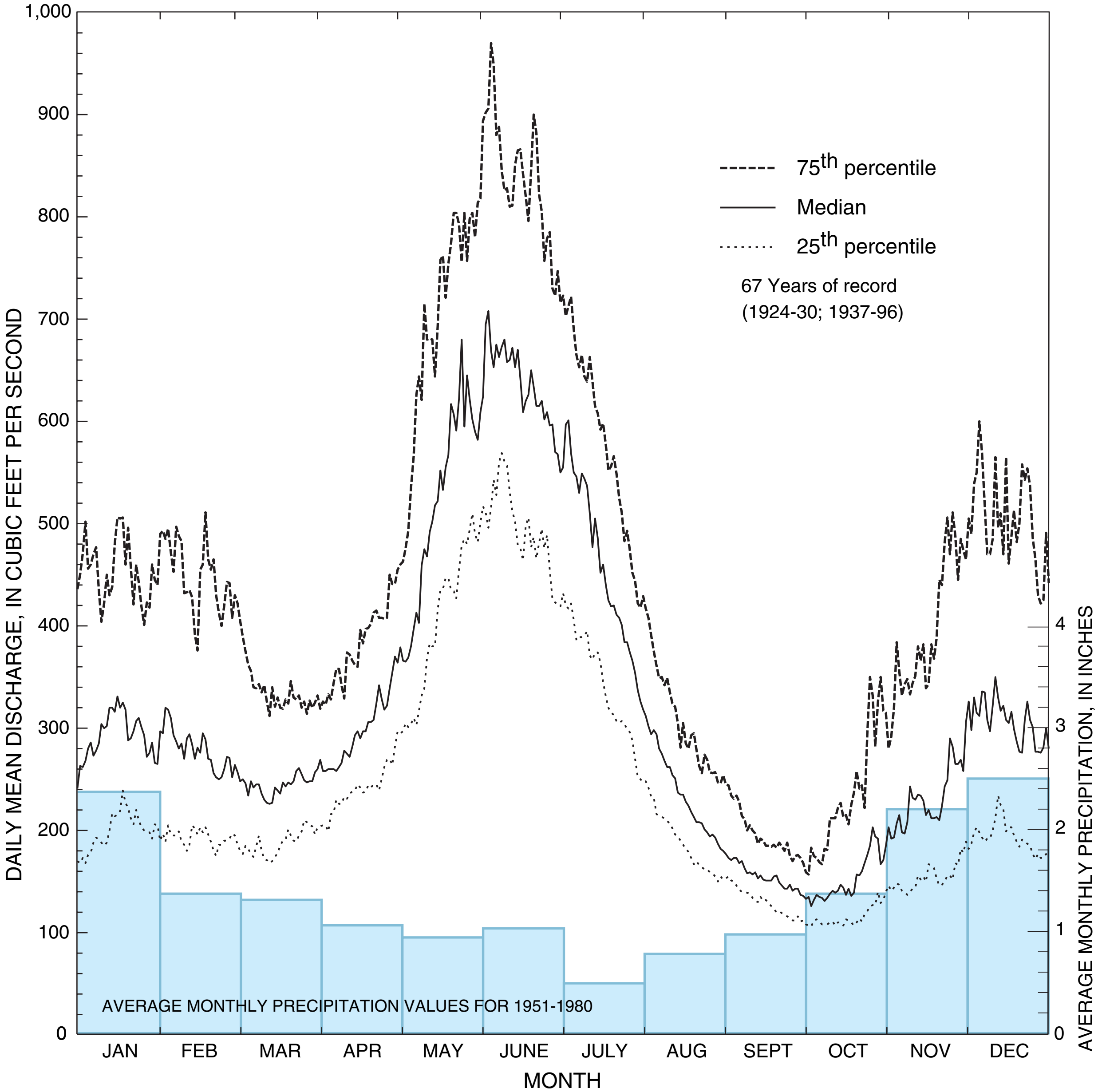


Figure 5. Mean daily discharge for the Dungeness River and average monthly precipitation near Sequim, Washington.

Discharge data are from U. S. Geological Survey streamgaging station 12048000 and precipitation data are from the National Oceanic and Atmospheric (1982).

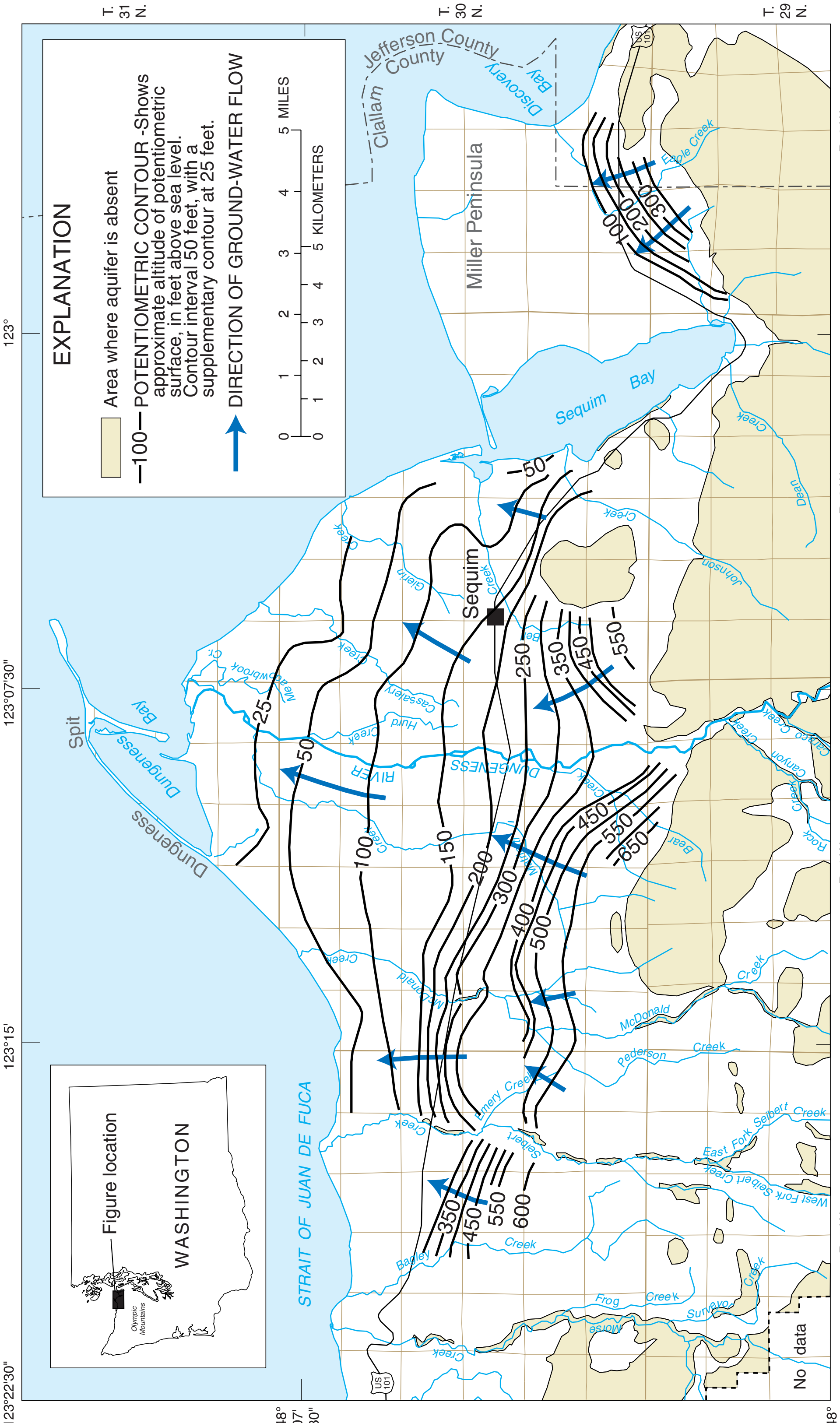


Figure 6. Horizontal ground-water flow in the water-table aquifer on the Sequim-Dungeness peninsula, Clallam County, Washington. (Modified from Thomas and others, 1999).

DATA COLLECTION AND METHODS OF ANALYSIS

The fieldwork for this study spanned a period of approximately 22 months. During this time, in-stream mini-piezometers were installed into the bed of the Dungeness River, multiple seepage runs were conducted, and two off-stream well transects were constructed adjacent to the river and were instrumented to continuously record ground-water levels and temperatures. Each of these activities is discussed in detail below, along with the analysis methods used to evaluate the study results.

Site locations for the in-stream mini-piezometers, seepage run discharge measurements, and off-stream well transects, were determined using a global positioning system (GPS) receiver (fig. 2). The receiver has a reported accuracy of about 50 feet. The latitude and longitude of all data collection sites were entered into a Geographic Information System (GIS) database. A GIS routing program was then used to determine the distance between sites and their approximate river-mile locations relative to the mouth of the Dungeness river at mile 0.0. The river mile locations derived through this technique are dependent on the scale of the GIS data used to perform the analysis. Thus, the station locations referenced in this report may differ slightly from those reported by prior investigators.

In-Stream Mini-Piezometers

Twenty-seven in-stream mini-piezometers were driven into the streambed of the lower Dungeness River to define the vertical hydraulic gradient and direction of flow between the river and the water-table aquifer (fig. 2). Initially, 12 mini-piezometers were installed to verify the gaining and losing reaches previously identified by Thomas and others (1999). As the study progressed, 15 additional mini-piezometers were installed to help define the extent of localized ground-water discharge zones. The 27 mini-piezometers are labeled in downstream order from P1 to P27.

The in-stream mini-piezometers for this study were constructed from 7-foot lengths of 1/2-inch-diameter galvanized pipe. One end of the pipe was crimped shut to form a drive point and was then perforated within the bottom 6 inches with several 1/8-inch-diameter holes to allow water entry (fig. 7). The upper end of each pipe was threaded and fitted with a standard pipe coupler. The coupler provided a robust "strike" surface and protected the pipe from damage during installation.

The mini-piezometers were hand driven into the streambed, approximately 3 to 5 feet from the stream bank, using a fence post driver. Each mini-piezometer was driven to a depth of approximately 5 feet or until downward progress ceased. Installation details are summarized in table 1. During the study, mini-piezometers at several sites were damaged or lost due to high water. In these cases a new mini-piezometer was installed at the same location and to the same depth as before.

A manometer board was used throughout the study to measure differences between water levels in the mini-piezometers and water level in the river (fig. 7 and fig. 8). Comparison measurements made with an electric tape gage indicate that the manometer is capable of reliably detecting water-level differences of approximately 0.03 foot or less throughout its 3-foot working range. Winter and others (1988) provide a detailed discussion of manometer board construction and use.

The difference in water levels between the mini-piezometer and the river provides an indication of the vertical direction of water flow. When the water level in the mini-piezometer is higher than the river stage, ground water is discharging to the river in the immediate vicinity of the mini-piezometer. Conversely, when the water level in the mini-piezometer is lower than the river stage, water from the river is seeping into the streambed and recharging ground water in the immediate vicinity of the mini-piezometer (see fig. 7).

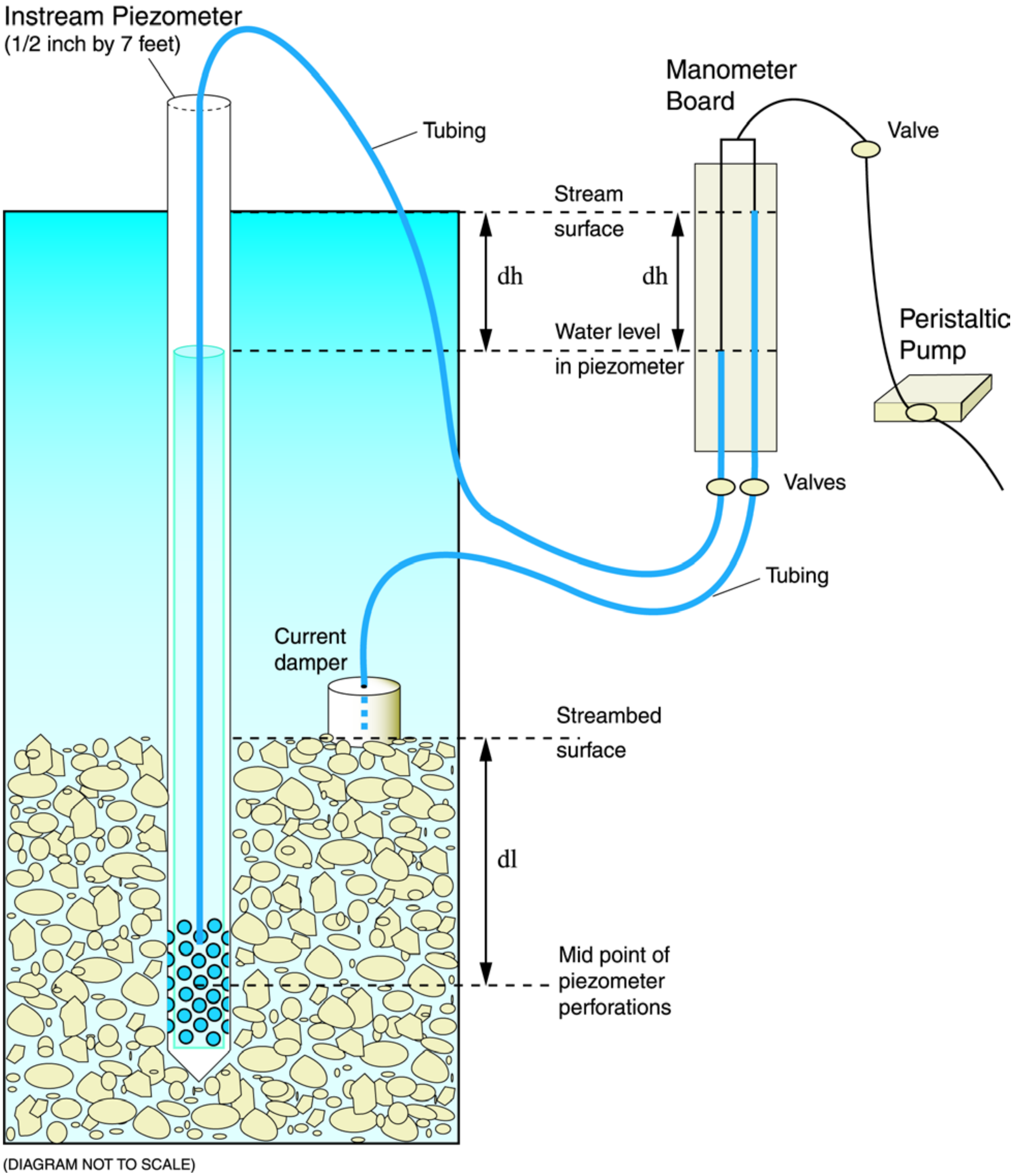


Figure 7. A typical in-stream mini-piezometer installation and manometer board configuration.
From equation 1 in the report, *dh* is the difference between head in the mini-piezometer and river stage, and *dl* is the vertical distance between the streambed and the midpoint of the mini-piezometer perforations.

Table 1. Details of construction and installation of the mini-piezometers along the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington

[LB, Left Bank; RB, Right Bank; Latitude, Longitude: degrees, minutes, and seconds; ft=feet]

Mini-piezometer number and location (see also fig. 2)		River mile	Latitude	Longitude	Installation date	Piezo-meter length (ft)	Installation depth (ft below streambed)	Depth to center of perforations (ft below streambed)
P1	Original Piezometer Site 7 (150 ft downstream from USGS gage on LB)	11.59	480052.0	1230753.0	9/22/1999	7	3.0	2.75
P2	Original Piezometer Site 11 (Above Dungeness Hatchery at bedrock pinch of river on LB)	11.02	480113.5	1230801.9	9/22/1999	7	2.5	2.25
P3	Original Piezometer Site 1 (At Dungeness Hatchery on LB)	10.29	480144.4	1230820.8	9/23/1999	7	3.0	2.75
P3	Piezometer Site 1B (New piezometer at Dungeness Hatchery on LB)	10.29	480144.4	1230820.8	4/11/2001	7	2.0	1.75
P4	Original Piezometer Site 10 (May Road below Dungeness Hatchery LB)	9.1	480229.7	1230851.3	9/23/1999	7	4.5	4.25
P5	Piezometer at upper end of Dungeness Meadows on RB	8.13	480318.0	1230846.6	7/18/2001	7	3.9	3.65
P6	Original Piezometer Site 2 (200 ft downstream from Dungeness Meadows piezo array on LB)	7.54	480342.5	1230911.6	9/22/1999	7	2.5	2.25
P7	Original Piezometer Site 6 (300 ft upstream from Old Railroad Bridge on RB)	5.54	480504.0	1230849.6	9/22/1999	7	3.0	2.75
P8	Original Piezometer Site 3 (300 ft downstream from Old Olympic Highway Bridge on LB)	3.68	480632.4	1230905.3	9/22/1999	7	3.0	2.75
P9	1st new piezometer downstream from P8	3.57	480637.2	1230903.2	7/17/2001	7	4.8	4.55
P10	2nd new piezometer downstream from P8	3.44	480642.3	1230857.3	7/17/2001	7	4.8	4.55
P11	3rd new piezometer downstream from P8	3.36	480647.1	1230855.5	7/17/2001	7	4.7	4.45
P12	4th new piezometer downstream from P8	3.23	480653.7	1230854.9	7/17/2001	7	4.2	3.95
P13	Original Piezometer Site 9 (At Ward Road Mary Wheeler Park on LB)	2.92	480708.6	1230846.7	9/22/1999	7	5.0	4.75
P14	1st new piezometer 300 ft downstream from P13	2.84	480712.6	1230843.9	7/17/2001	7	4.5	4.25
P15	2nd new piezometer downstream from P13	2.66	480721.3	1230838.6	7/17/2001	7	4.8	4.55
P16	3rd new piezometer downstream from P13	2.54	480725.7	1230831.3	7/17/2001	7	5.1	4.85
P17	4th new piezometer downstream from P13	2.35	470736.0	1230832.0	7/17/2001	7	4.6	4.35
P18	Original Piezometer Site 5 (Olympic Game Farm 1000 ft upstream from Matriotti Creek on LB)	1.52	480814.4	1230816.1	9/22/1999	7	6.0	5.75
P19	Original Piezometer Site 8A (Dike access off Towne Road on RB	1.13	480824.9	1230800.0	9/22/1999	7	6.0	5.75

Table 1. Details of construction and installation of the mini-piezometers along the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington—*Continued*

Mini-piezometer number and location (see also fig. 2)		River mile	Latitude	Longitude	Installation date	Piezo-meter length (ft)	Installation depth (ft below streambed)	Depth to center of perforations (ft below streambed)
P20	1st new Piezometer about 250 ft downstream from P19 on RB	1.09	480827.0	1230801.0	5/15/2001	7	5.0	4.75
P21	2nd new Piezometer about 600 ft downstream from P19 on RB	1.04	480830.0	1230801.0	5/15/2001	7	5.0	4.75
P22	Original Piezometer Site 4 (100 ft upstream from Schoolhouse Bridge on LB)	0.73	480837.0	1230741.1	9/24/1999	10	8.0	7.75
P22	New Piezometer at Site 4 (100 ft upstream from Schoolhouse Bridge on LB)	0.73	480837.0	1230741.1	5/15/2001	7	5.2	4.95
P22	New Piezometer at Site 4 (100 ft upstream from Schoolhouse Bridge on LB)	0.73	480837.0	1230741.1	7/18/2001	7	4.3	4.05
P23	New Piezometer at Schoolhouse Bridge (across from gage on LB)	0.71	480838.0	1230740.0	5/15/2001	7	5.2	4.95
P24	Piezometer 200 feet downstream from Schoolhouse Bridge on LB	0.67	480839.0	1230738.0	5/15/2001	7	4.7	4.45
P25	Piezometer 300 feet downstream from Schoolhouse Bridge on LB	0.65	480840.0	1230737.0	5/15/2001	7	5.0	4.75
P26	Original Piezometer Site 12 (1000 ft downstream from Schoolhouse Bridge on RB)	0.64	480840.8	1230737.2	9/22/1999	7	5.0	4.75
P27	Piezometer about 100 ft downstream from Piezometer P26 on LB	0.62	480841.9	1230736.9	5/15/2001	7	3.9	3.65

Figure 8. Demonstration of how a manometer board is used for measuring hydraulic head difference between surface water and ground water head.

In this case, the hydraulic head representing the river, on the right side of the board, is higher than the hydraulic head representing ground water, on the left side of the board. This condition indicates a downward gradient at the point where the mini-piezometer penetrates the streambed. Photograph taken by Kirk A. Sinclair, Washington State Department of Ecology, 2002.

Vertical hydraulic gradients between the river and ground water were calculated from the mini-piezometer and manometer data using the formula

$$iv = dh/dl \,, \qquad (1)$$

where

iv is the vertical hydraulic gradient, in units of length per unit length;

dh is the difference between the mini-piezometer and river stage (mini-piezometer water level - river water level, fig. 7), in units of length; and

dl is the vertical distance between the streambed and the midpoint of the mini-piezometer perforations (fig. 7), in units of length.

Negative values of *iv* indicate loss of water from the river to ground water (losing reaches), and positive values indicate ground-water discharge into the river (gaining reaches).

During each survey, the instream mini-piezometers and river were sampled for temperature and specific conductance to provide additional verification of the manometer measurements. In losing reaches, the river temperature and ground-water temperature tend to match closely and the specific conductance of the two water sources is often very similar. In gaining reaches ground water is typically warmer in the winter, or cooler in the summer, than the river, and the specific conductance of the river and ground water may differ significantly (Fryar and others, 2000).

Water temperature and specific conductance were measured at the stream center using a YSI TLC combination field meter or a Multiline P4 universal meter and Tetracon 325 conductivity/temperature probe. All field meters were calibrated where possible or were checked daily against known standards, in accordance with the project quality-assurance plan (Simonds and others, unpublished document, 1999). The mini-piezometers were purged for approximately 5 minutes with a peristaltic pump (at a rate of approximately 500 milliliters per minute) prior to sampling. Grab samples were then collected at approximately 1-minute intervals as purging progressed, and were evaluated using the above described meters. Water-quality values were considered stable when two successive grab samples yielded comparable results (that is, there was less than a 10-percent difference from the mean of two grab samples for all measurements). Water-level and water-quality data for the instream mini-piezometers are summarized in table 2, and the collected data are provided in table 6 (at back of report).

Seepage Runs

Seepage runs were conducted over a 1- or 2-day period during stable streamflow conditions in April 2000, October 2000, and April 2001. During the seepage runs discharge measurements were made at selected sites along the main stem of the Dungeness River, at tributary inputs to the river, and at irrigation ditch out-takes and fish-bypass-return flows (fig. 2). The increase or decrease in discharge between measurement sites that cannot be accounted for through tributary input or out-of-stream diversions is an estimate of the net volume of water exchanged between the river and ground water. The seepage measurement sites were arranged in downstream order, with site S1 the upstream-most location and site S15 the downstream-most location (fig. 2). Reaches of the river between the measurement sites are termed "seepage reaches" in this report.

To determine the volume of water gained or lost by the river, the seepage data were used in a mass balance calculation as follows.

$$\text{Net seepage gain or loss} = Qd - T - Qu + D \quad , \qquad (2)$$

where

Qd is the discharge measured at the downstream end of the reach, in ft^3/s;

Qu is the discharge measured at the upstream end of the reach, in ft^3/s;

T is the sum of tributary inflows, in ft^3/s; and

D is the sum of irrigation ditch diversions, in ft^3/s.

The result of equation 2 is the net volume of water entering or leaving the river. The sign of the number indicates if a given seepage reach is gaining water from (positive) or losing water to (negative) ground water. The data collected during the seepage runs are listed in table 7 (at back of report).

The seepage discharge measurements were made with a Swoffer Model 2100 horizontal axis current meter or a Price AA current meter using the cross section method described by Rantz and others (1982). Side-by-side comparison measurements of the two types of meter yielded differences of less than 3 percent. Duplicate discharge measurements were made at each of the seepage transects on the main stem of the Dungeness River to evaluate measurement precision.

Table 2. Summary of surface- and ground-water data collected during in-stream mini-piezometer surveys for the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington

[°C, degrees Celsius; μS/cm@25°C, Specific conductance in microsiemens per centimeter temperature compensated for 25 degrees Celsius; temperature and specific conductance differences were computed as values in the river minus values in the mini-piezometer; ft/ft, feet per feet; NR, time not recorded; —, parameter not measured; positive vertical gradients in **bold** type]

Mini-piezometer number	Date	Time	Temperature °C			Specific conductance μS/cm@25°C			Vertical hydraulic gradient (ft/ft)
			River	Ground water	Difference	River	Ground water	Difference	
P1	9/22/1999	NR	—	—	—	113	135	-22.0	-0.18
	10/14/1999	1045	6.1	7.2	-1.1	130	144	-14.0	-0.19
	4/12/2001	1200	—	—	—	—	—	—	-0.04
	5/14/2001	1410	7.4	6.9	0.5	98	155	-57.0	-0.19
	7/17/2001	1720	10.2	10.2	0	114	132	-18.0	-0.17
P2	9/22/1999	1436	—	—	—	117	—	—	**0.01**
	10/14/1999	1145	6.4	8.8	-2.4	130	136	-6.0	**0.04**
	4/11/2001	1345	5.1	6.1	-1	152	170	-18.0	**0.09**
	5/14/2001	NR	7.5	6.8	0.7	99	162	-63.0	**0.01**
	7/17/2001	1820	10.2	9.1	1.1	115	132	-17.0	**0.03**
P3	9/23/1999	1338	10.3	—	—	114	115	-1.0	-0.72
	10/14/1999	1216	6.6	7.1	-0.5	131	131	0.0	-0.72
	4/11/2001	1440	5.5	5.6	-0.1	142	142	0.0	-0.85
	5/14/2001	1550	7.5	7.5	0	99	103	-4.0	-0.99
	7/17/2001	1750	10.5	10.5	0	116	115	1.0	-1.04
P4	9/23/1999	1302	9.7	—	—	118	119	-1.0	-0.21
	10/14/1999	1252	7.8	8.3	-0.5	131	133	-2.0	-0.23
	4/11/2001	1548	6.6	6.5	0.1	148	150	-2.0	-0.11
	5/14/2001	NR	7.8	7.8	0	101	102	-1.0	-0.13
	7/17/2001	1900	10.9	11.2	-0.3	116	116	0.0	-0.13
P5	7/18/2001	1700	13.5	11.6	1.9	119	117	2.0	-0.39
P6	9/22/1999	924	11.9	10.1	1.8	115	118	-3.0	-0.54
	10/14/1999	1330	8.2	8.4	-0.2	132	132	0.0	-0.70
	4/11/2001	1730	7.1	4.4	2.7	149	149	0.0	-0.37
	5/14/2001	1155	8.3	8.5	-0.2	101	103	-2.0	-0.43
	7/17/2001	1935	11.3	11	0.3	117	116	1.0	-0.50
P7	9/22/1999	1500	—	—	—	—	117	—	-0.49
	10/14/1999	1503	9.6	11.8	-2.2	132	132	0.0	-0.53
	4/13/2001	1045	5	5.7	-0.7	80	100	-20.0	-0.75
	5/14/2001	1715	8.5	8.6	-0.1	103	114	-11.0	-0.67
	7/18/2001	1535	13.6	12.3	1.3	120	118	2.0	-0.71
P8	9/22/1999	1055	13.7	—	—	116	117	-1.0	-0.26
	10/14/1999	1542	9.7	8.9	0.8	132	133	-1.0	-0.38
	4/11/2001	1920	7.8	7.1	0.7	150	150	0.0	-0.14
	5/14/2001	NR	8.8	8.9	-0.1	104.2	105	-0.8	-0.23
	7/17/2001	1230	11.5	11.6	-0.1	116	115	1.0	-0.16

Table 2. Summary of surface- and ground-water data collected during in-stream mini-piezometer surveys for the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington—*Continued*

Mini-piezometer number	Date	Time	Temperature °C			Specific conductance µS/cm@25°C			Vertical hydraulic gradient (ft/ft)
			River	Ground water	Difference	River	Ground water	Difference	
P9	7/17/2001	1300	11.5	12.1	-0.6	116	119	-3.0	**0.01**
P10	7/17/2001	NR	11.8	9.1	2.7	116	130	-14.0	**0.02**
P11	7/17/2001	NR	12.5	12.1	0.4	116	121	-5.0	-0.08
P12	7/17/2001	1500	12.8	12.2	0.6	116	116	0.0	-0.18
P13	9/22/1999	1126	10.4	11.8	-1.4	119	—	—	-0.12
	10/14/1999	1618	9.7	8.8	0.9	132	132	0.0	-0.12
	4/11/2001	1830	8.8	5.6	3.2	149	149	0.0	-0.09
	5/14/2001	1830	8.8	8.7	0.1	105	117	-12.0	-0.08
	7/17/2001	NR	10.8	12.2	-1.4	116	114	2.0	-0.14
P14	7/17/2001	NR	11	12.5	-1.5	116	115	1.0	-0.40
P15	7/17/2001	NR	11.1	13.1	-2	116	113	3.0	-0.03
P16	7/17/2001	NR	11.3	12.8	-1.5	116	118	-2.0	**0.01**
P17	7/17/2001	1130	11.4	11.9	-0.5	116	115	1.0	-0.04
P18	9/22/1999	1338	—	—	—	117	122	-5.0	-0.07
	4/13/2001	918	4.5	5.7	-1.2	90	100	-10.0	-0.09
	5/15/2001	NR	10.8	9.4	1.4	109	110	-1.0	-0.10
	7/18/2001	1240	12.3	12.6	-0.3	120	117	3.0	-0.11
P19	9/22/1999	1000	—	—	—	124	127	-3.0	-0.02
	10/14/1999	1700	9.8	—	—	138	—	—	-0.02
	4/12/2001	1807	8	7.5	0.5	100	100	0.0	-0.02
	5/15/2001	1310	10	8.8	1.2	109	133	-24.0	-0.02
	7/18/2001	1445	13.6	12.3	1.3	125	126	-1.0	-0.02
P20	5/15/2001	1345	10.3	9.2	1.1	110	123	-13.0	-0.03
P21	5/15/2001	1420	10.7	9.1	1.6	111	171	-60.0	**0.01**
P22	9/24/1999	945	14.1	—	—	122	140	-18.0	-0.004
	10/13/1999	1447	—	—	—	—	—	—	-0.01
	4/11/2001	1745	10.2	6.9	3.3	100	110	-10.0	**0.01**
	5/14/2001	1950	8.9	8.5	0.4	109	155	-46.0	**0.01**
	7/18/2001	1806	14.9	12.5	2.4	126	129	-3.0	**0.01**
P23	5/15/2001	NR	8.1	9	-0.9	111	163	-52.0	**0.01**
P24	5/15/2001	1045	8.5	8.3	0.2	111	168	-57.0	**0.01**
P25	5/15/2001	1130	8.8	8.8	0	111	169	-58.0	**0.004**
P26	9/22/1999	1130	9.4	10.6	-1.2	126	160	-34.0	-0.02
	10/14/1999	1536	9.8	—	—	139	—	—	-0.02
	4/11/2001	1600	10.1	7	3.1	90	100	-10.0	-0.01
	5/15/2001	910	7.8	8.4	-0.6	110	177	-67.0	-0.03
	7/18/2001	1330	12.5	11.8	0.7	125	158	-33.0	-0.01
P27	5/15/2001	1235	9.3	9.4	-0.1	111	118	-7.0	-0.03
	7/18/2001	NR	12.5	13	-0.5	125	124	1.0	-0.02

Off-Stream Well Transects

Off-stream well transects were installed at two locations to verify the in-stream mini-piezometer results and to assess horizontal hydraulic gradients between the river and ground water within a typical losing reach (Dungeness Meadows transect, fig. 9) and a typical gaining reach (Schoolhouse Bridge transect, fig. 10). Six monitoring wells were installed at each site, three on either side of the river. Each well within a transect is identified by its latitude and longitude and by a unique Washington State Department of Ecology (DOE) well tag number consisting of three letters followed by three numbers (for example, AFK195).

Well installation began on March 28, 2000, using a Stratoprobe™ truck-mounted, direct-push drilling system. The wells were installed to depths of 15 to 30 feet and consisted of 1.25-inch-diameter PVC casing with a standard 5-foot length of 10-slot PVC well screen (see table 3 for construction details). The annular space around each well was backfilled with silica sand to within 8 feet of ground surface. The remainder of the annulus was filled with bentonite pellets to provide a hydraulic barrier to down-hole water movement. The wells were capped with a flush-mounted metal cover that was sealed with cement (fig. 11).

A temporary gaging station was established for the Dungeness River at the diversion structure for the Clallam-Cline-Dungeness (CCD) irrigation ditch to enable comparisons between the river stage and ground-water levels measured in the adjacent Dungeness Meadows well transect (fig. 9).

Table 3. Details of construction of the off-stream piezometer transects

	Dungeness Meadows					
Well number	AFK197	AFK196	AFK195	AFK192	AFK193	AFK194
Measuring point altitude (in feet above sea level)	328.6	328.6	329.5	332.9	328.9	329.3
Distance from edge of river (in feet)	90.0	37.0	20.0	191.0	225.0	257.0
Initial depth to water from measuring point (in feet)	6.4	7.6	8.6	12.6	8.6	8.8
Piezometer total depth below land surface (in feet)	15	15	15	20	15	15
Screened interval (in feet)	15 to 10	15 to 10	15 to 10	20 to 15	15 to 10	15 to 10
Sand pack (in feet)	none	none	none	20 to 8	15 to 8	15 to 8
Bentonite seal (in feet)	5 to 0	5 to 0	6 to 0	8 to 0	8 to 0	8 to 0
Ground material	Boulder and cobble gravel with pebbles and sand					
Width of river at site (in feet)	40					
"Note: AFK192, AFK193, and AFK194 are offset approximately 100 feet north of AFK195, AFK196, and AFK197						

	Schoolhouse Bridge					
Well number	AFK191	AFK190	AFK189	AFK186	AFK187	AFK188
Measuring point altitude (in feet above sea level)	22.9	22.3	21.6	29.2	19.8	19.7
Distance from edge of river (in feet)	146.0	114.0	79.0	39.0	81.0	101.0
Initial depth to water from measuring point (in feet)	9.2	16.0	7.5	14.1	12.3	15.5
Piezometer total depth below land surface (in feet)	20.0	18.0	18.0	30.0	20.0	20.0
Screened interval (in feet)	20 to 15	18 to 13	15 to 10	30 to 25	15 to 10	20 to 15
Sand pack (in feet)	20 to 8	18 to 8	18 to 10	30 to 18	20 to 8	20 to 8
Bentonite seal (in feet)	8 to 0	8 to 0	10 to 0	18 to 0	8 to 0	8 to 0
Ground material	Brown clay and silty clay with silty sand lenses and stringers					
Width of river at site (in feet)	40					
"Note: AFK186, AFK187, and AFK188 are offset approximately 75 feet north of AFK189, AFK190, and AFK191						

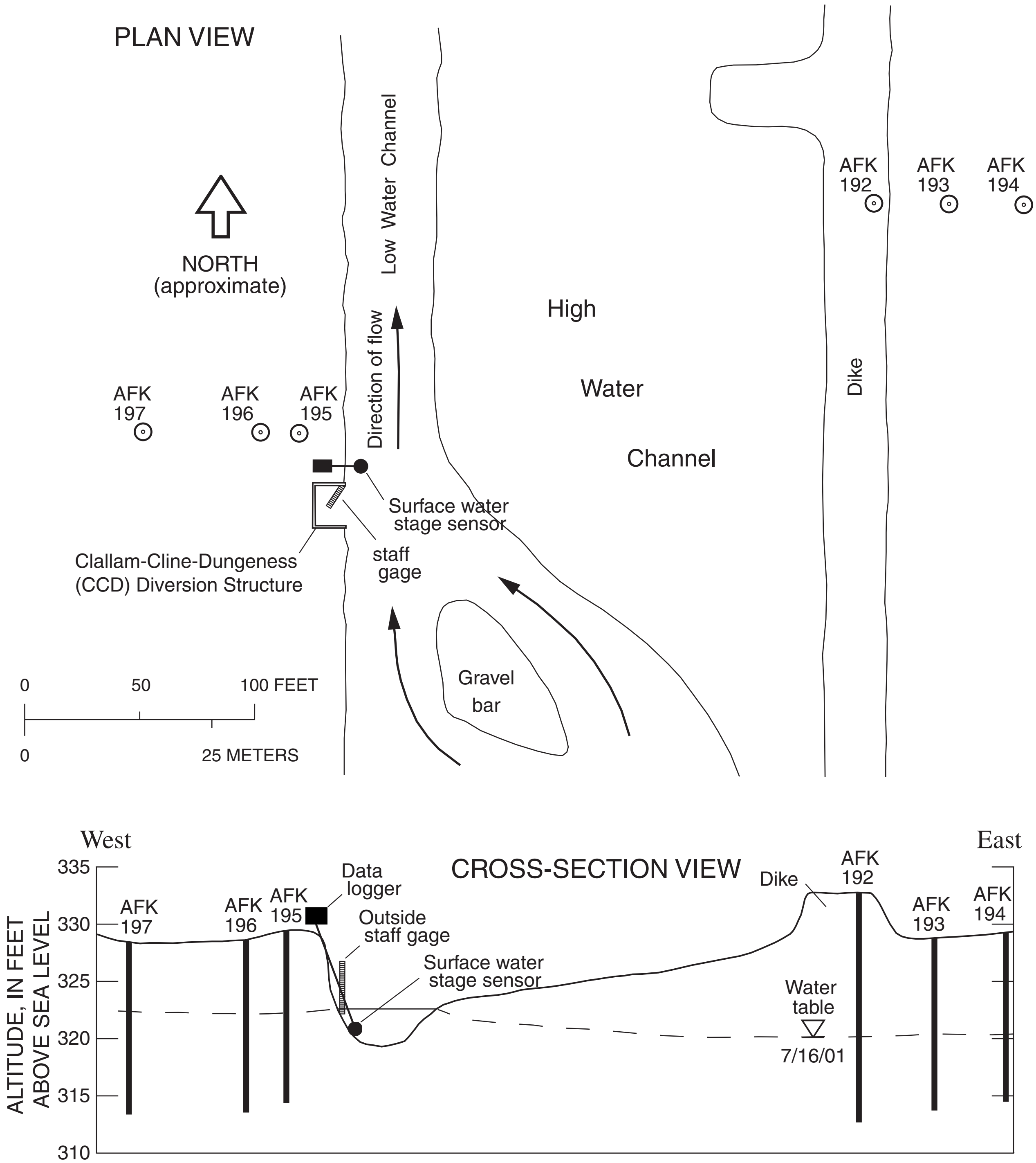


Figure 9. Configuration of the off-stream well transect at Dungeness Meadows on the Sequim-Dungeness peninsula, Clallam County, Washington.

Three monitoring wells are aligned on each side of the river adjacent to a surface-water gage. The wells on the side nearest the surface-water stage sensor were instrumented to collect hourly water level and temperature data.

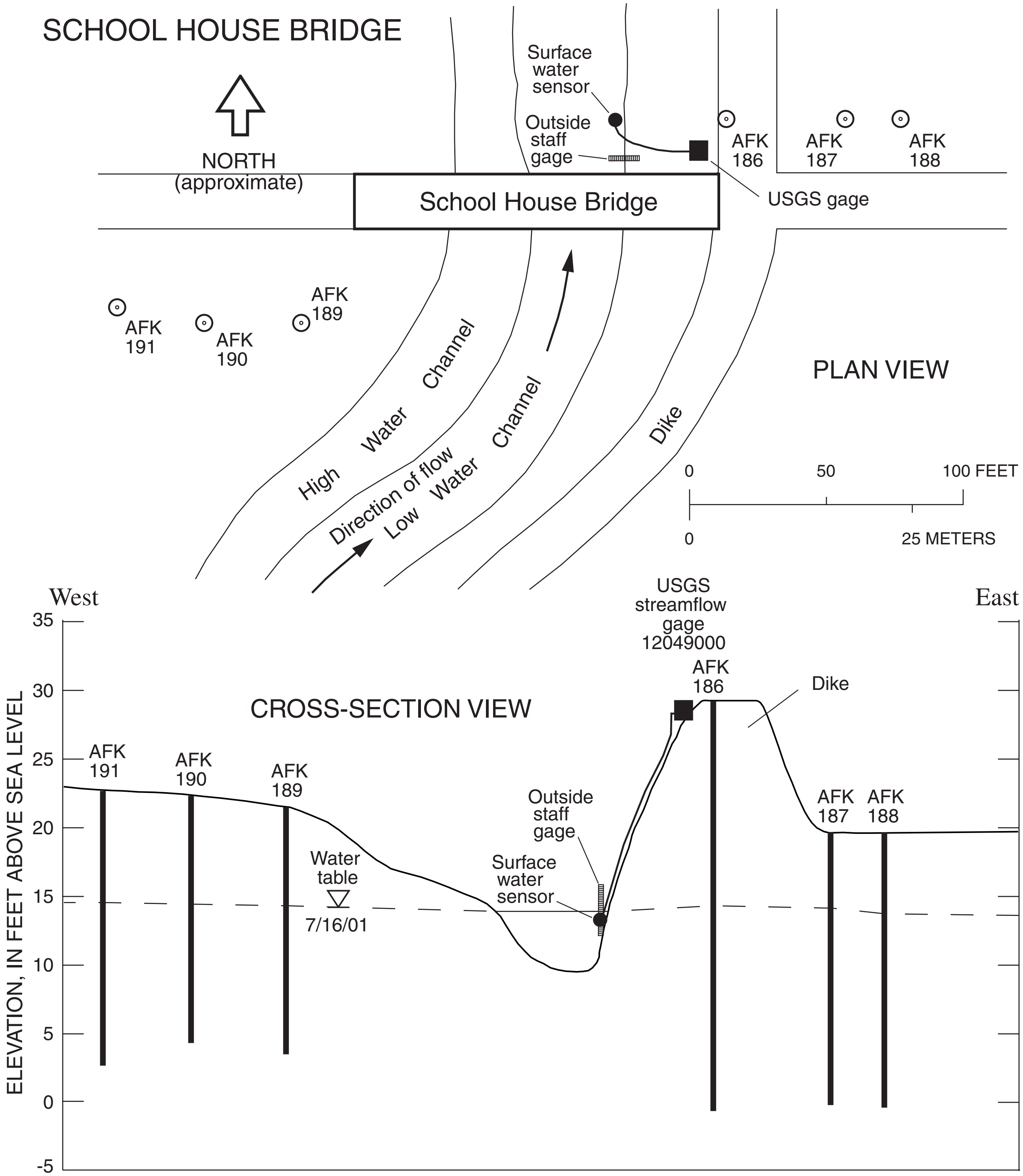


Figure 10. Configuration of the off-stream well transect at Schoolhouse Bridge on the Sequim-Dungeness peninsula, Clallam County, Washington.

Three monitoring wells are aligned on each side of the river adjacent to a surface water gage. The wells on the side nearest the surface water stage sensor were instrumented to collect hourly water level and temperature data.

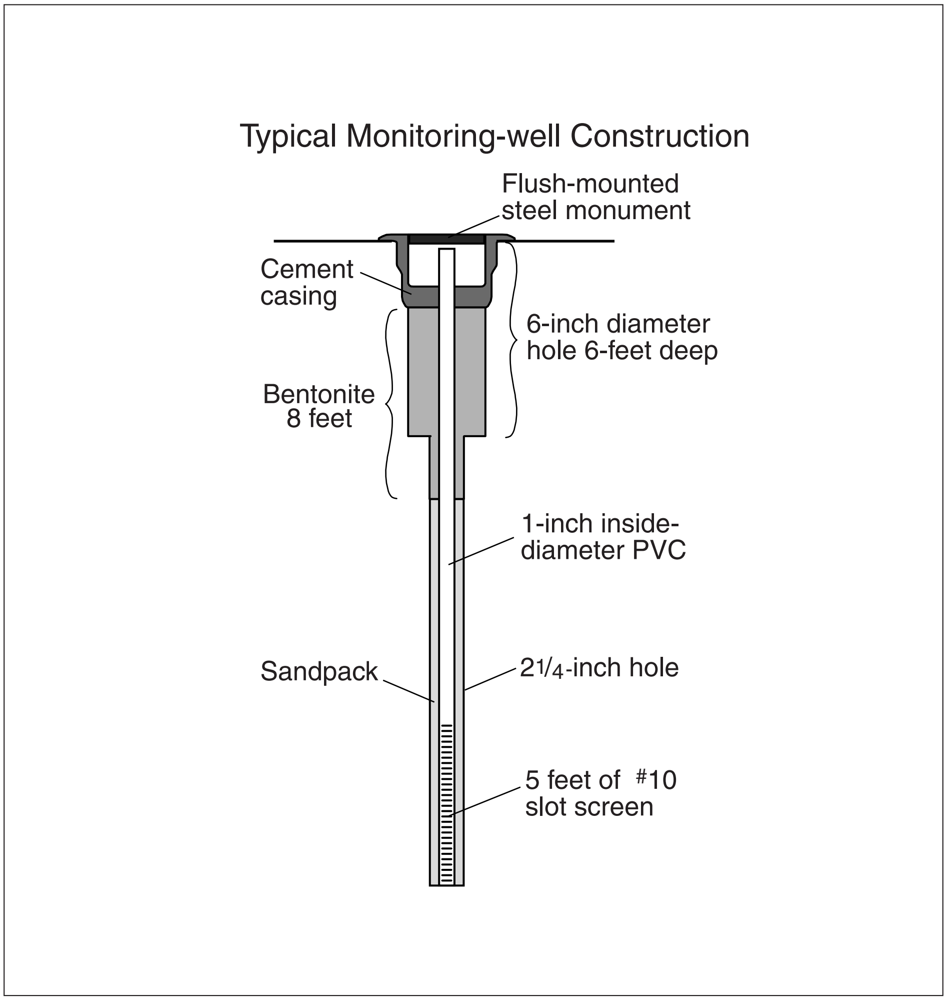


Figure 11. Construction of a typical monitoring well. The well is sealed with bentonite and cement.

Although this location was not ideal, it was the only site in the vicinity stable enough to secure and maintain a surface-water stage sensor. The existing USGS streamflow-gaging station (12049000) at the Schoolhouse Bridge was used to measure river stage and temperature at that location (fig. 10). Continuous stage data were collected at both sites between June 16, 2000, and July 20, 2001. From September 9 to October 3, 2000, data from the Dungeness Meadows site were lost because of battery failure.

Outside staff gages were installed in the river at both the Dungeness Meadows and Schoolhouse Bridge transects to verify the automated surface-water stage sensor. At both sites, two sensors were inserted into the three off-stream wells closest to the river stage sensor. A 15-pounds-per-square-inch range Druck™ PTX 1230 pressure transducer was used to measure ground-water levels and a Thermix™ thermister was used to measure temperature. Identical instruments were used to measure surface-water stage and temperature at the Dungeness Meadows gage. At the Schoolhouse Bridge gage, a gas-purge bubbler system with an Accubar™ pressure sensor and a Thermix™ thermistor were used to measure stage and temperature. All sensors were hard-wired to a Sutron™ 8200 data logger and set to record hourly water levels and temperatures.

The off-stream well transects were visited monthly to retrieve data and to conduct confirmatory "hand" measurements at the outside staff gages and transect wells. The transect wells with water-level recorders were measured with a steel tape. Those without instrumentation were measured with a Solinst™ water-level E-tape. For non-instrumented wells, temperature and specific conductance were measured using the multi-probe attachments on the Solinst™ meter. The data collected for the monthly confirmatory measurements are compiled in table 8 (at back of report). The monthly hand measurements were used to construct water level profiles of the river and ground water at both well transects.

The continuous river-stage, ground-water altitude, and temperature data for the river and transect wells were entered into the USGS National Water Information System (NWIS) database. The monthly ground-water level and temperature measurements were entered into the USGS Ground Water Site Inventory (GWSI) database. Datum corrections were made (as necessary) to the continuous river-stage and ground-water level data to compensate for instrument drift.

Measuring-point altitudes for the staff gage and off-stream wells at the Schoolhouse Bridge transect were determined using a Wild™ surveyor's level. Measuring points were referenced to a local benchmark of known altitude to an accuracy of +/-0.02 foot. At the Dungeness Meadows site, measuring-point altitudes were determined using differential GPS techniques and are considered accurate to approximately 0.33 foot (Donald Lindorfer, Clallam County Road Department, 2/8-9/2001, written commun.).

INTERACTION BETWEEN THE LOWER DUNGENESS RIVER AND THE WATER-TABLE AQUIFER

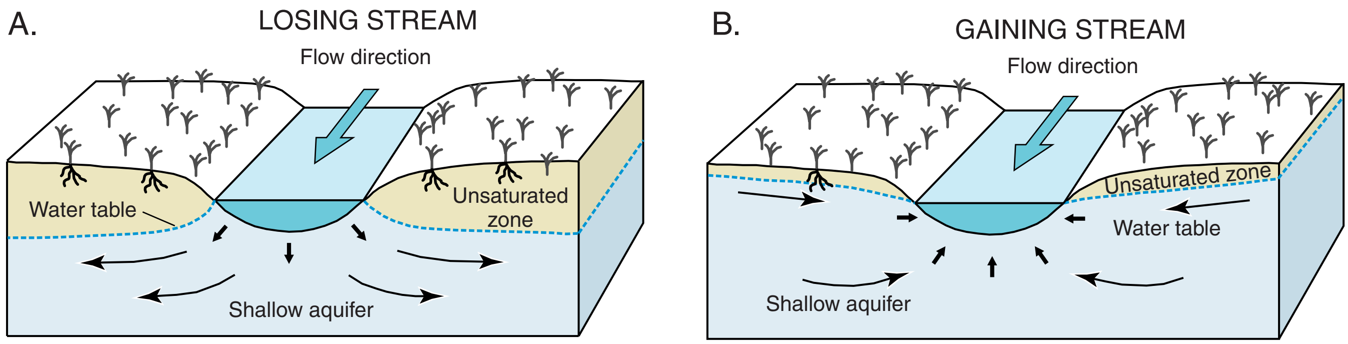
Direct exchanges of water between streams (or rivers) and ground water occur in three basic ways. Streams can gain water from ground-water inflow through their streambed, they can lose water through their streambed to ground water, or they may do both: gaining water in some reaches and losing it in others (Winter and others, 1998).

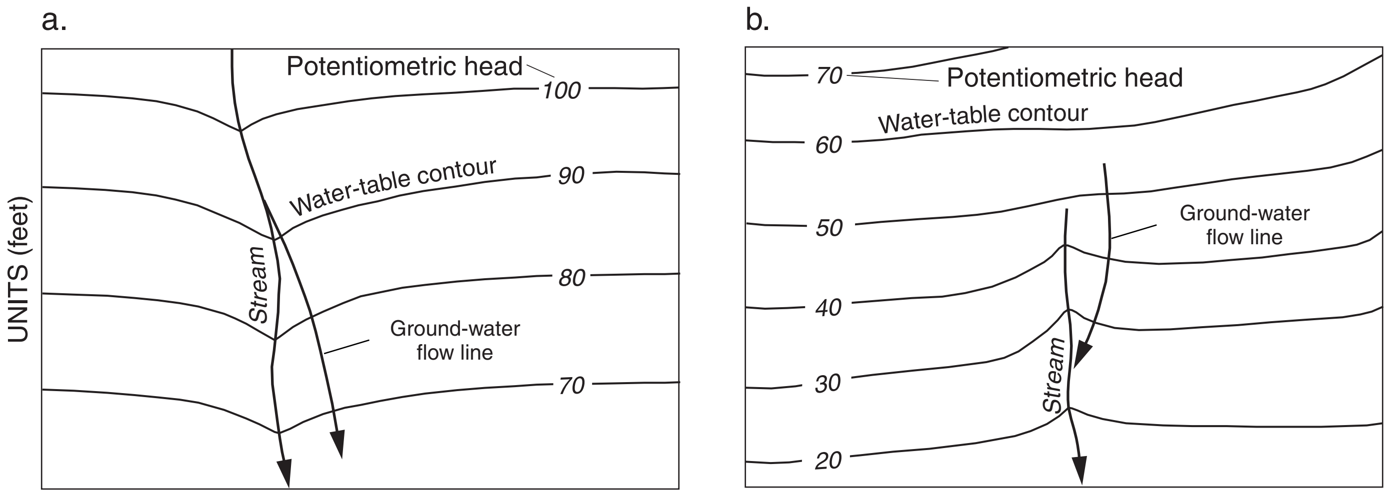
Water loss from a stream can occur whenever the stream stage exceeds the adjacent ground-water head, regardless of whether the stream and ground water are connected by saturated materials (fig. 12*A*) or are separated by a zone of unsaturated material (fig. 12*C*). In order for a stream to gain water directly from ground water, two conditions must exist. First, there must be a saturated connection between the stream and ground water, and second, the ground-water head adjacent to the stream must be higher than the stream surface (stream stage) (fig. 12*B*).

The rate of water exchange between a stream and ground water depends on several factors, including the vertical hydraulic conductivity of the streambed materials, the vertical hydraulic gradient between the stream and ground water, and the saturated area of the streambed across which flow occurs. When streams are separated from ground water by an unsaturated zone, the rate of streamflow loss depends primarily on the stream depth and the vertical hydraulic conductivity and geometry of the streambed (fig. 12C).

The simplistic depictions of stream and ground-water interchange shown in figures 12A, B, and C are in actuality complicated by the natural heterogeneity of streambed sediments and underlying geologic deposits. Under gaining conditions, lenses or beds of coarse material within finer-gained sediments can preferentially transmit and discharge ground water to a stream. When lenses or beds of coarse material occur within a losing stream reach, they may coincide with areas of unusually high water loss. In addition, a stream or stream reach may temporarily change from gaining to losing conditions when snowmelt or precipitation runoff temporarily elevates the river stage and causes it to exceed the head in the surrounding ground water. When the stream stage rises, surface water may be stored in the stream bank adjacent to the river, contributing to a local rise in the water table that persists until streamflow returns to a lower level (fig. 12*D*).

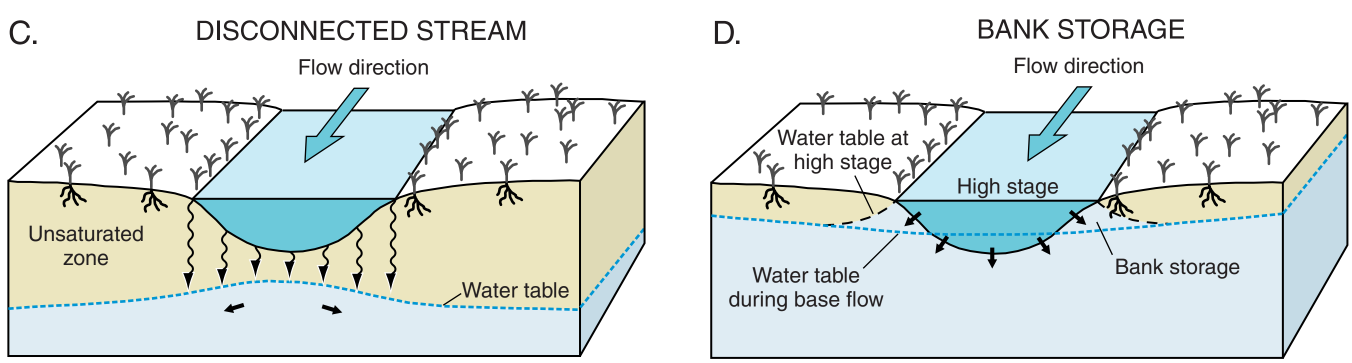
In the following discussion, surface water and groundwater exchange processes are evaluated in detail for each of the five seepage reaches examined during this study.





Losing streams lose water to the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the downstream direction where they cross the stream (a).

Gaining streams receive water from the ground-water system (B). This can be determined from water-table contour maps because the contour lines point in the upstream direction where they cross the stream (b).



Disconnected streams are separated from the ground-water system by an unsaturated zone.

If stream level rises higher than adjacent ground-water levels, stream water moves into the streambanks as bank storage.

Figure 12. Interaction between surface water and ground water to form a losing stream, a gaining stream, a disconnected stream, and bank storage.

(Modified from Winter and others, 1998).

Seepage Reach 1

Seepage reach 1 is approximately 3.7 miles in length and extends from river mile 11.8, at the USGS streamgaging station near Sequim (12048000), to the upper end of the Dungeness Meadows development at river mile 8.1 (fig. 13). The upper 0.7 mile of reach 1 lies within an alluvium-filled bedrock channel. The river flows directly over bedrock just below piezometer P2, where it is confined by a short bedrock constriction (fig. 14). Below the constriction the river widens and flows across poorly sorted deposits of coarse gravel and boulders that define the southern extent of the regional ground-water flow system for the Sequim-Dungeness Peninsula. Several small private levees protect homes from flooding within this reach.

Based on the results of three seepage runs, the river showed a net loss of 2.1 to 4.1 ft^3/s per river mile through reach 1. The largest loss occurred during the seepage run on April 10-11, 2000, when the river lost approximately 15 ft^3/s, or 4.6 percent of its total flow through this reach (fig. 13). The smallest loss occurred during the seepage run on October 4, 2000, when the river lost approximately 8 ft^3/s, or 5.9 percent of its total flow. The rate of streamflow loss for the three seepage runs was correlated with the river discharge and increased with increasing river flows (fig. 15). However, with only three data points, this correlation may not be statistically significant, and it is uncertain if this correlation is valid at higher flows.

Data from the mini-piezometers in reach 1 generally support these seepage results (fig. 13). Mini-piezometers P1, P3, and P4 exhibited negative hydraulic gradients ranging from -0.04 to -1.04 ft/ft. The average gradient for these piezometers was -0.15, -0.86, and -0.16 ft/ft for piezometers P1, P3, and P4 respectively (table 4). In contrast to the other piezometers in reach 1, piezometer P2 had an average gradient of about +0.04 ft/ft and consistently indicated a slight positive gradient, or ground-water discharge conditions. The positive gradients observed at piezometer P2 likely result from a bedrock constriction just downstream of this site that forces ground water to the surface as it moves down the river valley.

Together, the seepage run and mini-piezometer data suggest that the Dungeness River consistently loses water through reach 1 except in the vicinity of piezometer P2, where ground water is forced to the surface for a short distance as it passes a bedrock constriction.

Seepage Reach 2

Seepage reach 2 is approximately 2.6 miles in length and extends from the upstream end of the Dungeness Meadows Subdivision at river mile 8.1 to just above the Railroad Bridge Park at river mile 5.5. In this reach, the river flows across coarse deposits of poorly sorted gravel and cobbles. The channel is braided with numerous bars and islands and alternating pools and riffles. The river is restricted from a portion of its floodplain by a levee on the right bank that protects the Dungeness Meadows Subdivision from flooding. The levee prevents the river channel from migrating eastward and creates a straight reach where pools are filled in and large longitudinal cobble bars are common. Below the Dungeness Meadows levee, scouring and gravel deposition allow the channel to return to its braided configuration.

Based on three seepage runs, the river showed a net gain of approximately 0.23 to 3.5 ft^3/s per river mile through reach 2. The largest gain occurred during the seepage run on April 10-11, 2000, when the river gained approximately 9 ft^3/s, or approximately 3 percent of the total flow measured at the upper seepage transect (fig. 13). The smallest gain occurred during the seepage run on October 4, 2000, when the river gained approximately 0.6 ft^3/s, or approximately 0.5 percent of its total flow. Like reach 1, the rate of stream-flow loss was correlated with the river discharge and increased with increasing river flows (fig. 15). Again, this correlation may not be statistically significant and it is uncertain if the correlation is valid at higher flows.

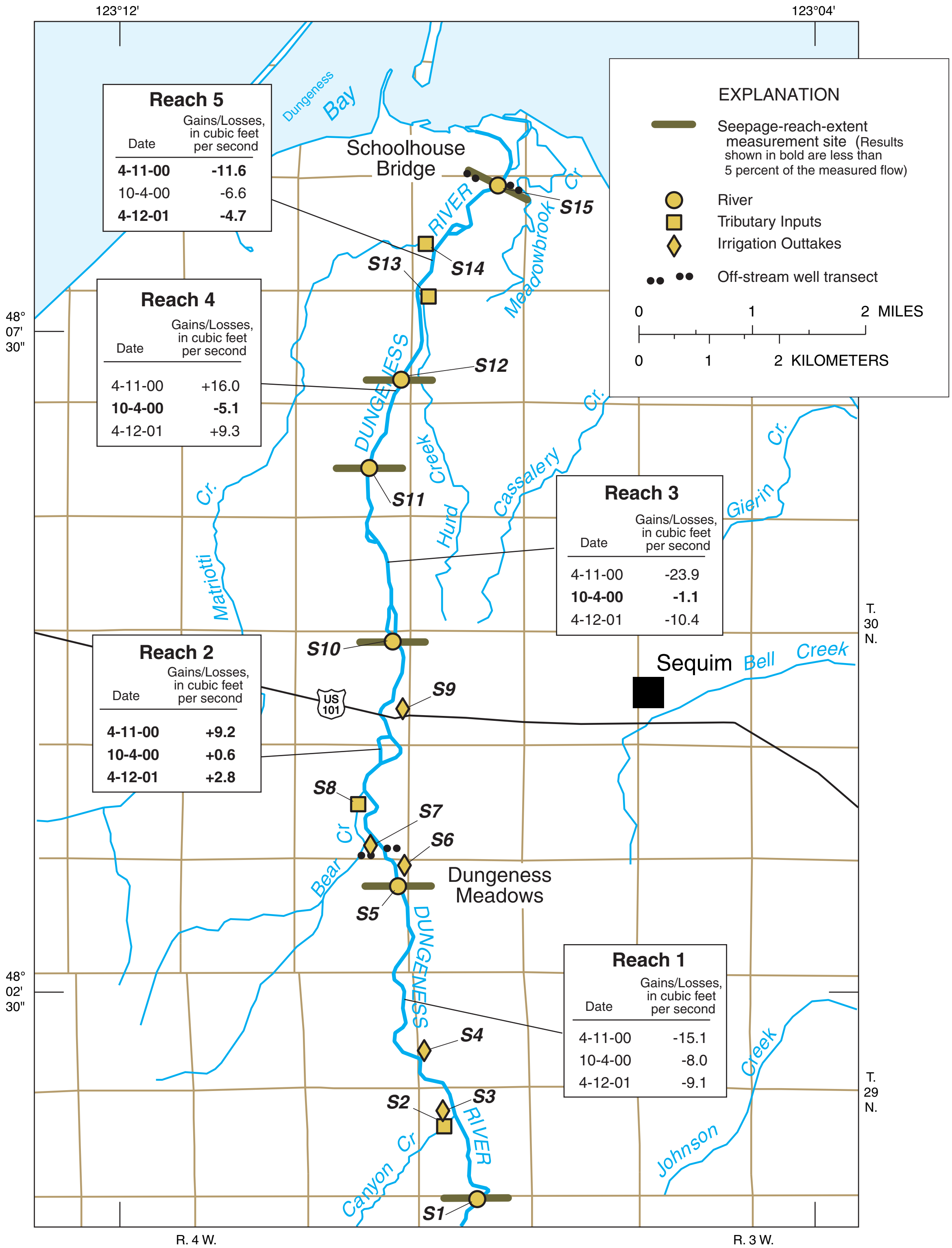


Figure 13. Results of the seepage runs on the five study reaches of the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, April 11 and October 4, 2000, and April 12, 2001.

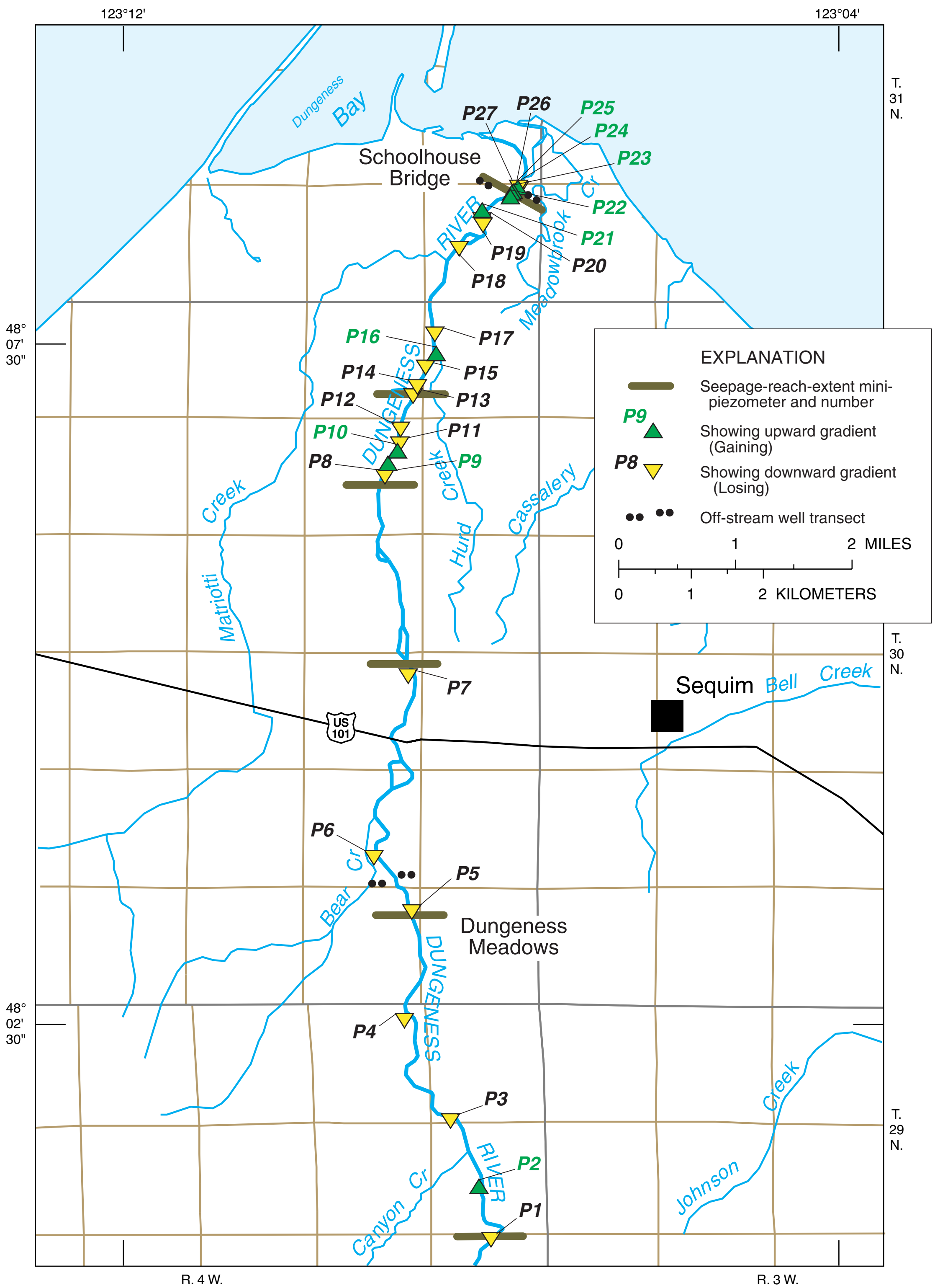


Figure 14. Locations of the river reaches and results of in-stream mini-piezometer measurements in the study area of the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington.

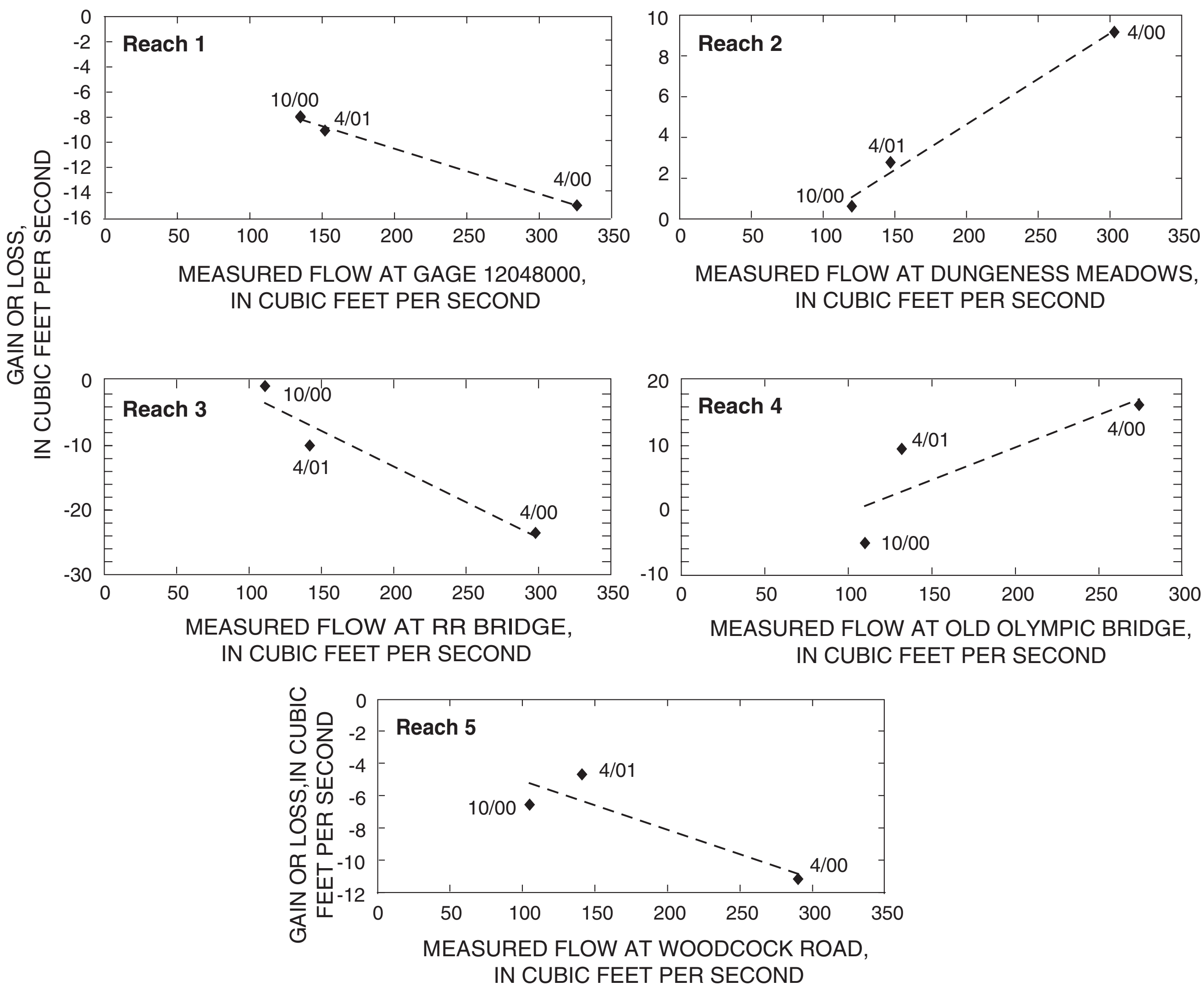


Figure 15. Correlation between streamflow gain or loss and river discharge during the three seepage runs in the five study reaches of the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington.

Table 4. Results of in-stream mini-piezometer surveys on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington

[Calibration tests on the manometer board show the greatest percentage of errors (up to 8 percent) occurred at small (or no) gradients while the greatest absolute error (approximately 0.03 inch) occurred when measuring larger gradients. Accuracy of the manometer board in determining vertical gradients is approximately +/- 0.01. LB, Left bank; RB, Right bank; ft, feet; —, Piezometer not measured; positive vertical gradients in **bold** type]

Map ID Figure 2	Piezometer location	Piezometer location (river mile)	Vertical hydraulic gradient (dimensionless)					Long-term average
			9/22-23/99	10/14/99	04/11-13/01	05/14-15/01	07/17-18/01	
			REACH 1					
P1	Original Piezometer Site 7 (150 ft downstream from USGS gage on LB)	11.59	-0.18	-0.19	-0.04	-0.19	-0.17	-0.15
P2	Original Piezometer Site 11 (Above Dungeness Hatchery at bedrock pinch of river on LB)	11.02	**0.01**	**0.04**	**0.09**	**0.01**	**0.03**	**0.04**
P3	Original Piezometer Site 1 (At Dungeness Hatchery on LB)	10.29	-0.72	-0.72	-0.85	-0.99	-1.04	-0.86
P4	Original Piezometer Site 10 (May Road below Dungeness Hatchery LB)	9.1	-0.21	-0.23	-0.11	-0.13	-0.13	-0.16
			REACH 2					
P5	Piezometer at upper end of Dungeness Meadows on RB	8.13	—	—	—	—	-0.39	-0.39
P6	Original Piezometer Site 2 (200 ft downstream from Dungeness Meadows piezo array on LB)	7.54	-0.54	-0.70	-0.37	-0.43	-0.50	-0.51
P7	Original Piezometer Site 6 (300 ft upstream from Old Railroad Bridge on RB)	5.54	-0.49	-0.53	-0.75	-0.67	-0.71	-0.63
			REACH 3					
No Piezometers are located within Reach 3								
			REACH 4					
P8	Original Piezometer Site 3 (300 ft downstream from Old Olympic Highway Bridge on LB)	3.68	-0.26	-0.38	-0.14	-0.23	-0.16	-0.23
P9	1st new piezometer downstream from P8	3.57	—	—	—	—	**0.01**	**0.01**
P10	2nd new piezometer downstream from P8	3.44	—	—	—	—	**0.02**	**0.02**
P11	3rd new piezometer downstream from P8	3.36	—	—	—	—	-0.08	-0.08
P12	4th new piezometer downstream from P8	3.23	—	—	—	—	-0.18	-0.18

Table 4. Results of in-stream mini-piezometer surveys on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington—*Continued*

Map ID Figure 2	Piezometer location	Piezometer location (river mile)	Vertical hydraulic gradient (dimensionless)					Long-term average
			9/22-23/99	10/14/99	04/11-13/01	05/14-15/01	07/17-18/01	
			REACH 5					
P13	Original Piezometer Site 9 (At Ward Road Mary Wheeler Park on LB)	2.92	-0.12	-0.12	-0.09	-0.08	-0.14	-0.11
P14	1st new piezometer 300 ft downstream from P13	2.84	—	—	—	—	-0.40	-0.40
P15	2nd new piezometer downstream from P13	2.66	—	—	—	—	-0.03	-0.03
P16	3rd new piezometer downstream from P13	2.54	—	—	—	—	**0.01**	**0.01**
P17	4th new piezometer downstream from P13	2.35	—	—	—	—	-0.04	-0.04
P18	Original Piezometer Site 5 (Olympic Game Farm 1000 ft upstream from Matriotti Creek on LB)	1.52	-0.07	—	-0.09	-0.10	-0.11	-0.09
P19	Original Piezometer Site 8A (Dike access off Towne Road on RB	1.13	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
P20	1st new Piezometer about 250 ft downstream from P19 on RB	1.09	—	—	—	-0.03	—	-0.03
P21	2nd new Piezometer about 600 ft downstream from P19 on RB	1.04	—	—	—	**0.01**	—	**0.01**
P22	Original Piezometer Site 4 (100 ft upstream from Schoolhouse Bridge on LB)	0.73	-0.004	-0.01	**0.01**	**0.01**	**0.01**	**0.002**
P23	New Piezometer at Schoolhouse Bridge (across from gage on LB)	0.71	—	—	—	**0.01**	—	**0.01**
			DOWNSTREAM OF REACH 5					
P24	Piezometer 200 feet downstream from Schoolhouse Bridge on LB	0.67	—	—	—	**0.01**	—	**0.01**
P25	Piezometer 300 feet downstream from Schoolhouse Bridge on LB	0.65	—	—	—	**0.004**	—	**0.004**
P26	Original Piezometer Site 12 (1000 ft downstream from Schoolhouse Bridge on RB)	0.64	-0.02	-0.02	-0.01	-0.03	-0.01	-0.02
P27	Piezometer about 100 ft downstream from Piezometer P26 on LB	0.62	—	—	—	-0.03	-0.02	-0.02

The mini-piezometer data for reach 2 (fig. 14) do not corroborate the above seepage results (fig. 13). Piezometer P5 was measured once and had a gradient of -0.39 ft/ft. Piezometers P6 and P7 were measured five times during the study and had consistently negative gradients that averaged -0.51 and -0.63 ft/ft, respectively (table 4). The gradient relations observed in the reach 2 mini-piezometers are supported by the continuous-water-level and temperature data collected at the Dungeness Meadows well transect. The continuous stage data for the river (fig. 16) show a decline through late summer 2000, followed by spikes associated with winter precipitation events and a snowmelt peak in late May 2001. Water levels in wells AFK195, AFK196, and AFK197 reflect variations in river stage but remain at a lower relative altitude throughout the year, indicating that the river loses water at this location. Like the river stage, ground-water levels in these wells generally were high during the spring and early summer and low during the winter between precipitation events.

The continuous temperature data for the Dungeness Meadows transect wells confirm these findings. Ground-water temperatures in well AFK195, which lies nearest the river, reflect both short-term and long-term variations in river temperature. Ground-water temperatures in wells AFK196 and AFK197, which lie farther from the river, are less influenced by short-term surface-water temperature variations (fig. 17). Water temperatures in wells AFK196 and AFK197 are closer to the apparent baseline ground-water temperature of approximately 9 degrees Celsius (^{o}C; equivalent to a mean annual air temperature of 48 ^{o}F).

Monthly cross-sectional profiles for the Dungeness Meadows transect (fig. 18) illustrate how ground-water levels react to river stage and seasonal variations. The pattern is similar to that shown in figure 12*D* where bank storage is an important factor. The fact that ground-water temperatures do not react as quickly as head changes suggests that the river exerts a pressure effect on the local water table adjacent to the river.

There are several possible explanations for the conflicting results between the seepage-run data for reach 2 and the mini-piezometer and well-transect data. It is possible that the mini-piezometers were not located at gaining sites in reach 2. It is also possible that a missed return flow from the CCD irrigation outtake (S7 on fig. 13) caused a bias in the seepage results. Return flows of 1 to 5 ft^3/s are typically shunted back to the river below the CCD outtake (to return fish that enter the ditch and to control flows) and were not measured during the seepage runs. In addition, in reach 2 the river is bounded by irrigation canals that may contribute flow to the river through subsurface seepage. Lower Bear Creek also may receive ground-water discharge that was not accounted for during this evaluation.

Regardless of the cause for the observed discrepancy between field methods, most of the results to date suggest that the Dungeness River loses water to ground water through reach 2.

Seepage Reach 3

Seepage reach 3 is approximately 1.8 miles in length and extends from just above the Railroad Bridge at river mile 5.5 to just below the Old Olympic Highway bridge at river mile 3.7. The river gradient decreases in reach 3, and the channel changes from the heavily braided system of reach 2, with its bars and small islands, to a less-braided channel morphology. The river velocity also decreases in reach 3, resulting in the deposition of somewhat finer-grained bed material than is observed upstream. Reach 3 contains no channel-restricting levees or flood-control structures.

All three seepage runs conducted during this study indicated a net loss of water from the river along reach 3. Measured losses ranged from -0.54 to -12.8 ft^3/s per river mile. The largest loss occurred during the April 10-11, 2000, evaluation, when the river lost approximately 24 ft^3/s, or 8 percent of the total flow measured at the upper seepage transect (fig. 13). The smallest loss occurred during the seepage run on October 4, 2000, when the river lost approximately 1.1 ft^3/s, or 1percent of its flow. The amount of loss through reach 3 was correlated with river discharge (fig. 15) and increased with river flow. As with the upstream reaches, however, this correlation may not be statistically significant.

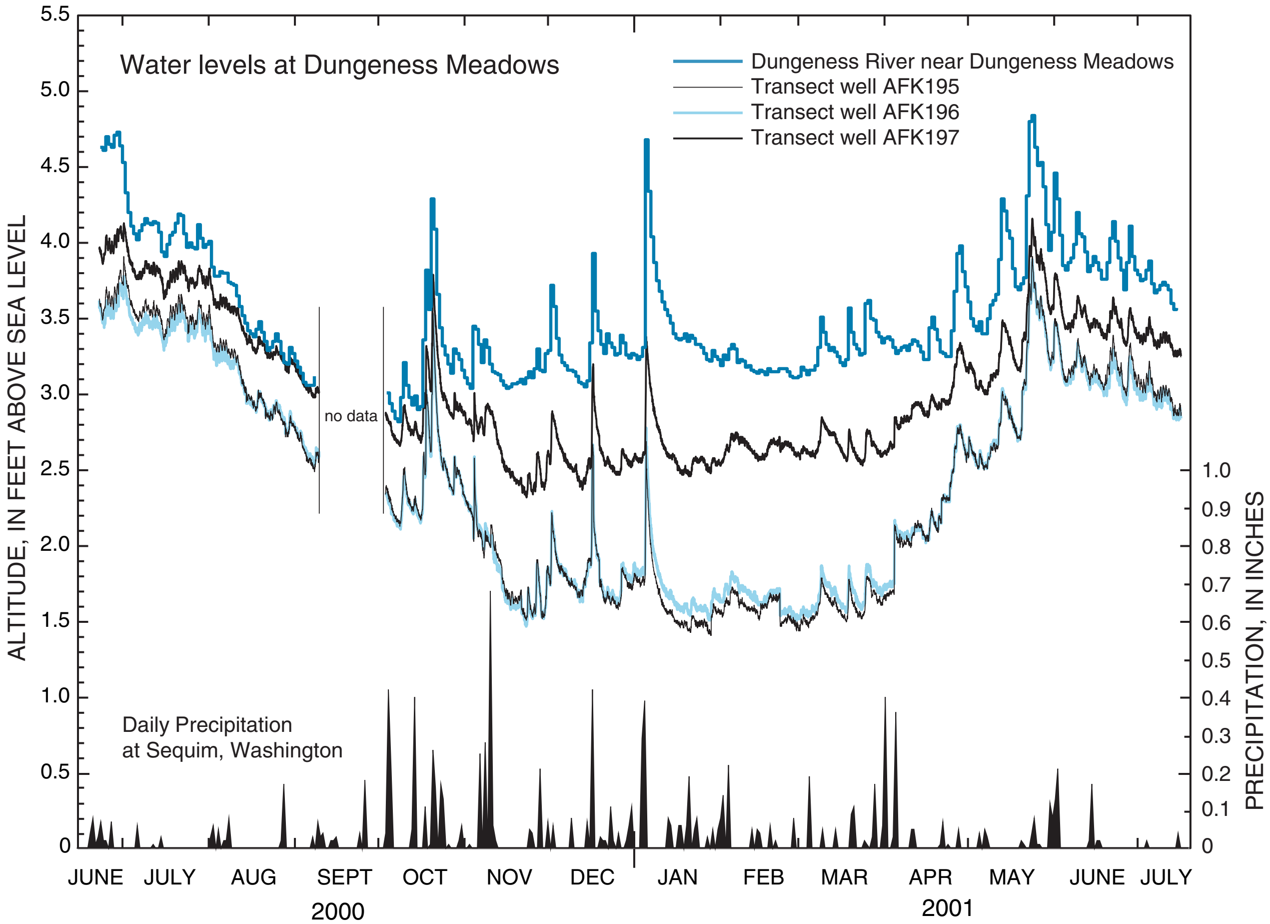


Figure 16. Continuous surface- and ground-water level data collected from June 2000 to July 2001 at the Dungeness Meadows off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.
Daily precipitation recorded at the wastewater treatment facility at Sequim, Washington, is shown for comparison.

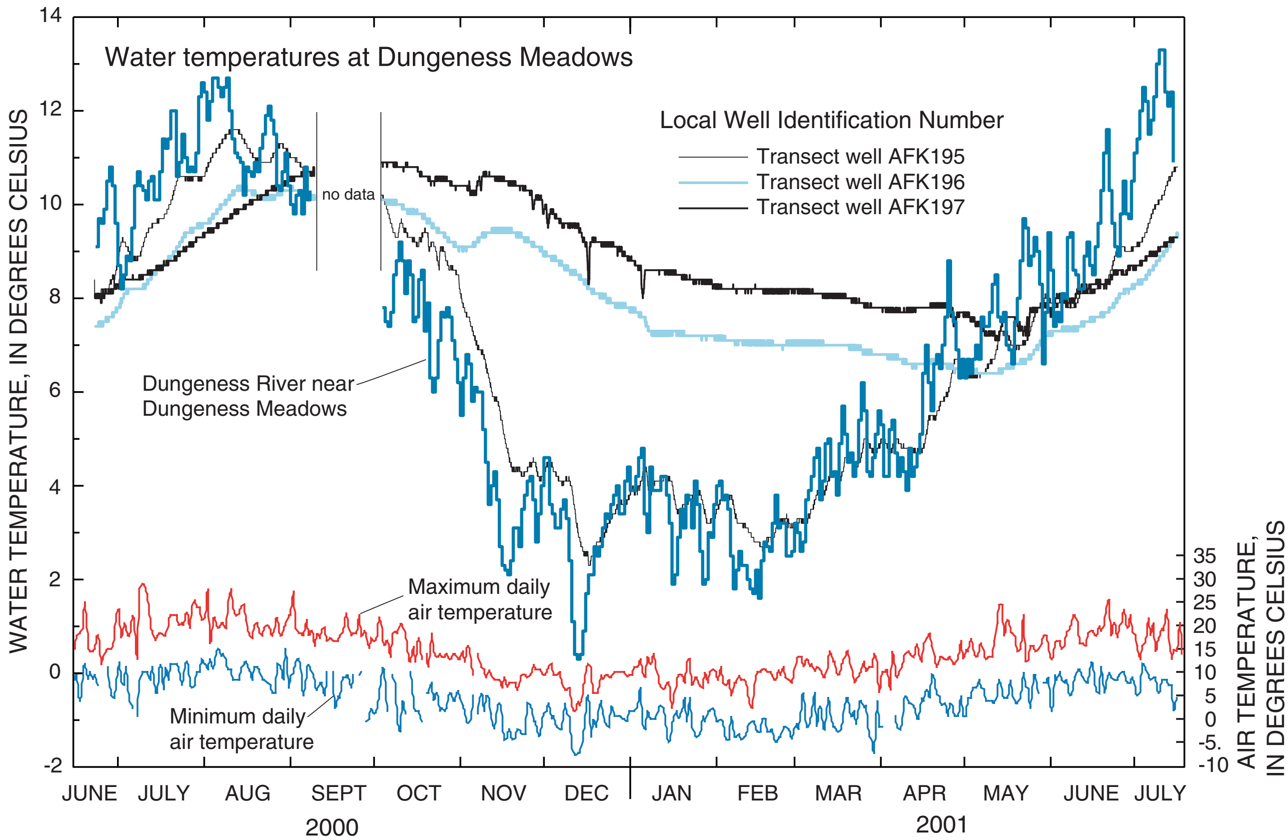


Figure 17. Continuous surface- and ground-water temperature data collected from June 2000 to July 2001 at the Dungeness Meadows off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.

Maximum and minimum daily air temperatures recorded at the wastewater treatment facility at Sequim, Washington, are shown for comparison. The gap in the water-temperature data from September 9, 2000 to October 3, 2000, was caused by a battery failure.

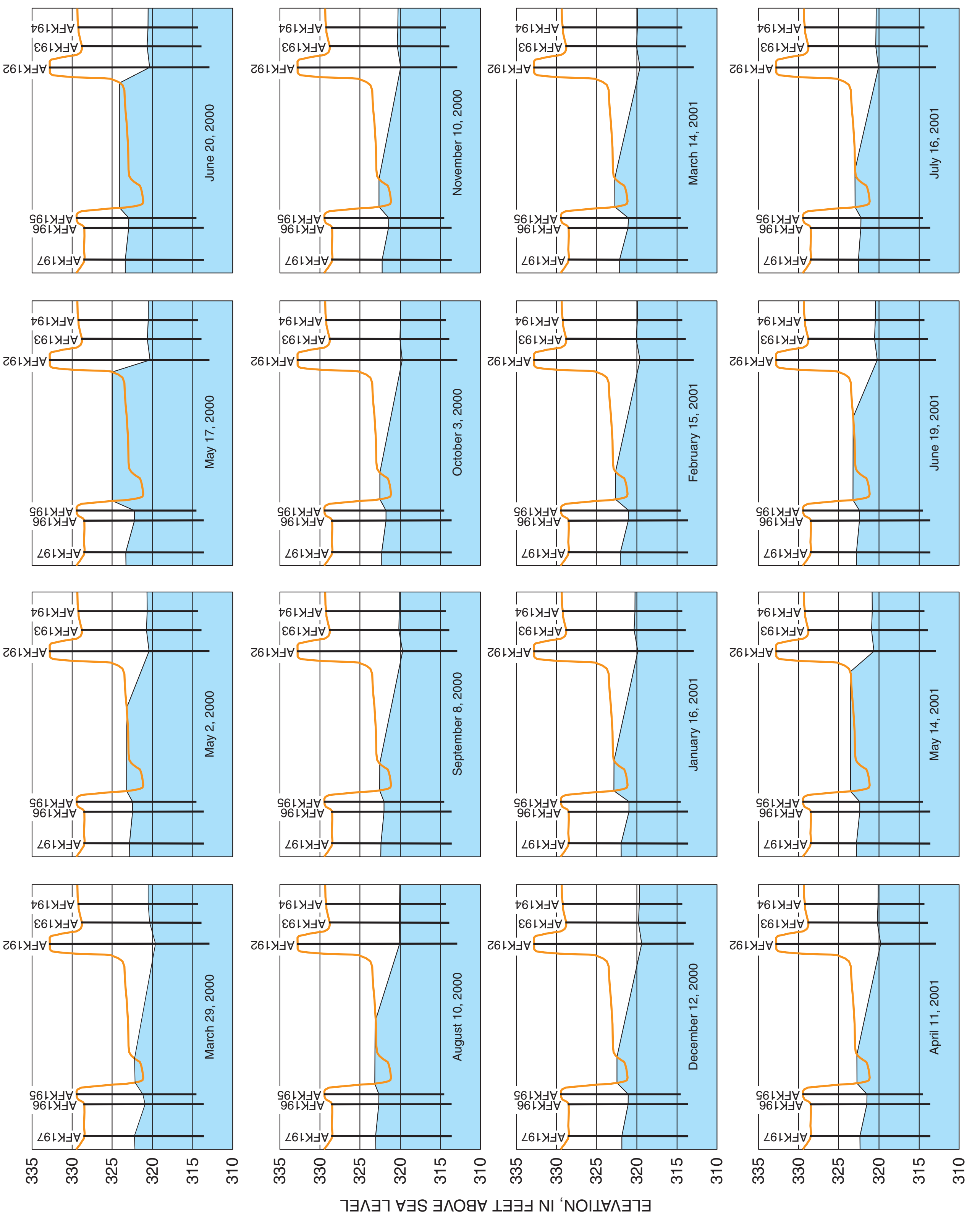


Figure 18. Water-level profiles of the water-table aquifer, constructed from monthly water-level measurements at the Dungeness Meadows off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.

Monitoring wells on the right side of the profile are offset approximately 100 feet downstream from wells on the left side. The water-level data are shown in table 8. A profile for August 1, 2000, is not included because of questionable data.

Reach 3 contained no in-stream mini-piezometers. However, piezometers P7 and P8, installed just beyond the upper and lower ends of the reach, indicated negative hydraulic gradients, supporting the losses observed during the seepage evaluations (fig. 14). Both mini-piezometers consistently exhibited strong negative hydraulic gradients during each of five measurements, and had average gradients of -0.63 and -0.23 ft/ft for piezometers P7 and P8, respectively, suggesting that the river consistently loses water through this reach.

Seepage Reach 4

Seepage reach 4 is approximately 0.8 mile in length and extends from just below the Old Olympic Highway Bridge at river mile 3.7 to just below the Woodcock Road Bridge at river mile 2.9. The active channel of reach 4 tends to be narrower than any of the upstream reaches, despite the absence of bounding levees or flood-control structures. The streambed within this reach is characterized by an abundance of sand, coarse gravel, and small cobbles (Jenifer Bountry, Bureau of Reclamation, Oct. 25, 2001, oral communication).

The seepage-run and mini-piezometer data suggest the occurrence of short, interspersed gaining and losing stream segments throughout reach 4. Net streamflow gains of 12.2 to 21.1 ft^3/s per river mile were observed during two seepage runs of reach 4, whereas the third seepage run showed a net loss of -6.7 ft^3/s per river mile. The largest gain, 16 ft3/s, occurred during the seepage run on April 10-11, 2000, and represented 5.8 percent of the total river flow measured at the upper seepage transect (fig. 13). The smallest gain, 9.3 ft^3/s, occurred during the seepage run on April 12, 2001, and represented about 7 percent of the river flow. A loss of -5.1 ft^3/s was observed during the seepage run on October 4, 2000, and represented about 4.6 percent of the river flow. The relation between seepage rate and river discharge was less clear for reach 4 than it was for reaches 1 and 3 where the river consistently lost water (fig. 15).

The in-stream mini-piezometers within reach 4 (P8-P12) reveal alternating positive and negative gradients over distances of less than a third of a mile (fig. 14). Piezometers P9 and P10 had slight upward gradients ranging from +0.01 to +0.02 ft/ft. Piezometers P8, P11, and P12 had negative gradients ranging from -0.08 to -0.23 ft/ft. The presence of positive and negative gradients in the mini-piezometers over relatively short distances may be attributable in part to locally high ground-water levels in the vicinity. Springs that feed lower Hurd Creek are evidence of near-surface ground water that locally may contribute flow to the Dungeness River through this reach.

Seepage Reach 5

Seepage reach 5 is approximately 2.2 miles long and extends from river mile 2.9, below the Woodcock Road Bridge, to the Schoolhouse Road Bridge at river mile 0.7. Like reach 4, the streambed in reach 5 is composed of relatively fined-grained sand, coarse gravel, and small cobbles. The east side of the river is entirely bounded by a levee, and the west side is partially bounded by a levee and a prominent bluff of glacial outwash. These features restrict the position of the active channel and prevent over-bank deposition of sediment load, resulting in aggradation of the streambed (Jenifer Bountry, Bureau of Reclamation, Oct. 25, 2001, oral communication). At present, the streambed within reach 5 is locally elevated above the adjacent floodplain.

The in-stream mini-piezometer data in reach 5 showed alternating positive and negative gradients (gaining and losing conditions) over distances of less than a third of a mile (fig. 14). Most of the piezometers had negative gradients ranging from -0.02 to -0.40 ft/ft. Piezometers P16, P21, and P23 showed small positive gradients of +0.01 ft/ft. Piezometer P22 changed from negative to positive gradients (-0.04 to +0.01 ft/ft) between September 22, 1999, and May 15, 2001. Piezometer P22 had to be reinstalled during subsequent measurements and showed small positive gradients of +0.01 ft/ft during the last two sampling events (table 4).

The three seepage runs for reach 5 consistently showed net losses ranging from -2.1 to -5.2 ft^3/s per river mile. The largest loss, -11.6 ft^3/s, occurred during the seepage run on April 10-11, 2000, and made up 4 percent of the total river flow measured at the upper seepage transect (fig. 13). The smallest loss, -4.7 ft^3/s, occurred during the seepage run on April 12, 2001, and made up about 2.8 percent of total river flow. There was no consistent relation between seepage rate and river discharge for reach 5 (fig. 14).

Recorded water-level data at the off-stream well transect at Schoolhouse Bridge (fig. 19) shows the same pattern previously described for the Dungeness Meadows well transect (reach 2). River stage declined through the late summer of 2000 and remained relatively low throughout the winter (between precipitation events), and then rose steeply during the snow melt peak in late May of 2001. Ground-water levels in off-stream wells AFK186, AFK187, and AFK188 generally followed the river stage trends caused by snowmelt and remained very close to the same relative altitude as the river during the spring and summer months. However, ground-water levels rose sharply in October 2000 and remained well above the river stage throughout the winter until May, when snowmelt raised the river stage. Spikes on the hydrograph for well AFK186 (fig. 19) were caused by a well construction defect that allowed surface runoff to enter the piezometer during periods of heavy precipitation.

The positive gradients observed in the mini-piezometers (P21 to P25) are supported by the continuous water-level and temperature data from the Schoolhouse Bridge well transect. Ground-water levels in the off-stream wells were consistently higher than the river stage (fig. 19) during the winter and spring and closely matched river stage during the summer and fall. Ground-water temperatures in all the instrumented wells remained nearly constant, irrespective of the river temperature (fig. 20). Together, these data indicate that the river gains water at the transect site, especially during the winter months. The continuous data are further supported by the monthly cross-sectional profiles for the Schoolhouse Bridge transect (fig. 21) that illustrate how ground-water levels react to river stage and seasonal variations. The pattern is similar to figure 12*B*, which shows the typical pattern for a gaining stream reach.

The hydraulic gradient relations observed in the mini-piezometers in reach 5 suggest that the river loses water throughout most of the reach except in the immediate vicinity of Schoolhouse Bridge. The areas of the reach where loss occurs appear to be areas where the streambed is elevated above the floodplain (Jenifer Bountry, Bureau of Reclamation, Oct. 25, 2001, oral communication). The area where gains occur begins upstream of Schoolhouse Bridge near where the levee comes close to the river and the river is underlain by Everson glaciomarine drift (fig. 3). Piezometers P24-P27 are located downstream of the Schoolhouse Bridge and indicate that the gaining conditions observed there extend no more than 300 feet downstream from the Bridge. It is possible that the clay layer observed during installation of the off-stream transect wells at Schoolhouse Bridge acts as a confining layer that impedes ground-water infiltration. Shallow ground water in the sediments along the river butts up against these lower-permeability materials, forcing water to the surface. More-detailed mapping of the clay layer and the water-table configuration in reaches 4 and 5 is needed to understand the complex interactions that occur there.

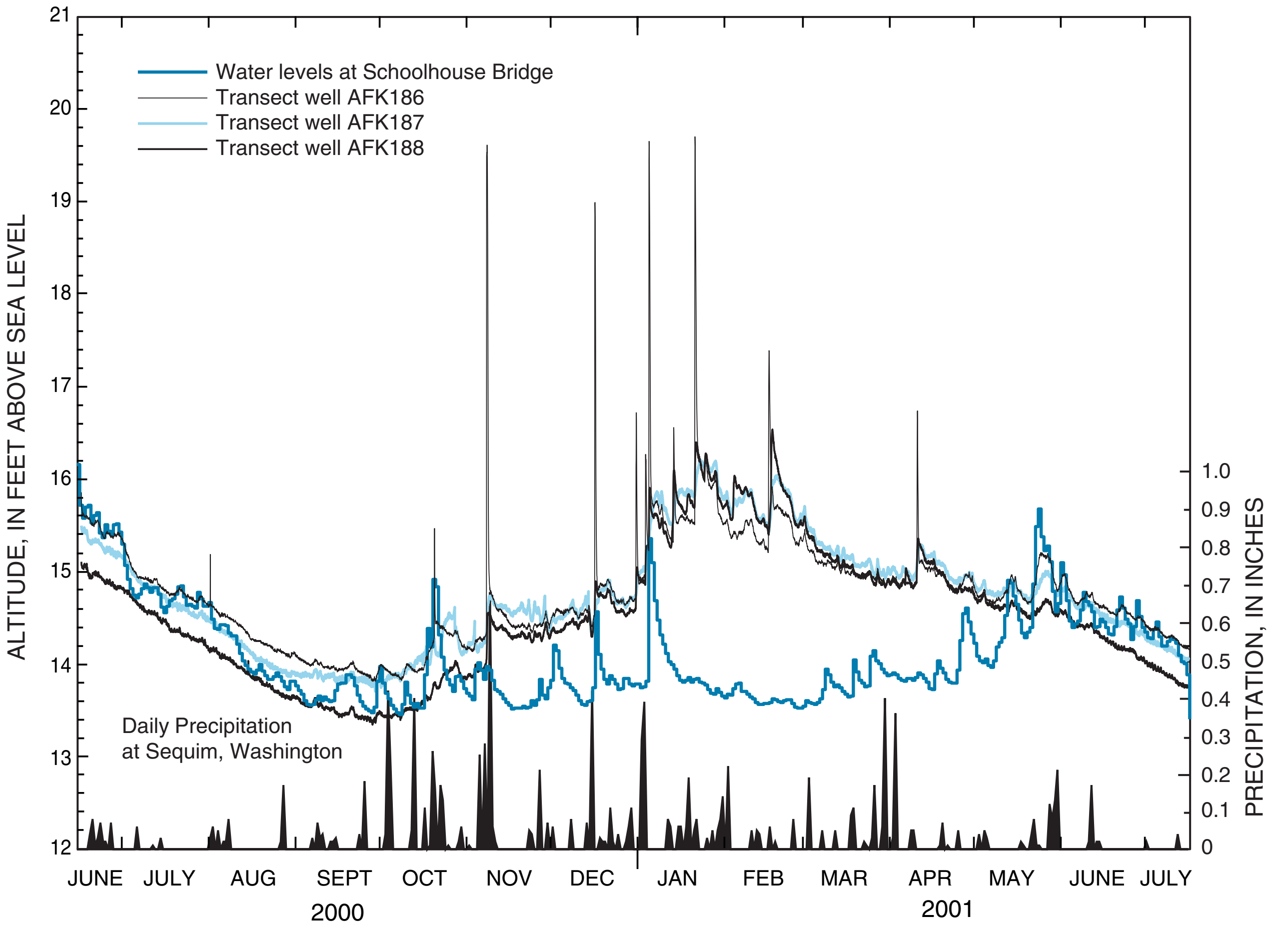


Figure 19. Continuous surface- and ground-water level data collected from June 2000 to July 2001 at the Schoolhouse Bridge off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.

Daily precipitation recorded at the wastewater treatment facility at Sequim, Washington, is shown for comparison. Water-level spikes in monitoring well AFK186 are the result of a construction defect that allowed precipitation to drain into the well casing.

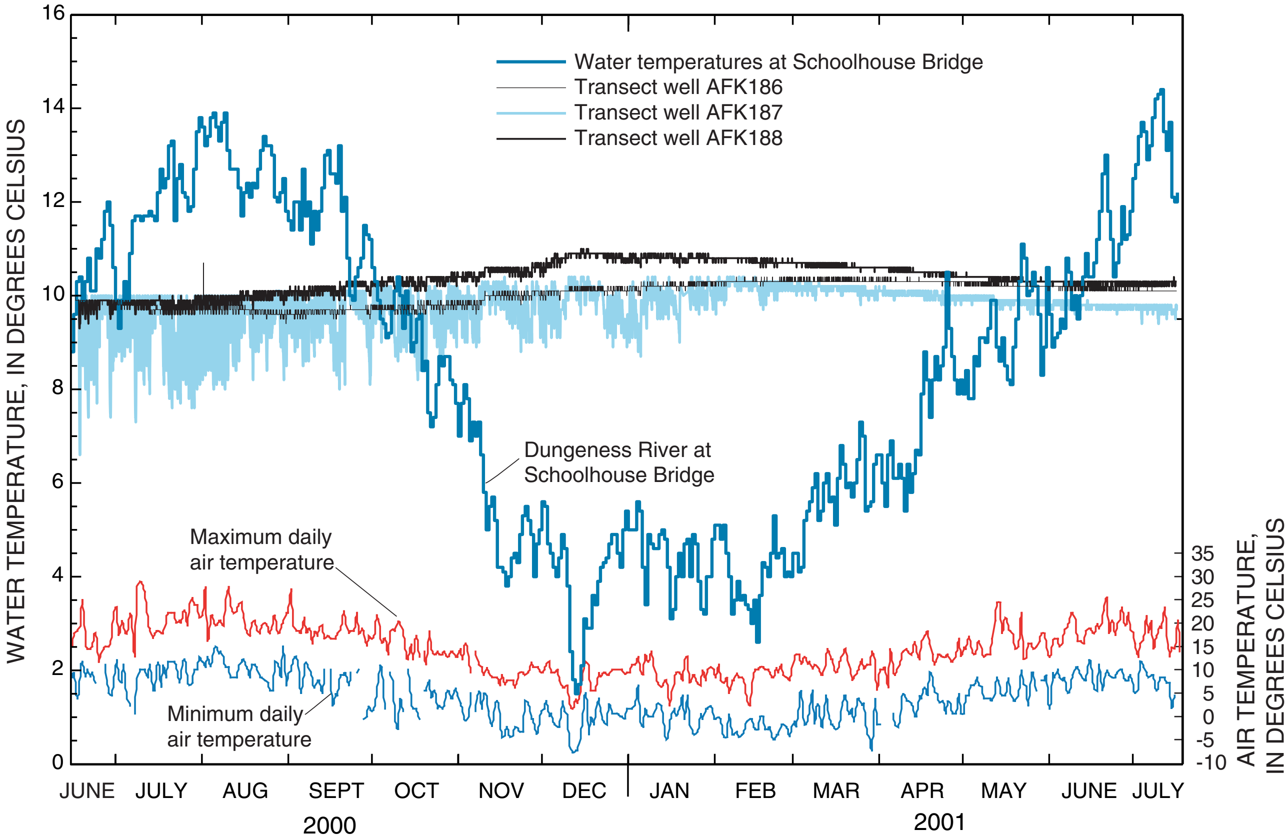


Figure 20. Continuous surface- and ground-water temperature data collected from June 2000 to July 2001 at the Schoolhouse Bridge off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.

Maximum and minimum daily air temperatures recorded at the wastewater treatment facility at Sequim, Washington, are shown for comparison. The wide temperature variations indicated in monitoring well AFK187 are caused by an unstable temperature sensor.

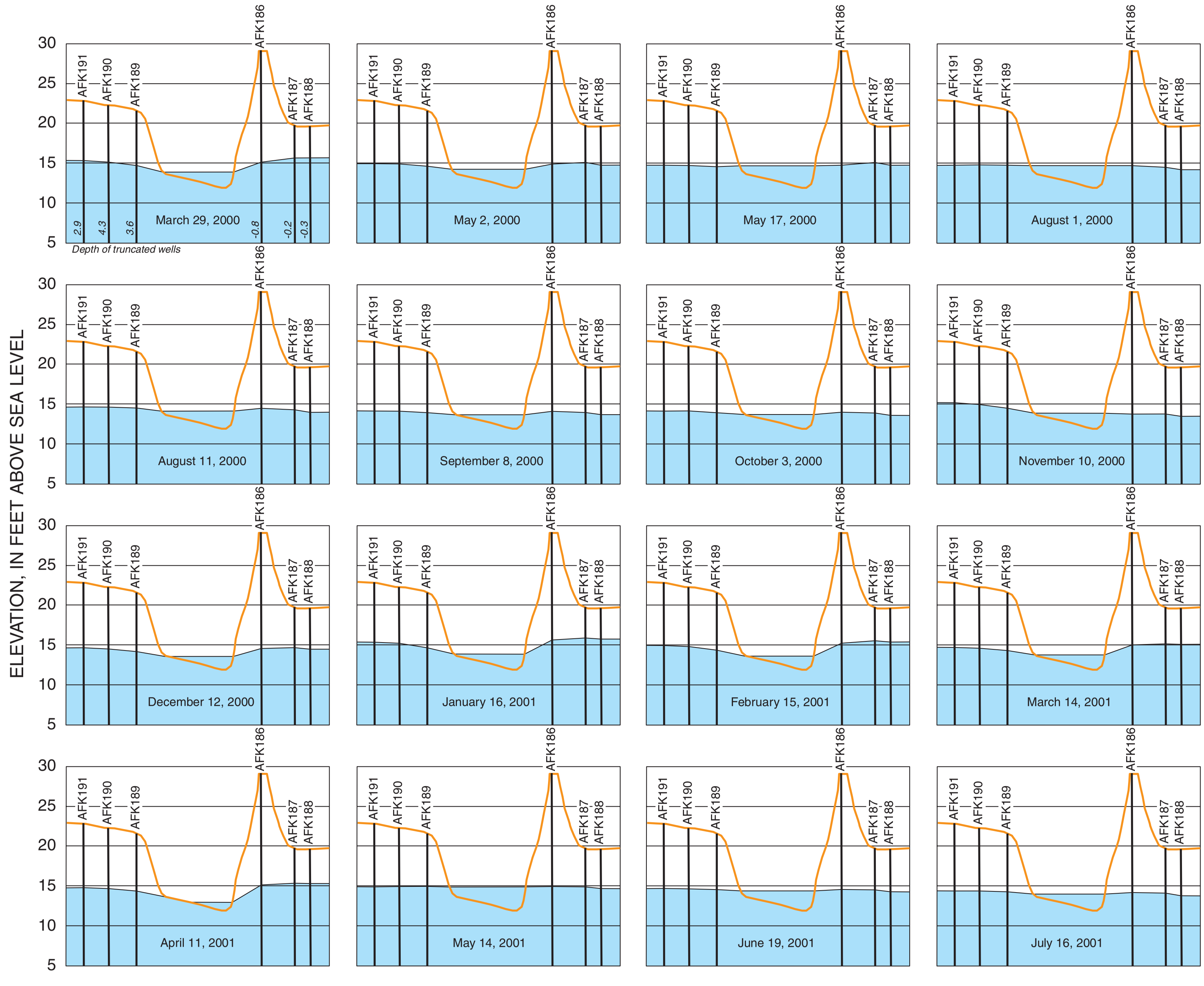


Figure 21. Water-level profiles of the water-table aquifer, constructed from monthly water-level measurements at the Schoolhouse Bridge off-stream well transect on the Sequim-Dungeness peninsula, Clallam County, Washington.

Monitoring wells on the right side of the profile are offset approximately 70 feet downstream from wells on the left side. The water-level data are shown in table 8. A profile for June 16, 2000, is not included because of questionable data.

VERTICAL HYDRAULIC CONDUCTIVITY OF STREAMBED SEDIMENTS

Darcy's law was applied to the mini-piezometer and stream-seepage data from April 10-11, 2001, to estimate average vertical hydraulic conductivity values for the streambed sediments in each of the five seepage reaches. Darcy (1856) demonstrated empirically that the volume rate of discharge (Q) through a porous medium is equal to the product of the hydraulic gradient (I) and the cross sectional area (A) through which water moves, times a constant of proportionality (K), which describes the hydraulic properties of the porous material.

$$Q = -KIA \tag{3}$$

When rearranged to solve for vertical hydraulic conductivity, Darcy's law becomes

$$Kv = -(Q/ Iv\ A)\ , \tag{4}$$

where, in this case,

Kv is the average vertical hydraulic conductivity of the streambed material in a seepage reach (feet/day);

Q is the total volume of water gained or lost by the river between the two transects that define a seepage reach (ft^3/s);

Iv is the average vertical hydraulic gradient between the river and groundwater, as determined from mini-piezometer measurements (dimensionless); and

A is the estimated streambed area across which water exchange occurs (square feet).

For this study the streambed area (*A*) in a seepage reach was calculated by averaging the widths of the upper and lower river transects that defined the seepage reach and then multiplying the average width by the reach length (table 5). The streamflow gain or loss (*Q*) for each seepage reach was the value determined using the mass balance calculations previously described (fig. 13). The average vertical hydraulic gradient (*Iv*) for a reach was determined by averaging the individual gradients for all of the mini-piezometers in the reach. The results of these calculations yield an approximation of the average vertical hydraulic conductivity (*Kv*) for the streambed within the reach (table 5) as represented by the April 2001 data.

In order to use this approach it was necessary to make several simplifying assumptions.

1. Flow between the Dungeness River and water-table aquifer occurs only in the vertical dimension (no horizontal flow component).
2. The net seepage volume (*Q*) is equal to the total volume of water exchanged between the river and the water-table aquifer.
3. The average gradient derived from the mini-piezometer data accurately represents the average vertical hydraulic gradient for the reach.
4. Averaging the upper and lower transect widths provides a good approximation of the average stream width.

The implications of these assumptions and their potential effect on the study results are discussed later in the section "Sources of Uncertainty in Data Collection and Methods Analysis."

Darcy's law was applied to the mini-piezometer and stream seepage data, as previously described, to estimate average vertical hydraulic conductivity values for the streambed sediments in each of the seepage reaches. The streambed conductivity values were generally highest in seepage reaches 4 and 5, at 29 and 8 ft/d respectively, and lowest in reaches 1, 2 and 3, at 2, 1, and 4 ft/d respectively (table 5).

Streambed conductivities in reaches 1, 2, and possibly 3 may be lower than those in reaches 4 and 5 because of the armoring effect of the poorly sorted bedload sediments in this area. Fine-grained materials are carried downward and fill in the voids between the boulders and cobbles. With time, this process may reduce the effective permeability of the streambed. In reaches 4 and 5 the streambed sediments are finer grained and better sorted and thus are less prone to infilling.

Table 5. Characteristics of and calculated average vertical hydraulic gradient and vertical hydraulic conductivity for the study reaches in the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, April 12, 2001

[Seepage run data from table 6, mini-piezometer data from table 4. ft^2, square feet; ft^3/s, cubic feet per second]

Reach desig-nation	Reach designation (by river miles)	Stream reach length		Stream reach width		Average stream width (feet)	Total area of reach (*A*) (ft^2)	Measured gain or loss for reach (*Q*) (ft^3/s)	Average vertical hydraulic gradient (I_V) (dimension-less)	Average vertical hydraulic conductivity (K_V) (feet/day)
		(miles)	(feet)	Upper (feet)	Lower (feet)					
1	11.8 to 8.13	3.67	19,377.6	75	45.2	60.1	1164594	-9.1	-0.28	2
2	8.13 to 5.54	2.59	13,675.2	45.2	49.5	47.35	647521	2.8	-0.51	1
3	5.54 to 3.68	1.86	9,820.8	49.5	59	54.25	532778	-10.4	-0.43	4
4	3.68 to 2.92	0.76	4,012.8	59	92	75.5	302966	9.3	-0.09	29
5	2.92 to 0.71	2.21	11,668.8	92	44	68	793478	-4.7	-0.06	8

Reach Designations (upper to lower transect)

Reach 1: USGS streamgaging station to Dungeness Meadows

Reach 2: Dungeness Meadows to Dungeness at Railroad Bridge

Reach 3: Dungeness at Railroad Bridge to Dungeness at Old Olympic Highway

Reach 4: Dungeness at Old Olympic Highway to Dungeness below Woodcock Road

Reach 5: Dungeness below Woodcock Road to Dungeness at Schoolhouse Bridge

The values determined during this study (1 - 29 ft/d) are reasonable for coarse alluvium and compare favorably with the general range of values (0.03 to 283 ft/d) found during similar river studies (Calver, 2001). These conductivity values represent only order-of-magnitude estimates for relatively long reaches of the river. The conductivity at any specific location within a reach may vary considerably from the average values presented here.

SOURCES OF UNCERTAINTY IN DATA COLLECTION AND METHODS OF ANALYSIS

Each of the field techniques and analysis methods used during this study has respective strengths and weaknesses. No single technique or analysis method can uniquely quantify the distribution, timing, volume, and rate of water exchange between a river and ground water. The use of multiple techniques, as was done here, helps to increase confidence in the collected data. Knowledge of the inherent uncertainty in each of the techniques becomes especially important when assigning confidence to data or combining the data and results from two or more techniques. In the sections that follow, the advantages, disadvantages, and sources of uncertainty are discussed for each of the field techniques and analysis methods used during this study.

In-Stream Mini-Piezometers

In comparison to the other field methods, mini-piezometers are inexpensive and relatively easy to deploy. They are especially useful for initial reconnaissance, verifying seepage-run results, and optimizing the locations of seepage reach extents. When properly used, a manometer board is capable of accurately measuring the differences in head (in the 0.03- to 3-foot range) that represent the hydraulic gradient at a point location in the streambed.

In-stream mini-piezometers that were installed close together showed similar head differences during this study. This suggests (for this study at least) that the vertical hydraulic gradient between the river and ground water did not vary greatly over distances of a few hundred feet or less. In addition, hydraulic gradients in the original mini-piezometers did not change much over the course of the study (see table 4 and table 6, at back of report). Plots of the calculated hydraulic gradient verses river mile (fig. 22) illustrate how the magnitude of the gradient varied slightly over time but remained consistent with regard to direction. The one exception is piezometer P22, which reversed from a negative to positive gradient on April 11, 2001, before it was destroyed. Subsequent measurements at site P22 were made using a new piezometer installed at a shallower depth and indicated consistent upward flow.

The major disadvantage of in-stream mini-piezometers is that, individually, they provide information for only one point within the streambed. Thus, many mini-piezometers are required to adequately characterize the longitudinal distribution and sign (positive or negative) of streambed hydraulic gradients. The manometer board is not good at measuring small head differences (in the 0 to 0.03-foot range), and care must be taken to ensure a good seal around the mini-piezometer so that a head difference can be measured. The question of whether the mini-piezometer is measuring flow within the streambed material (hyporheic flow) or ground-water flow can be addressed by comparing temperature and specific conductivity from the mini-piezometer with that of the river (Winter and others, 1999). Ground water, particularly in gaining reaches, can have temperature and specific conductance values that differ greatly from the river. In losing reaches the temperature and specific conductance from the mini-piezometer can be similar to the river.

Seepage Runs

Seepage runs are labor intensive and expensive to conduct, but provide estimates of the net gain or loss across larger reaches of the river (0.8 to 3.7 miles in this case). Because they provide only net estimates of water exchange, seepage evaluations reveal nothing about the distribution of local gains or losses that may occur within a seepage reach. Care must be taken in defining the reach boundaries. Ideally, the seepage-measurement transects should coincide with gaining and losing reach boundaries and all inflows and outflows within the reach should be accounted for. The seepage-measurement transects also should be far enough apart that the measured fluxes exceed the inherent measurement error.

Although duplicate discharge measurements are conducted to ensure precision, the uncertainty in seepage evaluations can be significant if the stream discharge is large compared to the loss or gain in seepage along the stream reach. The inherent error in a good discharge measurement in a natural river environment is estimated to be ± 3 percent (Rantz and others, 1982). Thus, the calculated seepage over a reach could range considerably. The range of seepage rates can be narrowed, however, by applying the findings from other techniques. Head relations from mini-piezometers and off-stream well transects provide additional data that help reduce uncertainty in seepage rates at the time of measurement.

The disadvantage of seepage runs, particularly on the Dungeness River, is that good measurement sites are few and far between. Wading discharge measurements become dangerous to impossible at river flows of 350 ft^3/s or higher. Thus, seepage runs cannot be conducted at high flows, and the relation between seepage rate and river discharge cannot be confirmed.

Off-Stream Well Transects

Off-stream well transects are an expensive but reliable technique for gathering ground-water data adjacent to the river. Continuous ground-water levels from multiple wells along the transect yield a wealth of information when compared with nearby surface-water stage data or the data from in-stream mini-piezometers (figs. 16 and 19). An attempt was made to compare observed ground-water levels with analytical model simulations in order to calculate hydraulic properties of the aquifer and stream bank and to estimate seepage rates and bank-storage volumes resulting from flood waves (Barlow and others, 2000). Unfortunately, this analytical technique did not yield conclusive results.

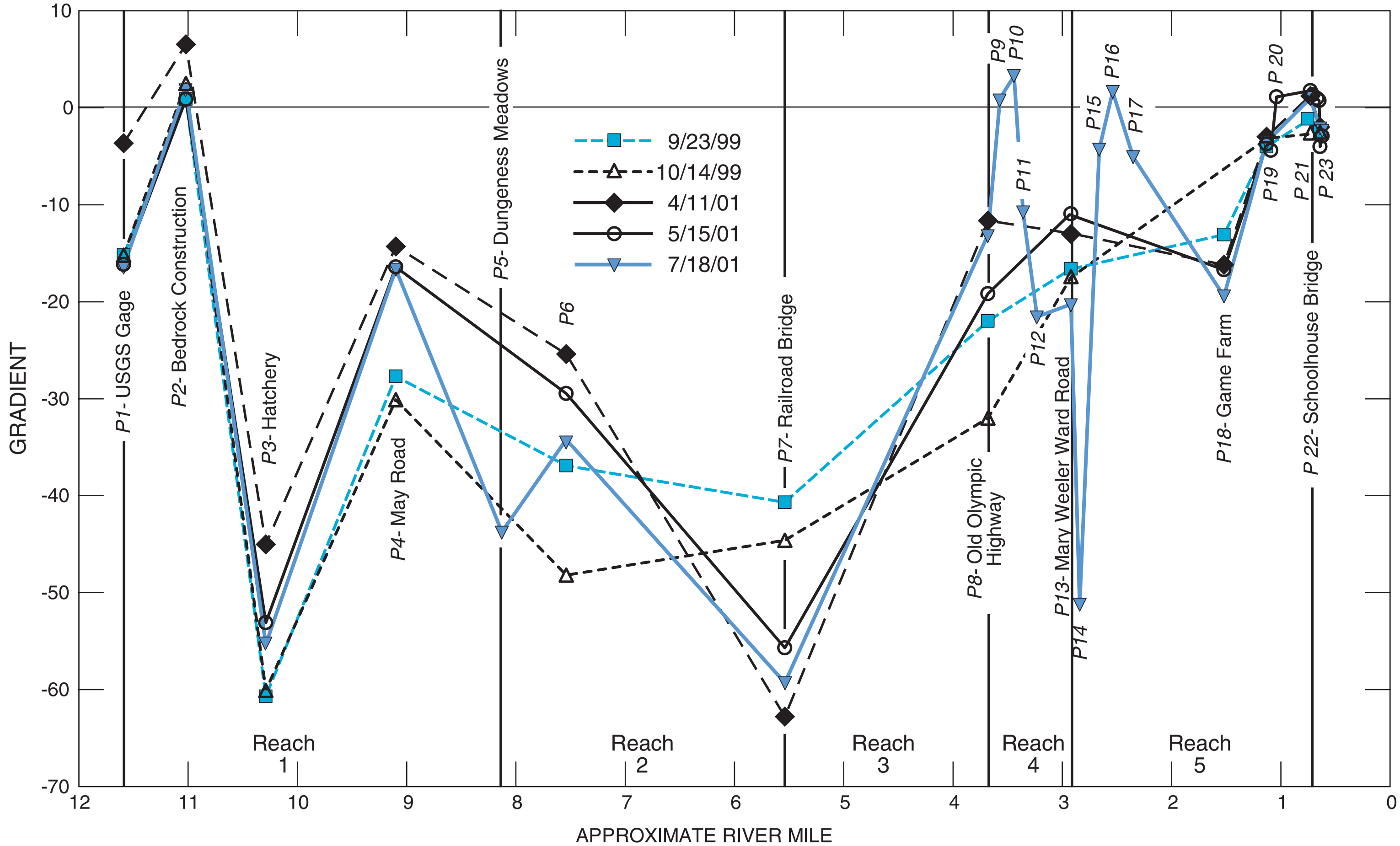


Figure 22. Comparison of vertical hydraulic gradient between the river and ground water at the in-stream mini-piezometer sites along the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington.

Vertical hydraulic gradients were calculated from measurements made between September 1999 and July 2001. Locations of the mini-piezometer sites are shown on figures 2 and 7 and the data are shown in table 4.

The fact that ground-water flow directions are parallel to the river at both transect sites introduced an unacceptable level of uncertainty in the Barlow model. An attempt also was made to use temperature data (figs. 17 and 20) to estimate ground-water flow directions and fluxes using the techniques developed by Constantz and others (1999). Although the direction of ground-water flow could be determined from the data, the lack of vertical hydraulic head and temperature data prevented the calculation of flux using temperature as a tracer.

One disadvantage of off-stream well transects is that installation typically requires site access by a truck-mounted drill rig, which can limit the possible locations for the transect. Check measurements need to be made to verify that the recorded data are accurate and to quantify the small amount of instrument drift that can occur. Like the mini-piezometers, the well transects provide information only for a single transect within a reach.

Calculation of Streambed Hydraulic Conductivity Values

Uncertainties in the in-stream mini-piezometer data and seepage run data are compounded when the data are combined to estimate streambed vertical hydraulic conductivity. Additional uncertainty is introduced by the assumptions that are used to simplify the calculations. The assumption that there is no horizontal exchange of flow between the streambed and water-table aquifer is contrary to what is seen in the off stream well transects. What is not known is which component of flow is dominant, horizontal or vertical. Due to the anisotrophic nature of aquifer materials, in most cases, horizontal ground-water flow is assumed to be 5 to 10 times that of vertical flow. The calculated vertical hydraulic conductivities (1-29 ft/d) would suggest horizontal conductivities of 5 to 290 ft/d; values similar to those reported by Thomas and others (1999).

The representativeness of point measurements of vertical hydraulic gradients within a given reach is another source of uncertainty. Although there are other ways of statistically weighting individual point measurements, in this study, point measurements were simply averaged within a given stream reach. Multiple measurements at in-stream mini-piezometers indicated slight variations in the magnitude of vertical gradients but no changes in the direction of flow (fig. 22).

The assumption that the net seepage volume (Q) is equal to the total volume of water exchanged between the river and the water-table aquifer is more problematic. In reach 5, for example, which contains both gaining and losing stretches, for net exchange to be negative, losing stream segments must lose more water than is gained through gaining segments. Thus, actual gross gains could be large if they were offset by large losses. Such large gains or losses, however, were not evident at the points where the in-stream mini-piezometers were located.

To assess the impact of these uncertainties a sensitivity analysis was conducted. Vertical streambed hydraulic conductivities were calculated while varying the average vertical hydraulic gradient (Iv), the net seepage volume (Q), and the total area of the reach (A) within reasonable limits. The sensitivity analysis resulted in a relatively small range of calculated vertical streambed hydraulic conductivities. The sensitivity analysis suggests that although there are many uncertainties and sources of inherent error when using Darcy's law with in-stream mini-piezometer and seepage-run data, the results represent reasonable order-of-magnitude estimates of vertical hydraulic conductivities for the streambed of the lower Dungeness River.

In this study, it was useful to view data from in-stream mini-piezometers, seepage runs, and off-stream well transects together. The results of each of these techniques are complimentary and provide a more complete perspective of water exchange than could be derived from the methods individually.

SUMMARY AND CONCLUSIONS

Three field techniques were used during this study to evaluate and document surface-water and ground-water interactions along the lower 11.8 miles of the Dungeness River corridor. Mini-piezometers were driven into the active stream channel at 27 locations along the river and provided point estimates of the vertical hydraulic gradient and the direction of water movement into or out of the river. Seepage runs were used to quantify net water exchanges between the river and ground water within five seepage reaches. Continuous water-level and water-temperature monitoring at two off-stream well transects provided horizontal hydraulic gradient information and revealed temporal patterns of water exchange within a representative gaining and losing stream reach.

Results for seepage reaches 1 and 3 (river miles 11.8-8.1 and 5.5-3.7) reveal that the river consistently lost water, with the exception of a short segment near river mile 11.0. There, the river is narrowly confined by a bedrock constriction that locally forces ground water into the river. Vertical hydraulic gradients in the mini-piezometers within these reaches generally decreased in the downstream direction from an average of -0.86 at river mile 10.3 to -0.23 at river mile 3.7. Repeat measurements of the piezometers at different times and flow conditions yielded some variation in the gradient estimates, but produced consistent results with regard to gradient direction. Net seepage losses through reach 1 confirmed the piezometer results and ranged from 2.1 to 4.1 ft^3/s per /river mile and made up 4.6 to 5.9 percent of the total river flow. Seepage losses for reach 3 ranged from 0.54 to 12.8 ft^3/s per river mile and made up between 1 and 8 percent of total river flow. The rate of water loss in reaches 1 and 3 appears to be correlated with river discharge and increases with increasing streamflow.

Seepage results for reach 2 (river miles 8.1 to 5.5) ranged from 0.23 to 3.5 ft^3/s per river mile and made up about 0.5 to 3 percent of total river flow. These results contradict the gradients observed in the mini-piezometers, which ranged from -0.39 to -0.63 ft/ft through reach 2. The reasons for this discrepancy are not well understood. However, ground-water levels at an off-stream well transect within this reach (near Dungeness Meadows) were consistently below the river stage and support the mini-piezometer results.

The mini-piezometer and seepage run data suggest the presence of small gaining and losing stream segments within the broader context of reach 4 (river miles 3.7 to 2.9). Net seepage between the river and ground water varied from -6.7 to 21.1 ft^3/s per river mile and made up 4.6 and 5.8 percent of total river flow, respectively, within reach 4. Piezometers P9 and P10 (river miles 3.57 and 3.44 respectively) exhibited positive gradients ranging from +0.01 to +0.02 ft/ft. Piezometers P8, P11, and P12 (river miles 3.68, 3.36, and 3.23) exhibited negative gradients ranging from -0.08 to -0.23 ft/ft.

Seepage reach 5 (river miles 2.9 to 0.7) showed a continuation of the interspersed gains and losses observed within reach 4. The seepage runs for reach 5 consistently showed net losses ranging from -2.1 to -5.2 ft^3/s per river mile and made up 2.8 to 4 percent of total river flow. Most of the mini-piezometers in reach 5 confirmed these results and exhibited negative hydraulic gradients ranging from -0.01 to -0.04 ft/ft. Piezometers P16, P21, and P23 (river miles 2.54,1.04, and 0.71, respectively) had consistently positive but small gradients of approximately +0.01 ft/ft, suggesting localized areas of stream flow gain. Localized zones of ground-water discharge to the river are confirmed by data collected at the off-stream well transect near Schoolhouse Bridge, where ground-water levels were consistently higher than the river stage.

In addition to providing a convenient means of verifying the mini-piezometer results, the off-stream well transects provide continuous water-level and water-temperature data that can be used to evaluate how near-stream ground-water levels respond to snow melt and precipitation. Ground-water levels at both transects increased during sustained periods of high river stage (such as spring snow melt), regardless of the overall streamflow gain/loss relation for the reach. At the Dungeness Meadows transect, where losing conditions prevailed, ground-water levels closely resembled river stage but remained at a lower relative altitude than the river throughout the study. As expected, ground-water temperatures in the well nearest the river closely tracked the river temperature. This effect decreased with distance from the river.

At the Schoolhouse Bridge well transect, where ground water discharges into the river, ground-water levels also followed the river stage trends caused by snow melt. However, ground-water levels rose sharply in the fall and remained well above the river stage throughout the winter months. Ground-water temperatures at the Schoolhouse Bridge transect remained nearly constant (about 10 degrees C) and were relatively unaffected by variations in river temperature. Ground-water temperatures did not peak in the transect wells until early October (at Dungeness Meadows) and mid December (at the Schoolhouse Bridge), long after the early August peak in river temperatures. The greater lag time at Schoolhouse Bridge may be due to the low hydraulic conductivity of the clay layer that underlies the site.

Average vertical hydraulic conductivity values for the streambed sediments within the five seepage reaches ranged from 1 to 29 feet per day (ft/d). Streambed conductivity values were highest in reaches 4 and 5, where values ranged from 29 to 8 ft/d, and lowest in reaches 1, 2, and 3, where values ranged from 2, 1, and 4 ft/d. The streambed conductivity values determined during this study compare favorably with the general range of values (0.03 to 283 ft/d) found during similar studies. The reported values represent order-of-magnitude estimates for relatively long reaches of the river. The conductivity at any particular location along the river may vary considerably from the average values presented here.

Each of the data collection and analysis techniques used during this study is subject to various degrees of uncertainty. Thus, none of the techniques or analysis methods can uniquely quantify surface-water and ground-water exchanges. Using multiple techniques, as was done during this study, provides several lines of evidence upon which to base findings, and provides greater certainty to those anticipating subsequent data analysis and modeling exercises.

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Tables 6 through 8

Table 6. Data collected during the mini-piezometer surveys on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, September 1999 to July 2001

[μS/cm@25^{o}C, Specific conductance in microsiemens per centimeter temperature compensated for 25 degrees Celsius; (^{o}C), degrees Celsius; NA, data not recorded; positive vertical hydraulic gradients in **bold** type]

Piezometer (see fig. 2 for location)	Measurement date	Time	Temperature (^{o}C)		Specific conductance (μS/cm@25^{o}C)		Piezometer depth with E-tape (ft)	River stage with E-tape (ft)	Head difference with E-tape (ft)	Average head difference with manometer board
			River	Ground water	River	Ground water				
P1	09/22/99	NA	NA	NA	113	135	NA	NA	NA	-0.50
P2	09/22/99	1436	NA	NA	117	NA	NA	NA	NA	0.03
P3	09/23/99	1338	10.3	NA	114	115	NA	NA	NA	-1.99
P4	09/23/99	1302	9.7	NA	118	119	NA	NA	NA	-0.91
P6	09/22/99	924	11.9	10.1	115	118	2.42	1.15	-1.27	-1.21
P7	09/22/99	1500	NA	NA	NA	117	NA	NA	NA	-1.34
P8	09/22/99	1055	13.7	NA	116	117	NA	NA	NA	-0.72
P13	09/22/99	1126	10.4	118	119	NA	NA	NA	NA	-0.55
P18	09/22/99	1338	NA	NA	117	122	NA	NA	NA	-0.43
P19	09/22/99	1000	NA	NA	124	127	NA	NA	NA	-0.13
P22	09/24/99	0945	14.1	NA	122	140	NA	NA	NA	-0.03
P26	09/22/99	1130	9.4	10.6	126	160	NA	NA	NA	-0.08
P1	10/14/99	1045	6.1	7.2	130	144	NA	NA	NA	-0.51
P2	10/14/99	1145	6.4	8.8	130	136	NA	NA	NA	0.08
P3	10/14/99	1216	6.6	7.1	131	131	NA	NA	NA	-1.97
P4	10/14/99	1252	7.8	8.3	131	133	NA	NA	NA	-0.99
P6	10/14/99	1330	8.2	8.4	132	132	NA	NA	NA	-1.58
P7	10/14/99	1503	9.6	11.8	132	132	NA	NA	NA	-1.46
P8	10/14/99	1542	9.7	8.9	132	133	NA	NA	NA	-1.05
P13	10/14/99	1618	9.7	8.8	132	132	NA	NA	NA	-0.57
P19	10/14/99	1700	9.8	NA	138	NA	NA	NA	NA	-0.09
P22	10/13/99	1447	NA	NA	NA	NA	NA	NA	NA	-0.09
P26	10/13/99	1536	9.8	NA	139	NA	NA	NA	NA	-0.08
P1	04/12/01	1200	NA	NA	NA	NA	2.34	2.22	-0.12	-0.12
P2	04/11/01	1345	5.1	6.1	152	170	4.32	4.45	**0.13**	0.21
P3	04/11/01	1440	5.5	5.6	142	142	5.21	3.7	-1.51	-1.48
P4	04/11/01	1548	6.6	6.5	148	150	NA	NA	NA	-0.47
P6	04/11/01	1730	7.1	4.4	149	149	NA	NA	NA	-0.83
P7	04/13/01	1045	5	5.7	80	100	NA	NA	NA	-2.06
P8	04/11/01	1920	7.8	7.1	150	150	2.78	2.27	-0.51	-0.38
P13	04/11/01	1830	8.8	5.6	149	149	2.15	1.73	-0.42	-0.43
P18	04/13/01	0918	4.5	5.7	90	100	NA	NA	NA	-0.53
P19	04/12/01	1807	8	7.5	100	100	NA	NA	NA	-0.10
P22	04/11/01	1745	10.2	6.9	100	110	NA	NA	NA	0.04
P26	04/11/01	1600	10.1	7	90	100	NA	NA	NA	-0.07

Table 6. Data collected during the mini-piezometer surveys on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, September 1999 to July 2001—*Continued*

Piezometer (see fig. 2 for location)	Measurement date	Time	Temperature (°C)		Specific conductance (µS/cm@25°C)		Piezometer depth with E-tape (ft)	River stage with E-tape (ft)	Head difference with E-tape (ft)	Average head difference with manometer board
			River	Ground water	River	Ground water				
P1	05/14/01	1410	7.4	6.9	98	155	2.04	1.51	-0.53	-0.53
P2	05/14/01	1200	7.5	6.8	99	162	3.5	3.55	**0.05**	0.03
P3	05/14/01	1550	7.5	7.5	99	103	4.81	3	-1.81	-1.74
P4	05/14/01	1200	7.8	7.8	101	102	NA	NA	NA	-0.54
P6	05/14/01	1155	8.3	8.5	101	103	2.65	1.53	-1.12	-0.97
P7	05/14/01	1715	8.5	8.6	103	114	2.84	1.04	-1.8	-1.83
P8	05/14/01	1200	8.8	8.9	104.2	105	2.26	1.68	-0.58	-0.63
P13	05/14/01	1830	8.8	8.7	105	117	1.55	1.2	-0.35	-0.36
P18	05/15/01	1200	10.8	9.4	109	110	1.49	0.95	-0.54	-0.55
P19	05/15/01	1310	10	8.8	109	133	1.05	0.94	-0.11	-0.12
P20	05/15/01	1345	10.3	9.2	110	123	1.4	1.3	-0.1	-0.14
P21	05/15/01	1420	10.7	9.1	111	171	1.26	1.3	**0.04**	0.04
P22	05/14/01	1950	8.9	8.5	109	155	0.87	0.93	**0.06**	0.06
P23	05/15/01	1200	8.1	9	111	163	0.67	0.73	**0.06**	0.04
P24	05/15/01	1045	8.5	8.3	111	168	1.09	1.15	**0.06**	0.03
P25	05/15/01	1130	8.8	8.8	111	169	NA	NA	NA	0.02
P26	05/15/01	0910	7.8	8.4	110	177	0.55	0.5	-0.05	-0.13
P27	05/15/01	1235	9.3	9.4	111	118	1.77	1.68	-0.09	-0.10
P1	07/17/01	1720	10.2	10.2	114	132	NA	NA	NA	-0.46
P2	07/17/01	1820	10.2	9.1	115	132	NA	NA	NA	0.07
P3	07/17/01	1750	10.5	10.5	116	115	NA	NA	NA	-1.82
P4	07/17/01	1900	10.9	11.2	116	116	NA	NA	NA	-0.55
P5	07/18/01	1700	13.5	11.6	119	117	NA	NA	NA	-1.44
P6	07/17/01	1935	11.3	11	117	116	NA	NA	NA	-1.12
P7	07/18/01	1535	13.6	12.3	120	118	NA	NA	NA	-1.95
P8	07/17/01	1230	11.5	11.6	116	115	NA	NA	NA	-0.43
P9	07/17/01	1300	11.5	12.1	116	119	NA	NA	NA	0.03
P10	07/17/01	NA	11.8	9.1	116	130	NA	NA	NA	0.11
P11	07/17/01	NA	12.5	12.1	116	121	NA	NA	NA	-0.35
P12	07/17/01	1500	12.8	12.2	116	116	NA	NA	NA	-0.71
P13	07/17/01	NA	10.8	12.2	116	114	NA	NA	NA	-0.67
P14	07/17/01	NA	11	12.5	116	115	NA	NA	NA	-1.68
P15	07/17/01	NA	11.1	13.1	116	113	NA	NA	NA	-0.14
P16	07/17/01	NA	11.3	12.8	116	118	NA	NA	NA	0.07
P17	07/17/01	1130	11.4	11.9	116	115	NA	NA	NA	-0.17
P18	07/18/01	1240	12.3	12.6	120	117	NA	NA	NA	-0.64
P19	07/18/01	1445	13.6	12.3	125	126	NA	NA	NA	-0.12
P22	07/18/01	1806	14.9	12.5	126	129	NA	NA	NA	0.03
P26	07/18/01	1330	12.5	11.8	125	158	NA	NA	NA	-0.06
P27	07/18/01	NA	12.5	13	125	124	NA	NA	NA	-0.08

Table 7. Data collected during the seepage runs on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, April and October 2000 and April 2001

[Computed gain/loss: Computed using all average discharges from the start of a seeepage reach (bold) through the end of the reach (next bold). ft^3/s, cubic feet per second; ^oC, degrees Celsius; µS/cm@25^{o}C, microsiemens per centimeter at 25 degrees Celsius; USGS, U.S. Geological Survey; NA, data not recorded]

River mile	Altitude (feet above sea level)	Station name	Map symbol	Date	Time	Staff gage reading	Measured discharge (ft^3/s)	Percent difference from mean	Temperature (^oC)	Specific conductance µS/cm@ 25^{o}C	Average discharge	Computed Gain (+) Loss (-)
						APRIL 2000						
11.8	**569**	**Dungeness River at USGS Gage**	**S1**	**4/11/00** **4/11/00**	**9:30** **10:12**	**NA** **NA**	**328.4** **323.8**	**1.41**	**5.5**	**90**	**326.1**	
11.2	525	Canyon Creek	S2	4/10/00 4/11/00	13:40 13:28	NA NA	8.96 8.27	8.01	7.2	115	8.615	
10.9	500	Agnew Ditch below fish screen	S3	4/10/00 4/11/00	17:10 13:31	NA NA	10.52 11.47	8.64	NA	NA	10.995	**-15.1**
10.7	490	Highland Ditch above first split	S4	4/11/00 [1]4/11/00	12:00 12:00	NA NA	5.77 5.77	0.00	NA	NA	5.77	
8.1	**380**	**Dungeness River at Dungeness Meadows**	**S5**	**4/11/00** **4/11/00**	**9:55** **11:41**	**NA** **NA**	**298.18** **307.59**	**3.11**	**8.3**	**124**	**302.885**	
7.7	310	Independent Ditch	S6	4/11/00 4/11/00	14:05 14:40	NA NA	3.33 3.11	6.83	9.1	124	3.22	
7.3	285	Clallam-Cline-Dungeness Ditch	S7	4/10/00 4/11/00	16:00 16:40	NA NA	8.28 8.97	8.00	9.3	125	8.625	+9.2
6.8	250	Bear Creek	S8	4/10/00 4/11/00 4/11/00	15:00 10:30 11:30	NA NA NA	1.16 1.1 1.13	5.38	NA	NA	1.115	
6.4	235	Sequim Prairie Ditch	S9	4/11/00 4/11/00	9:20 10:20	NA NA	3.55 3.58	0.84	NA	NA	3.565	
5.5	**190**	**Dungeness River at Railroad Bridge**	**S10**	**4/11/00** **4/11/00**	**13:45** **15:50**	**NA** **NA**	**297.16** **298.36**	**0.40**	**9.7**	**127**	**297.76**	**-23.9**
3.7	**105**	**Dungeness River at Old Olympic Highway**	**S11**	**4/11/00** **4/11/00**	**15:20** **16:40**	**NA** **NA**	**274.11** **273.68**	**0.16**	**NA**	**NA**	**273.895**	**+16.0**
2.9	**70**	**Dungeness River below Woodcock Bridge**	**S12**	**4/11/00** **4/11/00**	**9:45** **13:30**	**NA** **NA**	**291.24** **288.57**	**0.92**	**6.1**	**127**	**289.905**	
2.6	50	Hurd Creek	S13	4/10/00 4/11/00	16:45 11:15	NA NA	4.61 5.09	9.90	NA	NA	4.85	
1.8	27	Matriotti Creek	S14	4/10/00 4/11/00 [2]4/10/00 [2]4/10/00 [2]4/10/00 [2]4/10/00	13:00 13:15 15:55 16:20 16:15 16:18	NA NA NA NA NA NA	12.38 12.69 14.56 16.56 15.88 15.2	2.47	12.5	209	12.535	**-11.6**
0.71	**15**	**Dungeness River at School House Bridge**	**S15**	**4/11/00** **4/11/00**	**9:30** **11:20**	**NA** **NA**	**292.39** **298.97**	**2.23**	**8.6**	**132**	**295.68**	

Table 7. Data collected during the seepage runs on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, April and October 2000 and April 2001—*Continued*

River mile	Altitude (feet above sea level)	Station name	Map symbol	Date	Time	Staff gage reading	Measured discharge (ft^3/s)	Percent difference from mean	Temperature (^oC)	Specific conductance μS/cm@ 25^oC	Average discharge	Computed Gain (+) Loss (-)
						OCTOBER 2000						
11.8	569	Dungeness R. at USGS Gage	S1	10/4/00	8:37	2.65	135	0.00	7.3	NA	135	
				10/4/00	9:15	2.65	135					
11.2	525	Canyon Creek	S2	10/4/00	11:30	NA	1.817	2.98	NA	NA	1.8445	
				10/4/00	12:01	NA	1.872					
10.9	500	Agnew Ditch below fish screen	S3	10/4/00	12:28	0.53	4.43	2.01	NA	NA	4.475	-8.0
				10/4/00	13:04	0.53	4.52					
10.7	490	Highland Ditch above first split	S4	10/3/00	14:15	0.70	3.62	0.83	NA	NA	3.635	
				10/4/00	12:15	0.69	3.65					
8.1	380	Dungeness R. at Dungeness Meadows	S5	10/4/00	9:22	NA	121.1	0.60	NA	NA	120.735	
				10/4/00	10:00	NA	120.37					
7.7	310	Independent Ditch pre-return flow	S6	10/4/00	11:18	NA	8.54	0.00	NA	NA	8.54	
				10/4/00	12:05	NA	8.54					
		Independent Ditch (actual diversion)		10/4/00	13:30	23.75	0.89	2.22	NA	NA	0.9	
				10/4/00	14:10	23.75	0.91					
7.3	285	Clallam-Cline-Dungeness Ditch	S7	10/4/00	11:45	0.61	5.32	3.05	NA	NA	5.24	+0.6
				10/4/00	NA	0.61	5.16					
6.8	250	Bear Creek	S8	10/4/00	15:45	NA	0.28	0.00	NA	NA	0.28	
				10/4/00	15:58	NA	0.28					
6.4	235	Sequim Prairie Ditch	S9	10/4/00	9:20	71.95	3.92	4.73	NA	NA	4.015	
				10/4/00	NA	71.95	4.11					
5.5	190	Dungeness R. at Railroad Bridge	S10	10/4/00	8:45	NA	105.87	10.08	NA	NA	111.49	
				10/4/00	10:00	NA	117.11					
3.7	105	Dungeness R. at Old Olympic Highway	S11	[3]10/4/00	9:00	NA	105.52	6.20	NA	NA	108.895	-1.1
				[3]10/4/00	10:00	NA	112.27					
				[4]10/4/00	9:00	NA	114.1	4.11	7.5	0.2	111.8	
				[4]10/4/00	10:05	NA	109.5					
												-5.1
2.9	70	Dungeness R. below Woodcock Bridge	S12	10/4/00	9:15	NA	106.88	3.04	NA	NA	105.28	
				10/4/00	10:20	NA	103.68					
2.6	50	Hurd Creek	S13	10/4/00	12:10	NA	4.25	4.37	NA	NA	4.345	
				10/4/00	12:45	NA	4.44					-6.6
1.8	27	Martrioti Creek	S14	10/3/00	16:15	3.06	9.44	3.33	NA	NA	9.6	
				10/4/00	17:00	3.07	9.76					
0.71	15	Dungeness R. at School House Bridge	S15	10/4/00	8:58	13.64	113.45	1.40	8.5	0.143	112.66	
				10/4/00	9:51	13.64	111.87					

Table 7. Data collected during the seepage runs on the lower Dungeness River on the Sequim-Dungeness peninsula, Clallam County, Washington, April and October 2000 and April 2001—*Continued*

River mile	Altitude (feet above sea level)	Station name	Map symbol	Date	Time	Staff gage reading	Measured discharge (ft^3/s)	Percent difference from mean	Temperature (°C)	Specific conductance μS/cm@ 25°C	Average discharge	Computed Gain (+) Loss (-)
						APRIL 2001						
11.8	**569**	**Dungeness R. at USGS Gage**	**S1**	**4/12/01** **4/12/01**	**9:43** **11:03**	**2.70** **2.70**	**151** **152**	**0.66**	**5**	**100**	**151.5**	
11.2	525	Canyon Creek	S2	4/12/01	14:05	NA	13.7	0.00	NA	NA	13.7	
10.9	500	Agnew Ditch below fish screen	S3	4/12/01	12:00	0.38	3.48	NA	NA	NA	3.48	**-9.1**
10.7	490	Highland Ditch above first split	S4	4/12/01	12:25	0.60	5.39	NA	NA	NA	5.39	
8.1	**380**	**Dungeness R. at Dungeness Meadows**	**S5**	**4/12/01** **4/12/01**	**9:58** **11:15**	**NA** **NA**	**136.82** **136.72**	**0.07**	**NA**	**NA**	**147.21**	
		Side channel at Dungeness Meadows		**4/12/01**	**9:01**	**NA**	**10.44**					
7.7	310	Independent Ditch (actual diversion)	S6	4/12/01	12:40	0.31	1.92	NA	NA	NA	1.92	
7.3	285	Clallam-Cline-Dungeness Ditch	S7	4/12/01	11:30	0.50	5.36	NA	NA	NA	5.36	**+2.8**
6.8	250	Bear Creek	S8	4/12/01	15:55	NA	2.12	NA	NA	NA	2.12	
6.4	235	Sequim Prairie Ditch	S9	4/12/01	12:50	0.41	2.97	NA	NA	NA	2.97	
5.5	**190**	**Dungeness R. at Railroad Bridge**	**S10**	**4/12/01** **4/12/01**	**8:45** **10:05**	**NA** **NA**	**143.85** **139.86**	**2.81**	**NA**	**NA**	**141.86**	 **-10.4**
3.7	**105**	**Dungeness R. at Old Olympic Highway**	**S11**	**4/12/01** **4/12/01**	**12:50** **13:55**	**NA**	**133** **130**	**2.28**	**5.7** **5.9**	**NA** **NA**	**131.5**	 **+9.3**
2.9	**70**	**Dungeness R. at Woodcock Bridge**	**S12**	**4/12/01** **4/12/01**	**9:00** **10:05**	**NA** **NA**	**140.79** **140.17**	**0.44**	**NA**	**NA**	**140.8**	
2.6	50	Hurd Creek	S13	4/12/01	11:05	NA	3.96	NA	NA	NA	3.96	**-4.7**
1.8	27	Martrioti Creek	S14	4/12/01	12:00	NA	11.43	NA	NA	NA	11.43	
0.71	**15**	**Dungeness R. at School House Bridge**	**S15**	**4/12/01** **4/12/01**	**8:50** **10:30**	**13.90** **13.90**	**154** **149**	**3.30**	**4.4** **4.7**	**NA** **NA**	**151.5**	

[1] Duplicate measurement made by U.S. Geological Survey personnel.
[2] Measurements on Matriotti Creek were made for calibration purposes only. Flow was not steady due to work on a nearby fish weir.
[3] Measurements at Old Olympic Highway were made by Department of Ecology personnel for comparison of techniques.
[4] Measurements at Old Olympic Highway were made by U.S. Geological Survey personnel for comparison of techniques.

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001

[µS/cm@25°C; Specific conductance in microsiemens per centimeter temperature compensated for 25 degrees Celsius (°C); NA, Data not recorded]

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(°C)	Time (hours)	(µS/cm@25°C)
			DUNGENESS MEADOWS				
3/29/2000	AFK197	1458	322.25	1458	7.5	1458	150
3/29/2000	AFK196	1359	320.94	1359	7.0	1359	120
3/29/2000	AFK195	1352	321.17	1352	11.0	1352	100
3/29/2000	River	1500	322.18	1500	6.0	1500	100
3/29/2000	AFK192	1212	319.69	1212	8.0	1212	110
3/29/2000	AFK193	1627	320.37	1627	5.0	1627	100
3/29/2000	AFK194	1116	320.53	1116	5.0	1116	90
5/2/2000	AFK197	943	322.86	946	7.5	944	110
5/2/2000	AFK196	936	322.49	940	7.5	939	110
5/2/2000	AFK195	928	322.49	940	7.5	939	110
5/2/2000	River	922	323.18	922	6.0	925	100
5/2/2000	AFK192	1243	320.44	1251	10.0	1248	100
5/2/2000	AFK193	1258	320.77	1303	10.0	1300	100
5/2/2000	AFK194	1308	320.65	1312	7.5	1310	100
5/17/2000	AFK197	1714	323.03	1717	7.5	1919	100
5/17/2000	AFK196	1709	322.23	1711	9.0	1714	100
5/17/2000	AFK195	1710	322.22	1711	9.0	1707	100
5/17/2000	River	1656	324.99	1706	6.0	NA	NA
5/17/2000	AFK192	1744	320.31	1748	10.0	1753	100
5/17/2000	AFK193	1753	320.61	1755	6.0	1758	100
5/17/2000	AFK194	1758	320.50	1800	9.0	1801	90
6/20/2000	AFK197	1911	323.39	1922	6.5	1924	90
6/20/2000	AFK196	1908	322.98	1919	7.5	1932	80
6/20/2000	AFK195	1907	322.96	1917	7.0	1933	60
6/20/2000	River	1903	324.08	1916	8.0	1935	60
6/20/2000	AFK192	NA	NA	NA	NA	NA	NA
6/20/2000	AFK193	NA	NA	NA	NA	NA	NA
6/20/2000	AFK194	NA	NA	NA	NA	NA	NA
8/1/2000	AFK197	1700	323.23	NA	NA	NA	NA
8/1/2000	AFK196	1700	322.88	NA	NA	NA	NA
8/1/2000	AFK195	1700	319.53*	NA	NA	NA	NA
8/1/2000	River	1700	323.43	NA	NA	NA	NA
8/1/2000	AFK192	1732	324.48*	1732	10.0	1732	50
8/1/2000	AFK193	1740	321.02	1740	10.0	1740	90

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(^oC)	Time (hours)	($\mu S/cm@25^oC$)
			DUNGENESS MEADOWS—*Continued*				
8/1/2000	AFK194	1746	317.16*	1746	10.0	1746	80
8/10/2000	AFK197	1800	323.01	1800	9.7	NA	NA
8/10/2000	AFK196	1800	322.69	1800	10.2	NA	NA
8/10/2000	AFK195	1800	322.68	1800	11.5	NA	NA
8/10/2000	River	1800	323.16	1800	13.5	NA	NA
8/10/2000	AFK192	1823	320.56	1832	10.0	1833	130
8/10/2000	AFK193	1842	320.86	1845	10.0	1844	130
8/10/2000	AFK194	1855	320.72	1900	10.0	1857	50
9/8/2000	AFK197	1300	322.46	1300	10.6	NA	NA
9/8/2000	AFK196	1245	322.04	1245	10.1	NA	NA
9/8/2000	AFK195	1230	322.03	1230	10.6	NA	NA
9/8/2000	River	1228	322.58	1228	10.0	1228	20
9/8/2000	AFK192	1343	319.83	1345	12.0	1346	20
9/8/2000	AFK193	1350	320.18	1350	9.9	1350	10
9/8/2000	AFK194	1406	320.11	1406	9.0	1406	10
10/3/2000	AFK197	1500	322.31	1500	10.9	NA	NA
10/3/2000	AFK196	1505	321.78	1505	10.1	NA	NA
10/3/2000	AFK195	1506	321.77	1506	10.2	NA	NA
10/3/2000	River	1500	322.52	1500	10.1	1500	133
10/3/2000	AFK192	1556	319.80	1556	12.0	1556	100
10/3/2000	AFK193	1615	320.05	1615	10.0	1615	100
10/3/2000	AFK194	1630	319.97	1630	10.0	1630	100
11/10/2000	AFK197	1036	322.31	1000	6.5	NA	NA
11/10/2000	AFK196	1030	321.46	1000	9.4	NA	NA
11/10/2000	AFK195	1020	321.42	1000	10.6	NA	NA
11/10/2000	River	957	322.64	958	4.4	959	60
11/10/2000	AFK192	1154	319.99	1200	7.5	1202	100
11/10/2000	AFK193	1207	320.36	1210	5.2	1211	99
11/10/2000	AFK194	1217	320.29	1220	7.0	1223	99
12/12/2000	AFK197	1119	321.84	1047	9.5	NA	NA
12/12/2000	AFK196	1109	321.08	1047	8.6	NA	NA
12/12/2000	AFK195	1101	321.06	1047	3.3	NA	NA
12/12/2000	River	1034	322.46	1039	0.0	1041	50
12/12/2000	AFK192	1203	319.41	1205	4.9	1206	60
12/12/2000	AFK193	1215	319.82	1216	4.0	1218	90
12/12/2000	AFK194	1222	319.72	1223	2.5	1224	90

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(^oC)	Time (hours)	($\mu S/cm@25^oC$)
			DUNGENESS MEADOWS—*Continued*				
1/16/2001	AFK197	1120	321.97	1030	8.5	NA	NA
1/16/2001	AFK196	1110	320.99	1030	7.3	NA	NA
1/16/2001	AFK195	1100	320.93	1030	3.9	NA	NA
1/16/2001	River	1042	322.82	1046	1.8	1048	600
1/16/2001	AFK192	1200	319.91	1204	3.0	1205	80
1/16/2001	AFK193	1207	320.30	1208	3.0	1209	70
1/16/2001	AFK194	1215	320.20	1216	2.5	1217	80
2/15/2001	AFK197	1035	322.03	1000	8.2	NA	NA
2/15/2010	AFK196	1035	321.06	1000	7.1	NA	NA
2/15/2010	AFK195	1035	321.01	1000	2.8	NA	NA
2/15/2010	River	1015	322.62	1014	2.4	1015	155
2/15/2010	AFK192	1213	319.66	1220	8.1	NA	NA
2/15/2010	AFK193	1228	320.05	1230	3.5	NA	NA
2/15/2010	AFK194	1233	319.96	1234	3.5	NA	NA
3/14/2001	AFK197	1230	322.16	1236	8.0	NA	NA
3/14/2001	AFK196	1220	321.11	1236	7.0	NA	NA
3/14/2001	AFK195	1210	321.06	838	4.2	NA	NA
3/14/2001	River	1154	322.74	1204	5.3	1205	100
3/14/2001	AFK192	1320	319.65	1322	5.5	1325	100
3/14/2001	AFK193	1328	320.01	1329	5.0	1331	100
3/14/2001	AFK194	1336	319.96	1337	5.0	1338	100
4/11/2001	AFK197	1904	322.37	1839	7.6	NA	NA
4/11/2001	AFK196	1858	321.54	1839	6.6	NA	NA
4/11/2001	AFK195	1851	321.50	1839	4.7	NA	NA
4/11/2001	River	1836	322.74	1839	6.3	NA	NA
4/11/2001	AFK192	1837	319.84	1844	7.0	1846	110
4/11/2001	AFK193	1849	320.21	1853	7.0	1855	100
4/11/2001	AFK194	1858	320.14	1900	6.0	1903	100
5/14/2001	AFK197	1111	322.88	1118	7.3	NA	NA
5/14/2001	AFK196	1105	322.41	1118	6.5	NA	NA
5/14/2001	AFK195	1101	322.40	1118	7.3	NA	NA
5/14/2001	River	1047	323.52	1051	7.7	1051	101
5/14/2001	AFK192	1236	320.61	1246	8.7	1254	133
5/14/2001	AFK193	1300	320.92	1302	7.2	1302	132
5/14/2001	AFK194	1306	320.81	1314	7.0	1314	133
6/19/2001	AFK197	1104	322.82	1040	8.1	NA	NA

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(°C)	Time (hours)	(µS/cm@25°C)
			DUNGENESS MEADOWS—*Continued*				
6/19/2001	AFK196	1100	322.45	1040	7.6	NA	NA
6/19/2001	AFK195	1058	322.49	1040	8.3	NA	NA
6/19/2001	River	1040	323.24	4040	9.7	1040	85
6/19/2001	AFK192	1140	320.19	NA	NA	1145	100
6/19/2001	AFK193	11554	320.53	1058	10.1	1158	106
6/19/2001	AFK194	1158	320.43	1207	8.5	1207	87
7/16/2001	AFK197	1728	322.67	1700	9.2	NA	NA
7/16/2001	AFK196	1720	322.26	1700	9.4	NA	NA
7/16/2001	AFK195	1711	322.28	1700	10.8	NA	NA
7/16/2001	River	1700	322.99	1700	11.6	1700	112
7/16/2001	AFK192	1800	320.08	1805	12.8	1805	118
7/16/2001	AFK193	1810	320.42	1810	11.7	1810	115
7/16/2001	AFK194	1812	320.35	1812	11.3	1812	115
			SCHOOLHOUSE BRIDGE				
3/29/2000	AFK191	907	15.30	1430	10.0	1432	380
3/29/2000	AFK190	915	15.08	1242	10.0	1244	380
3/29/2000	AFK189	924	14.79	1230	10.0	1232	500
3/30/2000	River	900	13.85	NA	NA	NA	NA
3/30/2000	AFK186	1500	15.10	1500	16.0	1500	990
3/30/2000	AFK187	854	15.63	854	8.5	854	1100
3/30/2000	AFK188	844	15.67	844	8.5	844	1050
5/2/2000	AFK191	730	14.93	730	9.8	730	400
5/2/2000	AFK190	725	14.87	725	9.0	725	420
5/2/2000	AFK189	723	14.59	723	9.0	723	410
5/2/2000	River	708	14.20	856	7.0	858	100
5/2/2000	AFK186	756	14.87	756	10.0	756	900
5/2/2000	AFK187	822	15.03	822	10.0	822	1200
5/2/2000	AFK188	808	14.74	808	10.0	808	1000
5/17/2000	AFK191	1909	14.71	1915	10.0	1918	400
5/17/2000	AFK190	1904	14.58	1905	9.5	1906	400
5/17/2000	AFK189	1900	14.50	1901	10.0	1903	450
5/17/2000	River	1900	14.67	NA	NA	NA	NA
5/17/2000	AFK186	1827	14.75	1830	10.0	1834	700
5/17/2000	AFK187	1840	15.08	1843	12.5	1843	900
5/17/2000	AFK188	1845	14.70	1850	10.0	1850	900

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(^{o}C)	Time (hours)	($\mu S/cm@25^{o}C$)
			SCHOOLHOUSE BRIDGE—*Continued*				
6/16/2000	AFK191	1042	15.89	1044	12.0	1046	420
6/16/2000	AFK190	1050	15.89	1054	9.0	1055	580
6/16/2000	AFK189	1101	15.93	1103	10.0	1105	480
6/16/2000	River	1100	15.72	NA	NA	NA	NA
6/16/2000	AFK186	1030	15.67	1032	17.0	1034	1000
6/16/2000	AFK187	1014	12.34*	1015	12.0	1017	900
6/16/2000	AFK188	1024	14.99	1025	17.0	1027	1200
8/1/2000	AFK191	1316	14.80	1316	12.5	1316	320
8/1/2000	AFK190	1313	14.81	1313	13.0	1313	350
8/1/2000	AFK189	1304	14.80	1304	12.5	1304	350
8/1/2000	River	1300	14.78	NA	NA	NA	NA
8/1/2000	AFK186	1300	14.67	NA	NA	NA	NA
8/1/2000	AFK187	1300	14.48	NA	NA	NA	NA
8/1/2000	AFK188	1300	14.18	NA	NA	NA	NA
8/11/2000	AFK191	1321	14.59	1321	8.8	1321	370
8/11/2000	AFK190	1305	14.57	1305	7.4	1305	320
8/11/2000	AFK189	1251	14.46	1251	9.9	1251	380
8/11/2000	River	1228	14.08	1228	12.6	1339	60
8/11/2000	AFK186	1155	14.43	1155	9.8	NA	NA
8/11/2000	AFK187	1205	14.27	1205	10.0	NA	NA
8/11/2000	AFK188	1220	13.98	1220	10.0	NA	NA
9/8/2000	AFK191	1550	14.10	1550	11.0	1550	310
9/8/2000	AFK190	1542	14.07	1542	10.0	1542	310
9/8/2000	AFK189	1537	13.89	1537	10.1	1537	80
9/8/2000	River	1430	13.63	1430	13.1	1430	80
9/8/2000	AFK186	1450	14.03	1450	9.7	NA	NA
9/8/2000	AFK187	1500	13.93	1500	10.0	NA	NA
9/8/2000	AFK188	1510	13.63	1512	10.1	NA	NA
10/3/2000	AFK191	1747	14.01	1748	11.0	1749	350
10/3/2000	AFK190	1743	14.01	1744	10.0	1745	350
10/3/2000	AFK189	1737	13.87	1740	10.0	1700	400
10/3/2000	River	1652	13.67	1652	11.8	1652	139
10/3/2000	AFK186	1719	13.95	1719	9.8	NA	NA
10/3/2000	AFK187	1725	13.87	1725	10.1	NA	NA
10/3/2000	AFK188	1730	13.55	1730	10.3	NA	NA
11/10/2000	AFK191	1522	15.17	1523	10.0	1524	310

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(°C)	Time (hours)	(µS/cm@25°C)
			SCHOOLHOUSE BRIDGE—*Continued*				
11/10/2000	AFK190	1515	14.98	1516	9.0	1517	320
11/10/2000	AFK189	1507	14.44	1508	9.8	1510	370
11/10/2000	River	1400	13.82	1400	6.4	1537	100
11/10/2000	AFK186	1420	14.72	1400	10.0	NA	NA
11/10/2000	AFK187	1436	14.70	1400	10.3	NA	NA
11/10/2000	AFK188	1446	14.46	1400	10.6	NA	NA
12/12/2000	AFK191	1323	14.60	1324	7.5	1324	300
12/12/2000	AFK190	1315	14.48	1316	9.0	1318	310
12/12/2000	AFK189	1309	14.13	1310	13.5	1312	320
12/12/2000	River	1341	13.52	1517	2.1	1327	90
12/12/2000	AFK186	1443	14.55	1424	10.1	NA	NA
12/12/2000	AFK187	1451	14.64	1424	10.4	NA	NA
12/12/2000	AFK188	1458	14.48	1424	10.9	NA	NA
1/16/2001	AFK191	1345	15.34	1442	9.0	1343	310
1/16/2001	AFK190	1334	15.21	1336	6.0	1337	300
1/16/2001	AFK189	1325	14.60	1326	6.0	1327	320
1/16/2001	River	1250	13.83	NA	NA	NA	NA
1/16/2001	AFK186	1255	15.60	1246	10.2	NA	NA
1/16/2001	AFK187	1300	15.88	1246	3.3	NA	NA
1/16/2001	AFK188	1310	15.71	1246	10.8	NA	NA
2/15/2001	AFK191	1312	14.90	1313	8.9	NA	NA
2/15/2001	AFK190	1308	14.77	1309	8.4	NA	NA
2/15/2001	AFK189	1305	14.31	1306	8.8	NA	NA
2/15/2001	River	1415	13.59	1345	3.6	NA	NA
2/15/2001	AFK186	1439	15.23	1400	10.3	NA	NA
2/15/2001	AFK187	1435	15.52	1400	10.3	NA	NA
2/15/2001	AFK188	1431	15.38	1400	10.7	NA	NA
3/14/2001	AFK191	1554	14.66	1555	10.1	1556	400
3/14/2001	AFK190	1549	14.56	1550	10.1	1551	400
3/14/2001	AFK189	1540	14.27	1541	10.5	1542	480
3/14/2001	River	1424	13.74	1428	7.4	1429	100
3/14/2001	AFK186	1450	15.00	1524	10.3	NA	NA
3/14/2001	AFK187	1456	15.15	1524	10.2	NA	NA
3/14/2001	AFK188	1500	15.05	1524	10.6	NA	NA
4/11/2001	AFK191	1725	14.76	1730	9.0	1733	400
4/11/2001	AFK190	1715	14.62	1718	9.0	1722	450

Table 8. Data measured monthly in the lower Dungeness River and at the off-stream well transects on the Sequim-Dungeness peninsula, Clallam County, Washington, March 2000 to July 2001—*Continued*

Date	Site	Water-level altitude		Temperature		Specific conductance	
		Time (hours)	(feet above sea level)	Time (hours)	(^oC)	Time (hours)	($\mu S/cm@25^oC$)
			SCHOOLHOUSE BRIDGE—*Continued*				
4/11/2001	AFK189	1700	14.35	1708	12.0	1710	530
4/11/2001	River	1647	13.90	1647	10.2	1646	110
4/11/2001	AFK186	1610	15.10	1600	10.2	NA	NA
4/11/2001	AFK187	1627	15.31	1600	10.1	NA	NA
4/11/2001	AFK188	1637	15.29	1600	10.4	NA	NA
5/14/2001	AFK191	1930	14.87	1926	8.7	1926	576
5/14/2001	AFK190	1013	14.90	1917	8.2	1917	600
5/14/2001	AFK189	1900	14.94	1908	8.9	1908	678
5/14/2001	River	1937	14.84	1937	9.0	1908	109
5/14/2001	AFK186	820	14.91	755	10.2	NA	NA
5/14/2001	AFK187	833	14.84	755	9.8	NA	NA
5/14/2001	AFK188	841	14.63	755	10.3	NA	NA
6/19/2001	AFK191	1406	14.64	1408	10.4	1408	457
6/19/2001	AFK190	1400	14.60	1402	8.8	1402	466
6/19/2001	AFK189	1349	14.50	1351	9.6	1351	541
6/19/2001	River	1243	14.36	1243	11.8	1243	96
6/19/2001	AFK186	1305	14.57	1245	10.0	NA	NA
6/19/2001	AFK187	1322	14.50	1245	9.8	NA	NA
6/19/2001	AFK188	1327	14.26	1245	10.1	NA	NA
7/16/2001	AFK191	739	14.34	742	10.8	742	563
7/16/2001	AFK190	735	14.33	738	9.7	738	598
7/16/2001	AFK189	732	14.22	734	10.1	734	655
7/16/2001	River	652	13.98	652	13.4	652	119
7/16/2001	AFK186	707	14.17	652	10.1	NA	NA
7/16/2001	AFK187	705	14.04	652	9.8	NA	NA
7/16/2001	AFK188	725	13.76	652	10.2	NA	NA

* Data falls outside the range of expected values and is considered questionable.

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