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Prepared in cooperation with
Clallam County Department Of Community Development and
Washington State Department of Ecology

Hydrogeologic Assessment of the Sequim-Dungeness Area, Clallam County, Washington

By Blakemore E. Thomas, Layna A. Goodman, and Theresa D. Olsen

Water-Resources Investigations Report 99-4048

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

Cover — Photo of Sequim, Washington, and surrounding area by Dan Crowell, Soundview Aerial Photography, Arlington, Washington, March 1993.

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Tacoma, Washington
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
square foot (ft^2)	0.0929	square meter
acre	4,047	square meter
	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
gallon per day (gal/d)	3.785	liter per day
pounds per acre (lb/acre)	1.121	kilograms per hectare

Temperature: To convert temperature given in this report in degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation: °C = 5/9(°F-32).

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

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

HYDROGEOLOGIC ASSESSMENT OF THE SEQUIM-DUNGENESS AREA, CLALLAM COUNTY, WASHINGTON

By Blakemore E. Thomas, Layna A. Goodman, and Theresa D. Olsen

ABSTRACT

The Sequim-Dungeness area covers 116 square miles (mi^2) on the northern part of the Olympic Peninsula in northwestern Washington. The central part of this area (74 mi^2) was designated as a primary study area. During the past two decades, the population has rapidly increased, land use has changed from mostly agricultural to residential, and salmon populations in the Dungeness River have appreciably declined. The increasing competition for water combined with a close relation between ground water, the Dungeness River, and an extensive irrigation system has created a need for a better understanding of ground water and the relation between ground water and surface water in the study area.

The Sequim-Dungeness area is underlain by as much as 2,000 feet of unconsolidated Quaternary deposits that are mostly of glacial origin. Interpretation of 10 hydrogeologic cross sections and lithologic logs of about 600 wells led to the delineation of three aquifers, two confining beds, and a lower unit of undifferentiated deposits. A bedrock unit at the bottom is considered the base of the ground-water system.

Ground water in the study area is recharged from infiltration and percolation of precipitaton, percolation of unconsumed irrigation water, leakage from irrigation ditches, subsurface inflow through the southern study-area boundary, and leakage from streams. Average annual recharge for the study period (December 1995 to September 1997) was estimated to be 17.7 inches (in.) (151 cubic feet per second (ft^3/s)). The distribution of recharge was 8.6 in. (74 ft^3/s) from precipitation, 2.7 in. (23 ft^3/s) from subsurface inflow, 3.1 in. (26 ft^3/s) from irrigation, and 3.3 in. (28 ft^3/s) from leakage from the Dungeness River. The 8.6 in. of recharge from precipitation is much higher than would be expected in an average year because average annual precipitation during the study period was about 28 in., which is 1.35 times higher than long-term average annual-precipitation. The long-term average annual recharge from precipitation was estimated to be 5.4 in. (48 ft^3/s).

Ground water discharges as subsurface flow to saltwater bodies, flow to streams, flow to springs, and as withdrawals from wells. Subsurface flow to saltwater bodies and flow to springs were not estimated in this study. Estimated average annual discharge was 3.2 inches (in.) (27 ft^3/s)) to the Dungeness River and 4.6 in. (39 ft^3/s) to other streams in the study area. Gross withdrawals from wells in 1996 were estimated to be 1.0 in. (8.4 ft^3/s).

There was a small but statistically significant increase in nitrate concentrations in ground water from 1980 to 1996. Median concentrations in the primary study area were 0.37 milligrams per liter (mg/L) in 1980 and 0.46 mg/L in 1996. The areal pattern of elevated nitrate concentrations has not changed appreciably during the past 15 years. Elevated concentrations were found in a large area east of the Dungeness River and at scattered locations west of the Dungeness River.

About 543,200 pounds of nitrogen are estimated to enter the ground-water system in the primary study area each year. Four sources account for about 85 percent of the nitrogen; residential fertilizers, septic systems, mineralization of soil organic matter, and agricultural fertilizers. It appears that the four major sources are approximately equivalent in amounts of nitrogen.

Concentrations of nitrate in the shallow aquifer were significantly higher under residential areas than under natural grasslands or forests. Median nitrate concentrations were 1.3 mg/L under residential areas, 0.55 mg/L under agricultural areas, and 0.12 mg/L under natural grasslands or forests.

INTRODUCTION

This report describes an assessment of the hydrogeology of the unconsolidated geologic deposits in the Sequim-Dungeness area of eastern Clallam County in northwestern Washington (fig. 1). The 116-square-mile study area is bounded by the Olympic Mountains to the south and the Strait of Juan De Fuca to the north.

There is increasing competition for the use of the water resources of the study area. The water resources are limited, because the study area has only about 21 in. of average annual precipitation. Drinking water has primarily been withdrawn from ground water, and most water for irrigation of crops has been withdrawn from the Dungeness River. During the past 20 years, the population of the study area increased by about 250 percent, and land use and corresponding water use has been changing from agricultural to residential. These changes have caused an increase in ground-water withdrawals and a decrease in irrigation withdrawals from the Dungeness River. Another water-related issue in the study area is that salmon populations in the Dungeness River have declined appreciably during the past 30 years, resulting in calls for requirements of minimum levels of streamflow in the Dungeness River to sustain and improve the salmon populations (U.S. Forest Service, 1995; Jamestown S'Klallam Tribe, 1994). The increasing ground-water withdrawals due to increasing population can lower ground-water levels, which might result in lower Dungeness River streamflows because of less ground-water discharge.

Ground water and surface water in the study area are closely related. Surface water includes the Dungeness River, other streams, and an extensive system of irrigation ditches and irrigated fields that have been built up over the past 100 years. Leakage from the Dungeness River, irrigation ditches, and unconsumed irrigation water is an important part of the ground-water recharge. Much of the flow in the streams in the Sequim-Dungeness area is from ground-water discharge or irrigation tailwaters. The leakage from ditches and unconsumed irrigation water during the past 100 years increased the amount of ground-water recharge and created an artificially high water table in the study area.

There is increasing concern about the quality of ground water in the study area. Nitrate concentrations in ground water increased between 1980 and 1994 (A.C. Soule, Clallam County, written commun., 1995). The sources of the increase in nitrate are uncertain. Potential sources are septic systems, residential fertilizers, and leaching of nitrogen stored in soils from past agricultural activity. In addition, there may be less dilution of nitrate because of decreasing amounts of ground-water recharge during the past 15 years. Recharge might have decreased because of less irrigation diversions and less leakage from irrigation ditches.

A better understanding of ground water and the relation between ground water and surface water is needed to effectively manage the water resources and water quality of the study area. In February 1995, the U.S. Geological Survey (USGS) and the Clallam County Department of Community Development (CCDCD) entered into a cooperative agreement to study the hydrogeology of the Sequim-Dungeness area in Clallam County, Wash. The Washington State Department of Ecology (Ecology) also contributed to the funding of this study in the form of a Centennial Clean Water Fund grant to Clallam County.

Purpose and Scope

This report describes the results of a study of the hydrogeology of the Sequim-Dungeness area. During 1995-97, data were collected and analyzed to achieve the following specific objectives

1. Describe and quantify the hydrogeologic framework, ground-water flow, and hydraulic properties of the ground-water system.
2. Improve existing estimates of ground-water recharge.
3. Estimate the flows between the ground-water system and streams and irrigation ditches.
4. Describe the magnitude and distribution of nitrate and estimate the probable major sources of nitrate in the ground-water system.
5. Determine pumpage from the major aquifers for one calendar year.
6. Estimate subsurface inflow from bedrock areas south of the study area.

The results of this study are expected to be used to develop a numerical ground-water flow model. Therefore, the design of data collection and the selection of areas of emphasis for quantification and interpretation of the ground-water system were made to improve the data base on which a model would be calibrated.

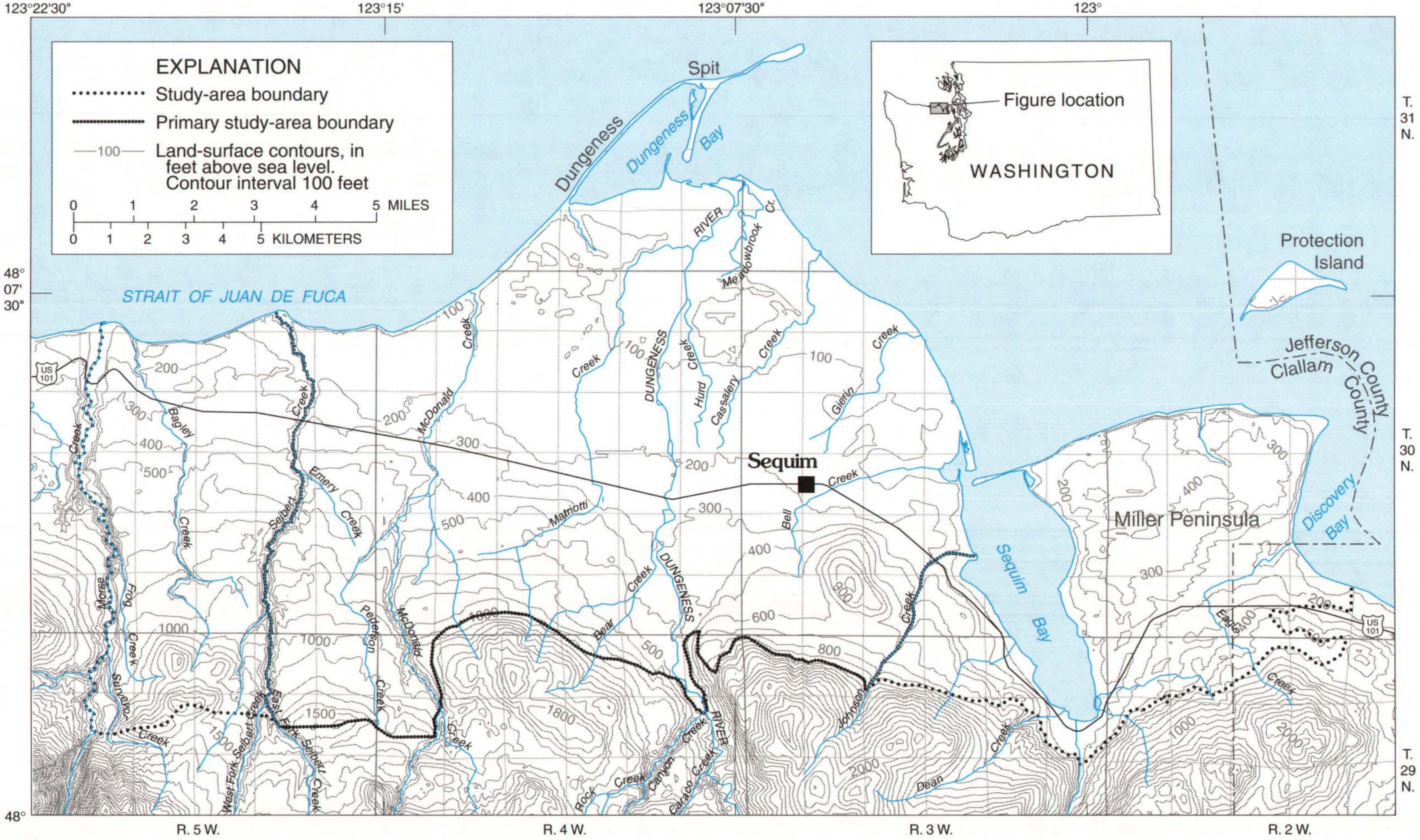


Figure 1. Location of study area.

Physical and Cultural Setting

Location and Extent of Study Area

The study area is 116 mi^2 and is bounded by Morse Creek on the west, the Strait of Juan De Fuca on the north, Discovery Bay on the east, and the edge of the unconsolidated deposits at the base of the Olympic Mountains on the south (fig. 1). A primary area of study was specified for this study; it includes most of the population and all of the irrigated areas. The primary study area is 74 mi^2 and is between Siebert Creek on the west and Johnson Creek on the east.

Climate, Vegetation, and Topography

The Sequim-Dungeness area has a temperate marine climate with cool, wet winters and warm, dry summers. The study area lies in a rain shadow of the Olympic Mountains to the south and west. Sequim receives only an average of about 16 in. of annual rainfall. Average annual rainfall ranges from 15 in. in the north to about 35 in. in the hills in the southwest part of the study area (fig. 2). The average annual precipitation for the entire study area is about 21 in.

The annual precipitation at Sequim has been moderately variable since 1923 (fig. 3). There were no significant increasing or decreasing trends in annual precipitation for its entire record (1923-96) or from 1979 to 1996 (Kendall-Theil test, $p > 0.05$; Helsel and Hirsch, 1992). However, precipitation in 1995 was 120 percent of the long-term average and precipitation in 1996 was 140 percent of average.

The distribution of precipitation varies throughout a typical year, and 38 percent of the annual precipitation is during the winter, December through February (fig. 3). Summers are typically dry, with only 14 percent of the annual precipitation in June through August (National Oceanic and Atmospheric Administration, 1982).

Air temperatures are moderate throughout a typical year (fig. 3). The average monthly maximum temperature ranges from 45 degrees Fahrenheit in January to 72 degrees Fahrenheit in July; the average monthly minimum temperature ranges from 32 degrees Fahrenheit in January to 51 degrees Fahrenheit in August.

Fifty-three percent of the study area is covered by forests of conifer trees (fig. 4). Natural grassland, brush, and non-irrigated pastures cover about 30 percent of the study area, mostly in the central and northern parts. About 7 percent of the study area is irrigated with water from the Dungeness River. Residential and urban land makes up the remaining 10 percent of the study area.

The topography of the study area is mostly a flat plain in the primary study area, with hills in the south, west, and in Miller Peninsula (fig. 1). Altitudes range from sea level to about 300 ft in the central plain and from 300 to 1,500 ft in the hills. McDonald Creek, Siebert Creek, and Morse Creek have cut deep canyons into the land surface and have exposures of bedrock in a few areas. The Dungeness River meanders from south to north through the central part of the study area; unlike the smaller streams, it has not cut a deep canyon into the land surface.

Streamflow

The Dungeness River is the only large river in the study area, and it provides most of the water used for irrigation. The drainage area at the mouth of the river is about 200 mi^2, mostly in the Olympic Mountains south of the study area. A streamflow gage located just south of the study area has been operated by the USGS for most of the years since 1923 (67 years of record). The Dungeness River has two distinct high flow periods; snowmelt in the upper watershed causes consistently high flows in late spring and early summer, and rainfall in the upper watershed causes high and more variable flows in the winter (fig. 5). The lowest flows are in September and October. From September to mid-November, 25 percent of the daily mean flows during the 67-year record were below 150 cubic feet per second (ft^3/s).

Streams in the study area can be classified into two types on the basis of sources of flow; snowmelt and rainfall runoff produce most of the flow in larger streams with upper watersheds in the hills or mountains south of the study area; and ground-water discharge and irrigation tailwaters produce most of the flow in smaller streams with watersheds contained entirely in the study area. Distinctly different monthly flow patterns for these two stream types can be seen in flows measured once a month during 1979 (fig. 6). The larger streams, Siebert Creek and McDonald Creek, have high flows in the winter and spring and low flows during the remainder of the year. The smaller streams, which include Bell Creek, Gierin Creek, Cassalery Creek, and others, have relatively constant flows for the entire year. The magnitude of flows during this study period (July 1995 to September 1997) was different than in 1979, but the annual pattern probably was the same.

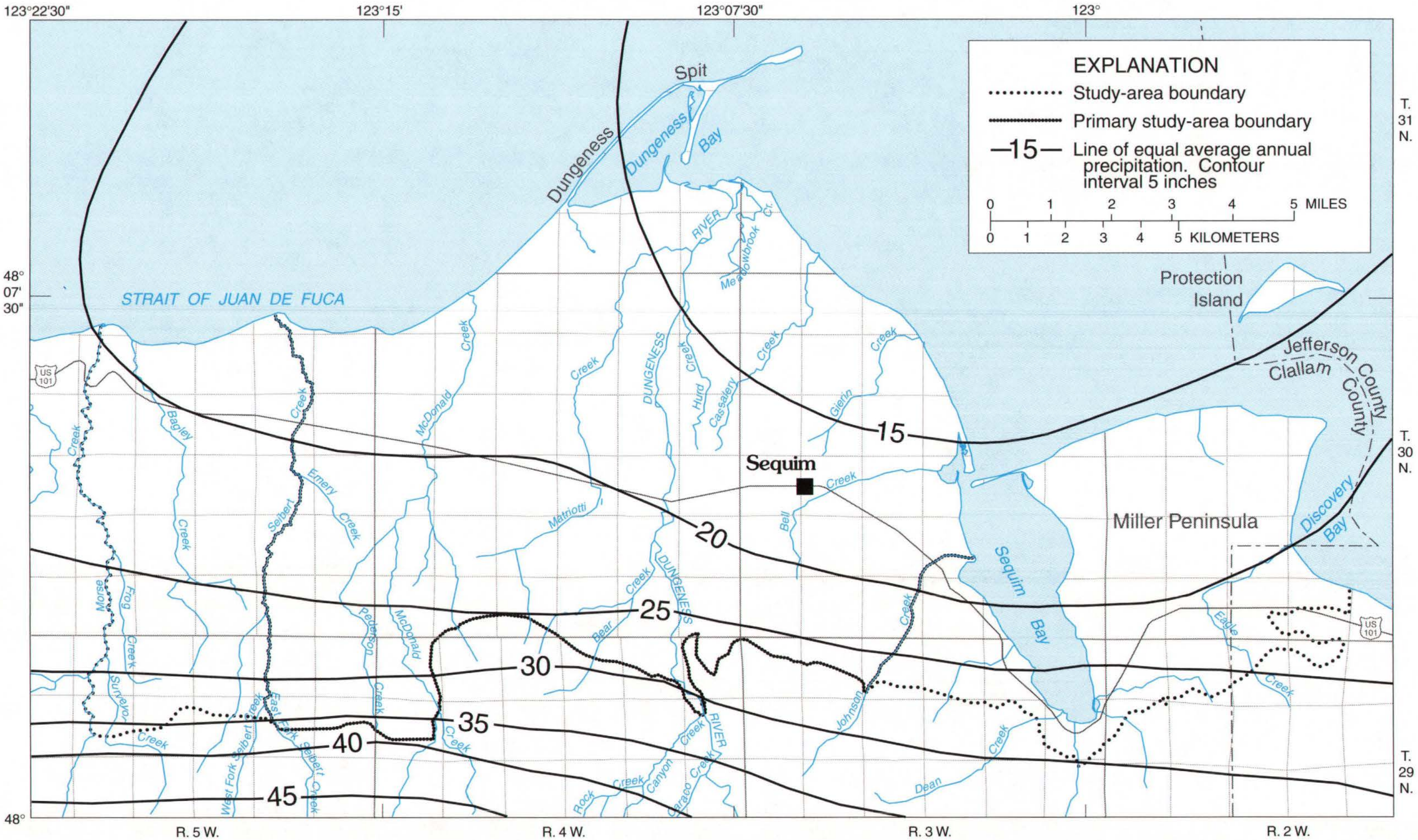
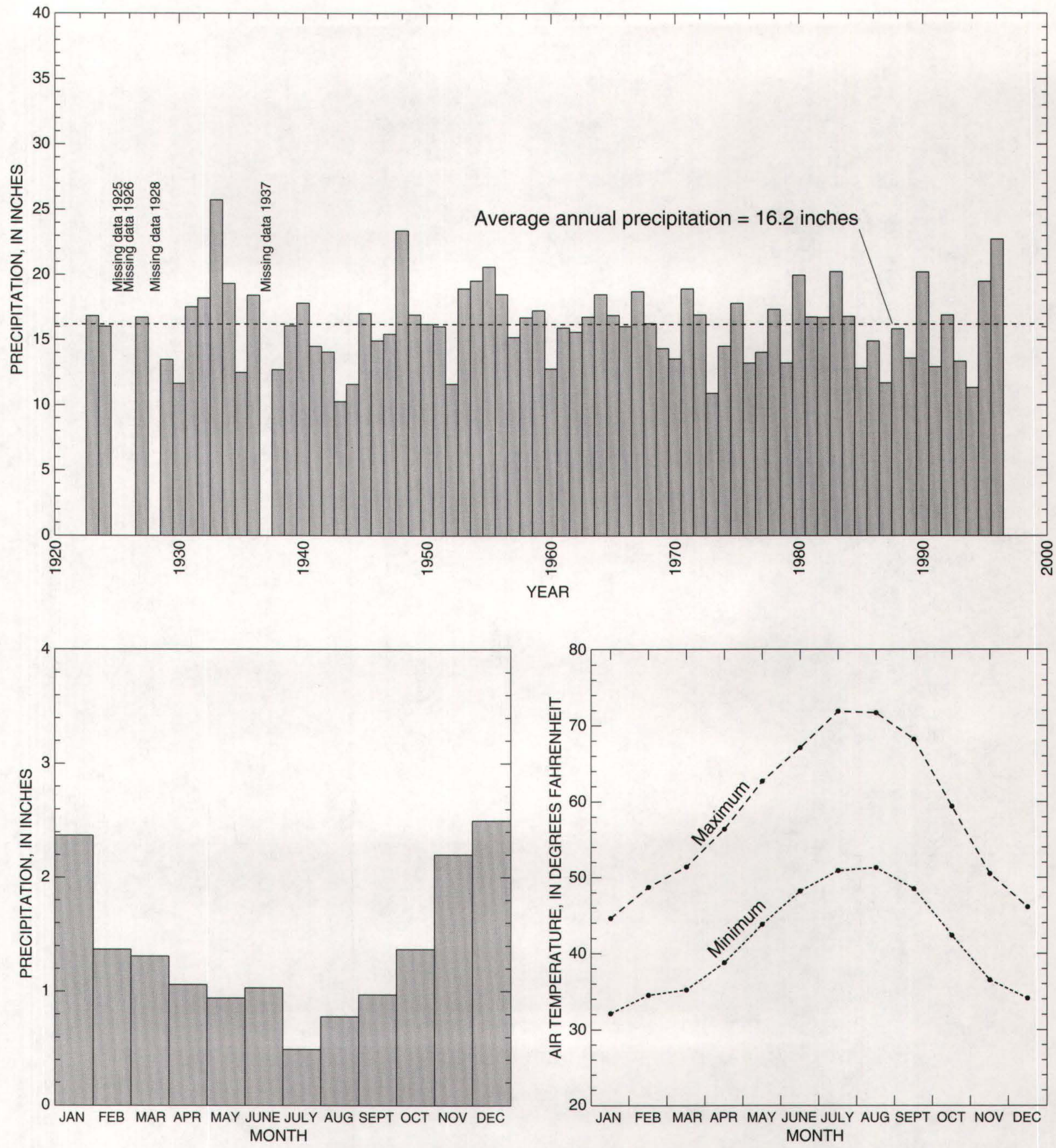


Figure 2. Average annual precipitation (U.S. Weather Bureau, 1965).



AVERAGE MONTHLY VALUES FOR 1951-1980
(National Oceanic and Atmospheric Administration, 1982)

Figure 3. Historical annual precipitation, average monthly precipation, and average monthly air temperature at the National Weather Service station near Sequim, Washington.

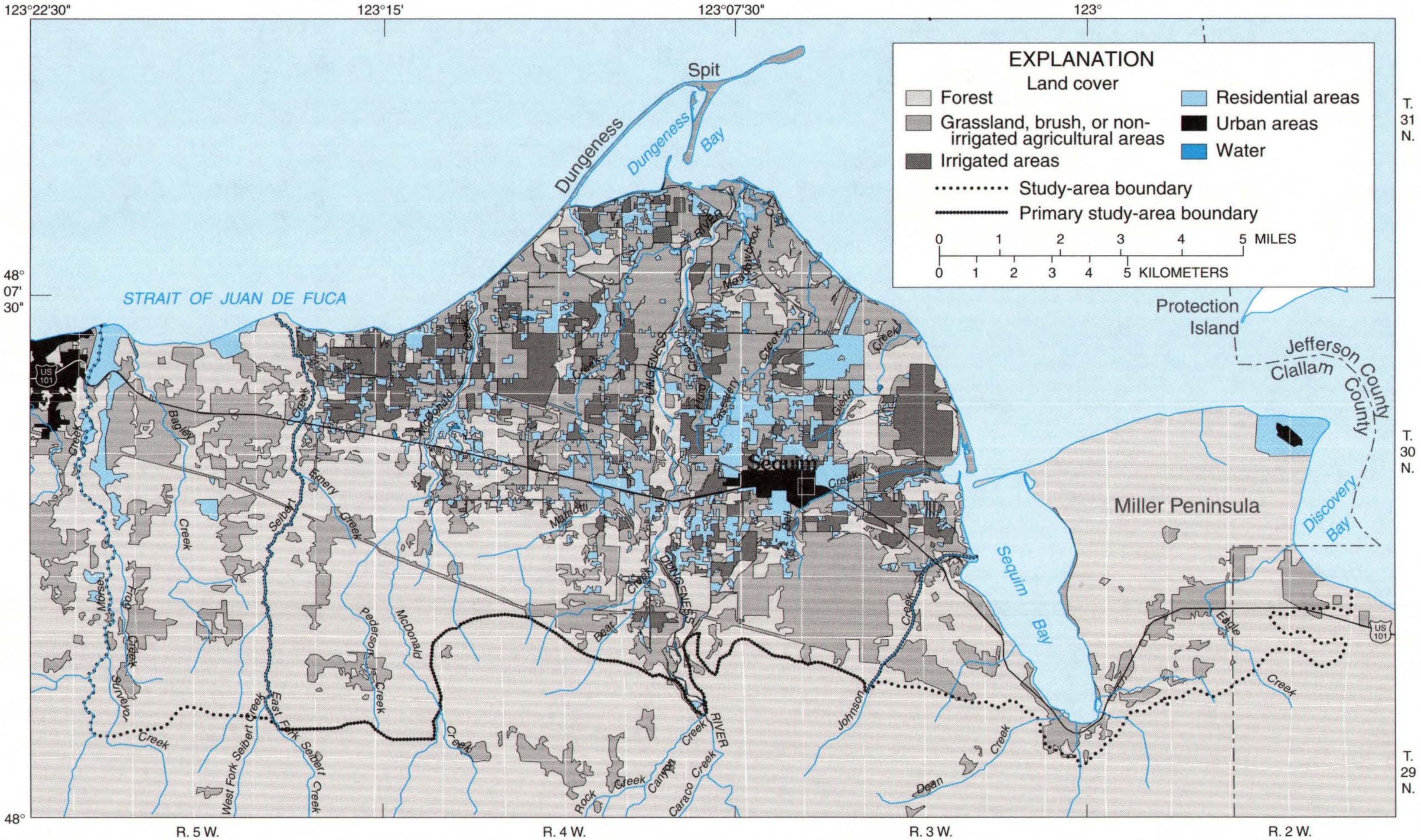


Figure 4. Generalized land cover in 1994. (Penelope Eckert, University of Washington, written communication, 1998; Steve Gray, Clallam County, written communication, 1998; Montgomery Water Group, Inc., Kirkland, Washington, written communication, 1998).

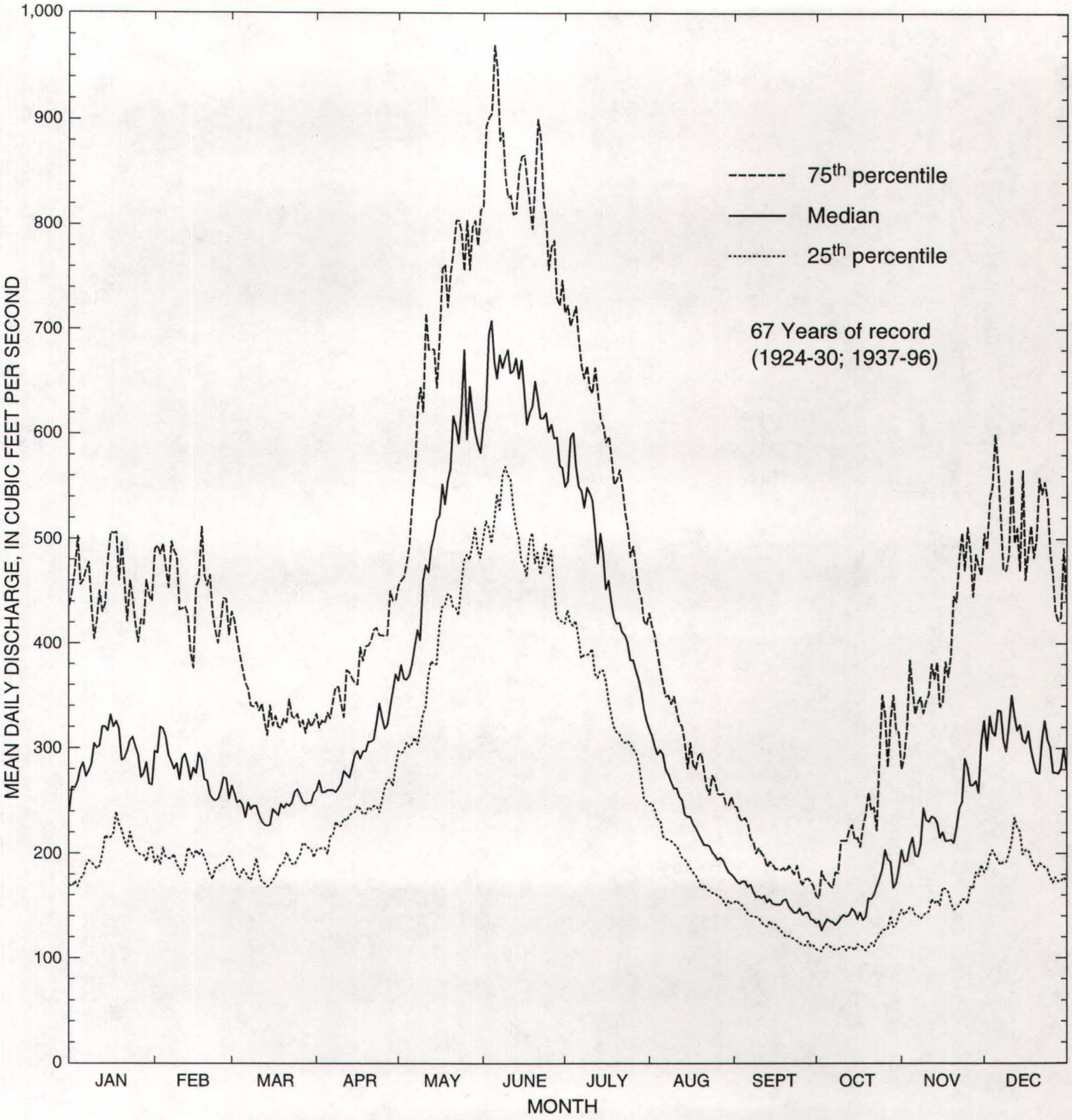


Figure 5. Distribution of historical streamflows for Dungeness River near Sequim, Washington (station 12048000).

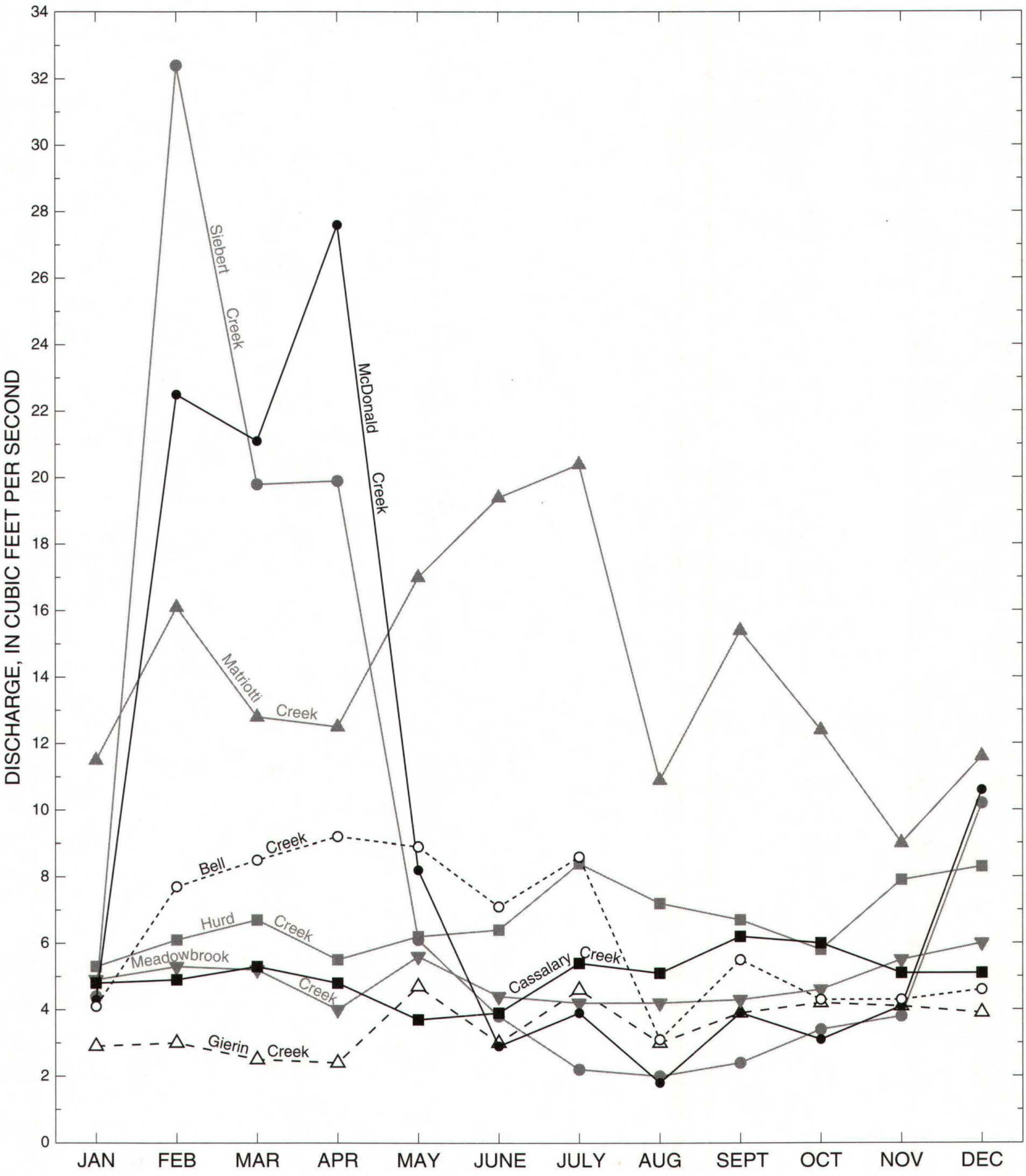


Figure 6. Discharges in selected streams, measured once-a-month during 1979, Sequim-Dungeness area, Washington.

Population, Land Use, and Irrigation

In 1960, most land use in the Sequim-Dungeness area was agricultural, and the population was about 5,000. Since 1960, the population has been steadily increasing, and land use has been changing from agricultural to residential. The population was about 7,000 in 1970, 12,000 in 1980, and about 20,000 in 1990. In 1990, the primary study area had about 17,000 people, and the remainder of the study area had about 3,000 people (fig. 7).

The Sequim-Dungeness area has been irrigated extensively with water from the Dungeness River since about 1895. Despite the recent trends in land use from agricultural to residential, most of the irrigation ditches are still used to convey water from the river for irrigation of pasture lands. Nine irrigation companies and districts were established between 1895 and 1921. An extensive system of ditches was constructed, and in 1996, there were about 200 mi of ditches (fig. 8). During 1996-97, about 9 mi^2 of land was irrigated (fig. 4) (Montgomery Water Group, Inc., 1998). Most diversions from the Dungeness River are during the irrigation season of May through September. Some water is also used for stock supply, fire protection, and individual domestic use; therefore, most of the major ditches flow throughout the year.

The domestic water needs of the population in the study area are met largely by withdrawals of ground water from public-supply and domestic wells. During the past 20 years, the water table of the surficial aquifer has declined slightly in some parts of the study area, and there is concern about the cause of these declines.

Most of the disposal of domestic sewage in the study area is by individual septic systems. The city of Sequim has a centralized sewer system that serves an area of about 3.5 mi^2 and included about 5,500 people in 1996. It discharges treated wastewater to Sequim Bay. A community of about 800 residents in the north-central part of the study area has a centralized septic system.

Previous Studies

There have been many studies of the geology, ground water, and surface water in the Sequim-Dungeness area. The Dungeness-Quilcene Water Resources Management Plan (DQ Plan) is a comprehensive document describing the water resources of eastern Clallam County and western Jefferson County (Jamestown S'Klallam Tribe, 1994). It summarizes previous water-resource studies and makes recommendations for future studies and management of water resources.

The three regional ground-water studies that have been conducted in the Sequim-Dungeness area are by Noble (1960), Drost (1983), and Sweet-Edwards/EMCON (1991a,b,c). Basic data for the Drost (1983) report are provided by Drost (1986). Clallam County Department of Community Development (1994) developed a ground-water protection strategy on the basis of these previous studies and some newly collected data. Many small, local-scale studies have been made of ground water in the study area, and most of those are mentioned in the selected references section of this report. Previous studies of ground-water recharge from irrigation include Drost (1983) and Montgomery Water Group, Inc. (1993 and 1998).

The principal geologic studies of the study area were by Othberg and Palmer (1980 a,b,c,d) at a 1:24,000 scale and Tabor and Cady (1978) at a 1:125,000 scale. Jones (1996a) provides a map of the thickness of unconsolidated deposits of the entire Puget Sound Lowland in western Washington, which includes the study area. Jones (1996b) constructed five hydrogeologic cross sections in the study area.

Well-Numbering System

The well-numbering system used by the USGS in the State of Washington is based on the rectangular subdivision of public land, and indicates township, range, section, and a 40-acre tract within the section. For example, in well number 30N/03W-06B01 (fig. 9), the part preceding the hyphen indicates the township and range (T. 30 N., R. 03 W.) north and west of the Willamette base line and meridian, respectively. The first number following the hyphen (06) indicates the section, and the letter (B) gives the 40-acre tract within that section. The last number (01) is the sequence number of the well in that 40-acre tract, and it indicates that the well was the first one inventoried.

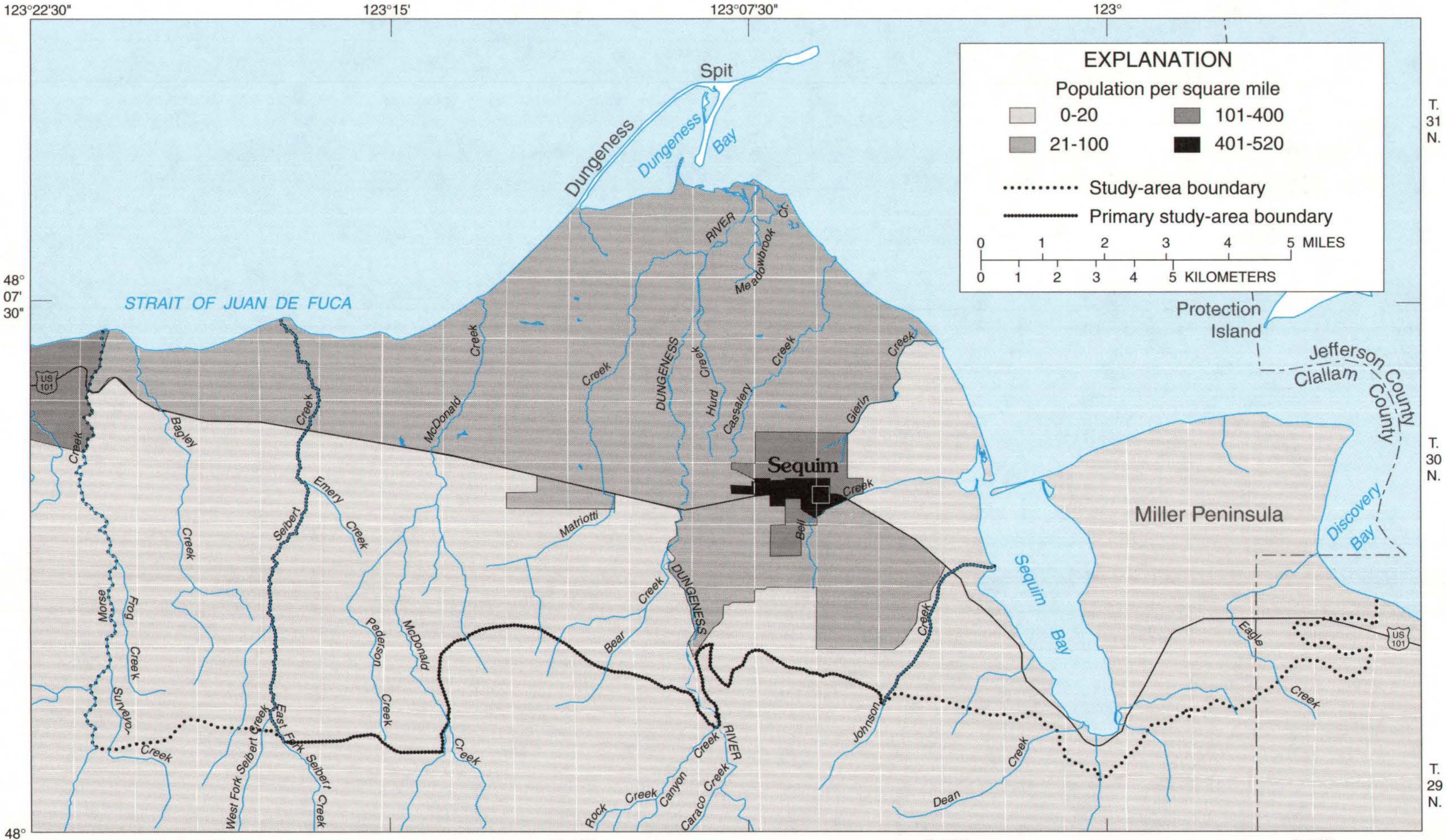


Figure 7. Population density in 1990 (U.S. Bureau of the Census, 1997).

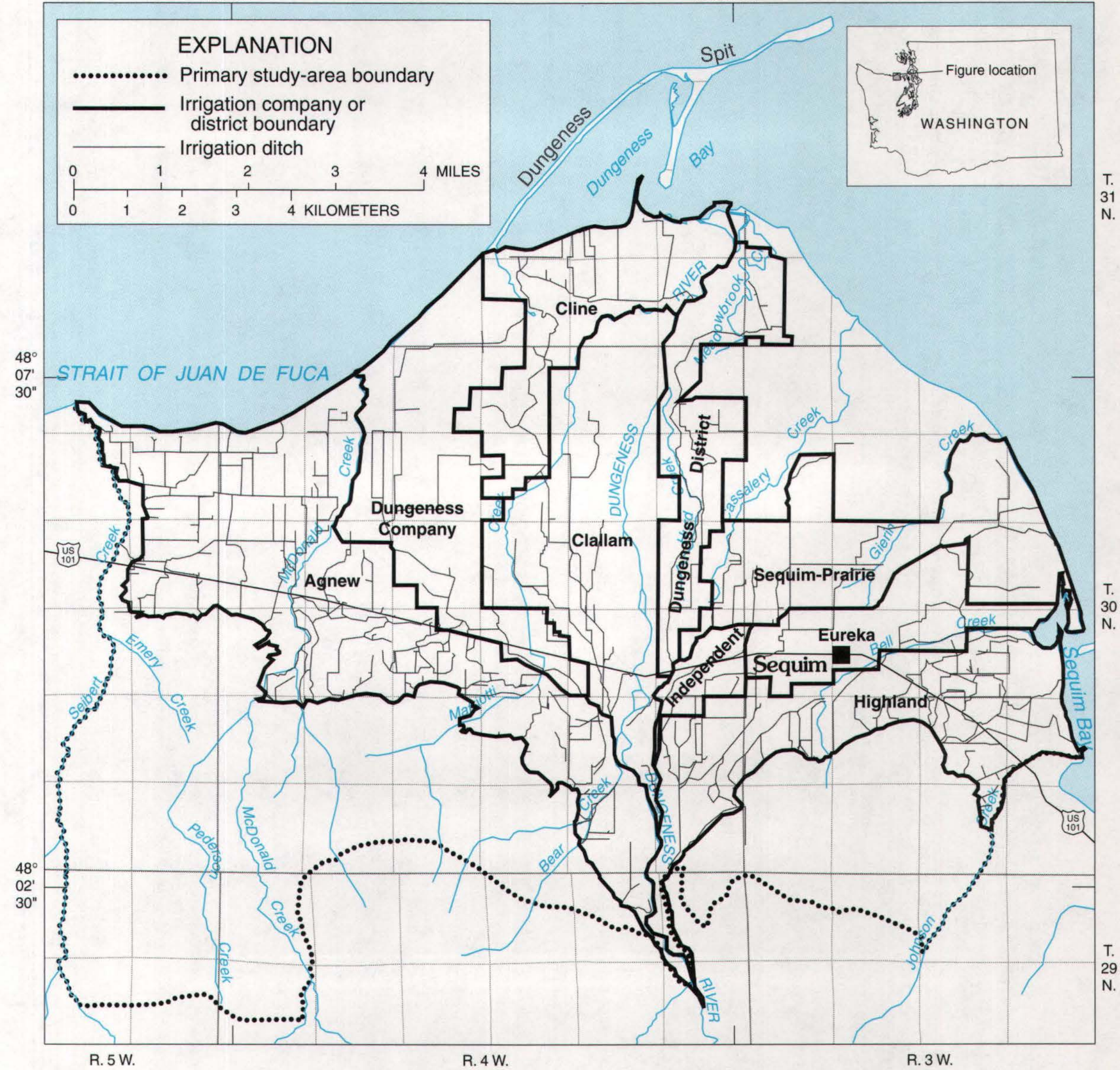


Figure 8. Irrigation ditches and boundaries of irrigation companies or districts in 1996.

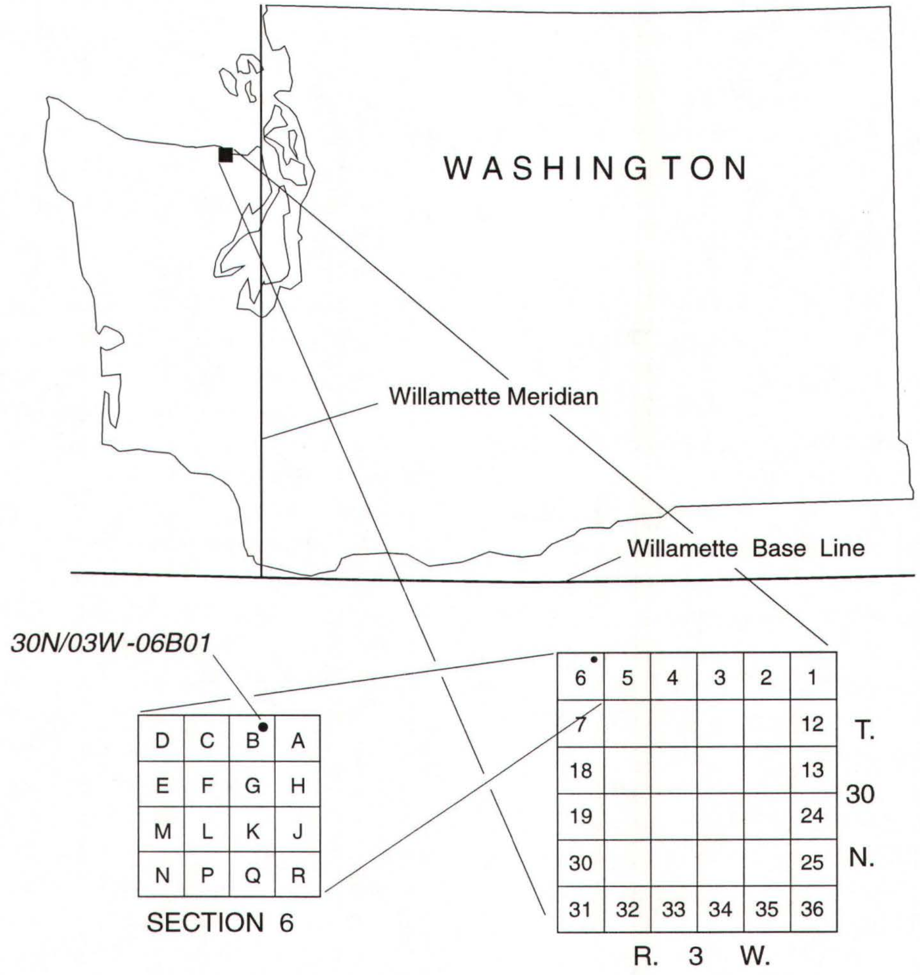


Figure 9. Well-numbering system used in Washington.

Acknowledgments

The authors acknowledge the cooperation and effort of the approximately 35 volunteers who measured water levels at staff gages in irrigation ditches and six volunteers who measured daily precipitation. Twenty-two months of data were collected at 74 staff gages in the irrigation ditches and at five precipitation sites. About 9,500 staff-gage readings were made, and about 3,500 measurements of daily precipitation were made.

The authors acknowledge the cooperation of the many well owners and tenants who supplied information and access to their wells and property during the field work, and owners and managers of various water systems, farms, and companies who supplied well and water-use data. The authors also wish to acknowledge the cooperation and data sharing of Clallam County, Montgomery Water Group, Inc., Pacific Groundwater Group, Jamestown S'Klallam Tribe, and Washington State Department of Ecology.

METHODS OF INVESTIGATION

To assess the hydrogeology of the Sequim-Dungeness area, existing data and previous studies of the area were evaluated, new data were collected, and the new and existing data were analyzed.

General Information

Ground-water wells were the primary source of information used to define the hydrogeologic framework, ground-water system, and magnitude and distribution of nitrogen in ground water. The hydrogeologic framework (boundaries of aquifers and confining units) was defined by evaluating and correlating the lithology described in drillers' logs of wells. Ground-water flow was estimated by measuring water levels in wells, and hydraulic properties of aquifers were estimated using well-pumpage data. The magnitude and distribution of nitrogen in ground water were described by analyzing water samples collected from wells. In addition to the wells in the study area, data were collected from several other sources. Ground-water recharge was estimated by evaluating measured precipitation, soil moisture, surface-water runoff, and water levels and discharge in irrigation ditches. Part of the ground-water discharge was estimated by evaluating measured discharges in selected streams.

A field inventory of 369 wells was conducted from July 1995 to November 1996. Location and land-surface altitude were estimated using 7.5-minute topographic maps. For some wells, the location was also estimated using a global positioning system (GPS). Water levels were measured in 238 wells, and 20 wells were added to an existing Clallam County water-level observation network for a total of 47 wells in the network.

In addition to the wells inventoried during this study, data from another 402 wells in the USGS computer data base, National Water Information System, were used for analysis in this study. These 402 wells had been inventoried in previous studies, and their locations were field-checked. Data analyzed from these wells included lithologic logs, pumpage data, historical water levels, and water quality measured in 1980. The 771 inventoried wells are referred to as the study wells. The locations of the study wells are shown on figure 10, and the data describing the study wells are in appendix A.

Goals of the field inventory in this study were to improve upon the distribution of data available from the 402 previously inventoried wells and to re-inventory a representative sample of the wells that were inventoried by Drost (1983) in 1979. The improvement goals were to obtain a more complete areal distribution of wells and to inventory more deep wells. The approach was to select three wells of varying depths in each section or square mile of the study area. Previously inventoried wells in a section were given priority, and attempts were made to locate them. The goal of an even areal distribution of wells was mostly achieved within the primary study area, but wells are scarce in the remainder of the study area, so many gaps remain in the data (fig. 10). The distribution of depths of wells is biased toward shallow wells because most of the wells in the study area are less than 200 ft deep (fig. 11). One hundred and seventeen wells inventoried by Drost (1983) were re-inventoried; the measured water levels and water samples collected from these wells provided an opportunity to evaluate possible temporal changes in water levels or water quality.

The 771 wells used in this study are a small part of about 4,000 wells that exist in the study area. Clallam County Department of Community Development maintains a data base of most of these wells, including information on location, depth, owner, and date of construction. The distribution of depths of the study wells is similar to the distribution of depths of all wells in the study area (fig. 11).

Hydrogeologic Framework

The hydrogeologic framework describes the boundaries and lithology of the hydrogeologic units (aquifers and confining beds) in the study area. Seven hydrogeologic units were evaluated in this study. This partitioning scheme was established by Drost (1983) and was also used by Jones (1996b). There are seven units, from top to bottom: shallow aquifer, upper confining bed, middle aquifer, lower confining bed, lower aquifer, undifferentiated unconsolidated deposits, and bedrock, which forms the base of the ground-water system.

The hydrogeologic units were mapped by constructing 10 hydrogeologic cross sections, and mapping the extent, thickness, and top altitude of selected hydrogeologic units. Five cross sections previously defined by Jones (1996b) were reproduced in this study, and new sections were constructed in areas not defined by Jones (1996b).

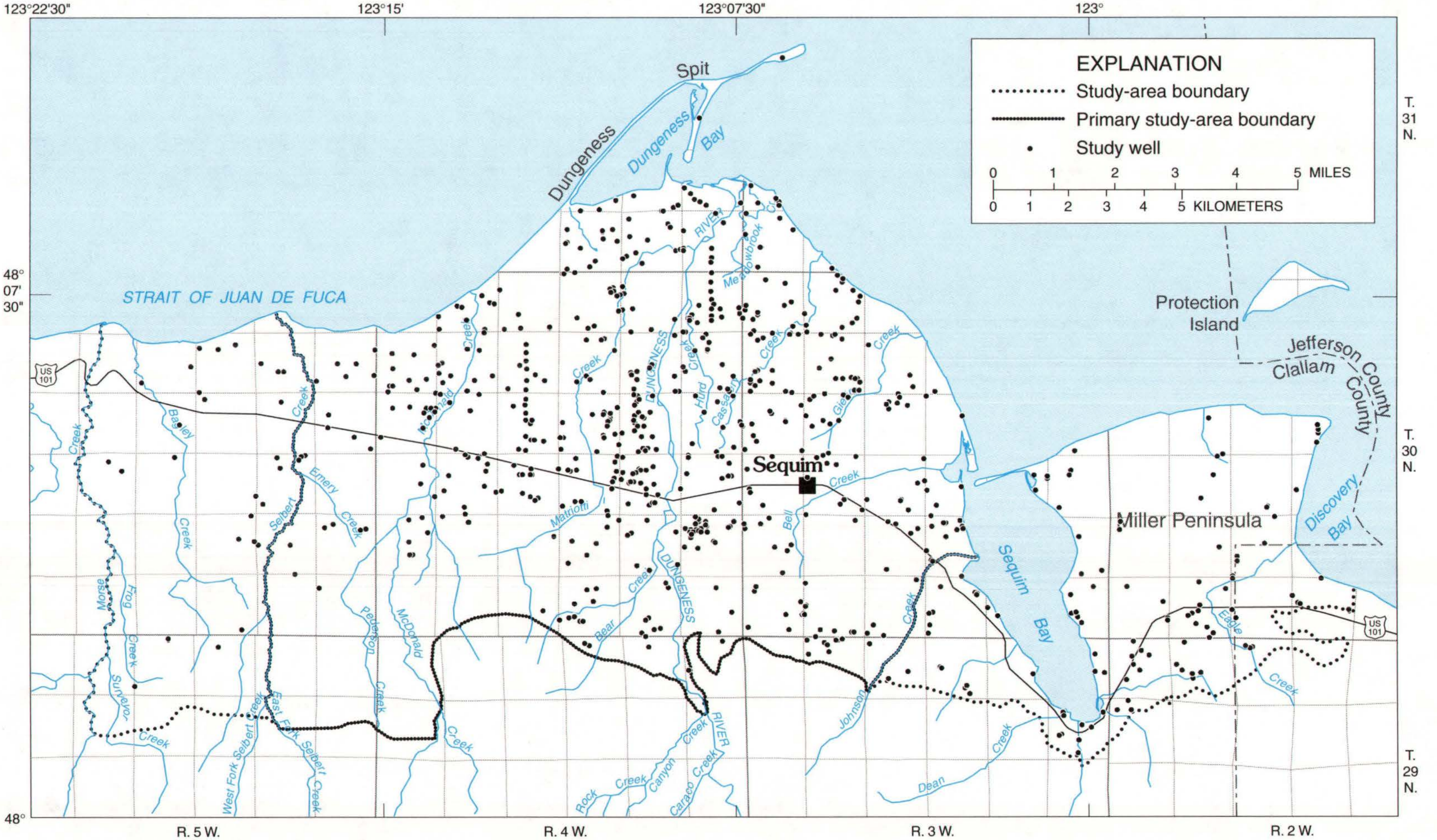


Figure 10. Locations of the study wells.

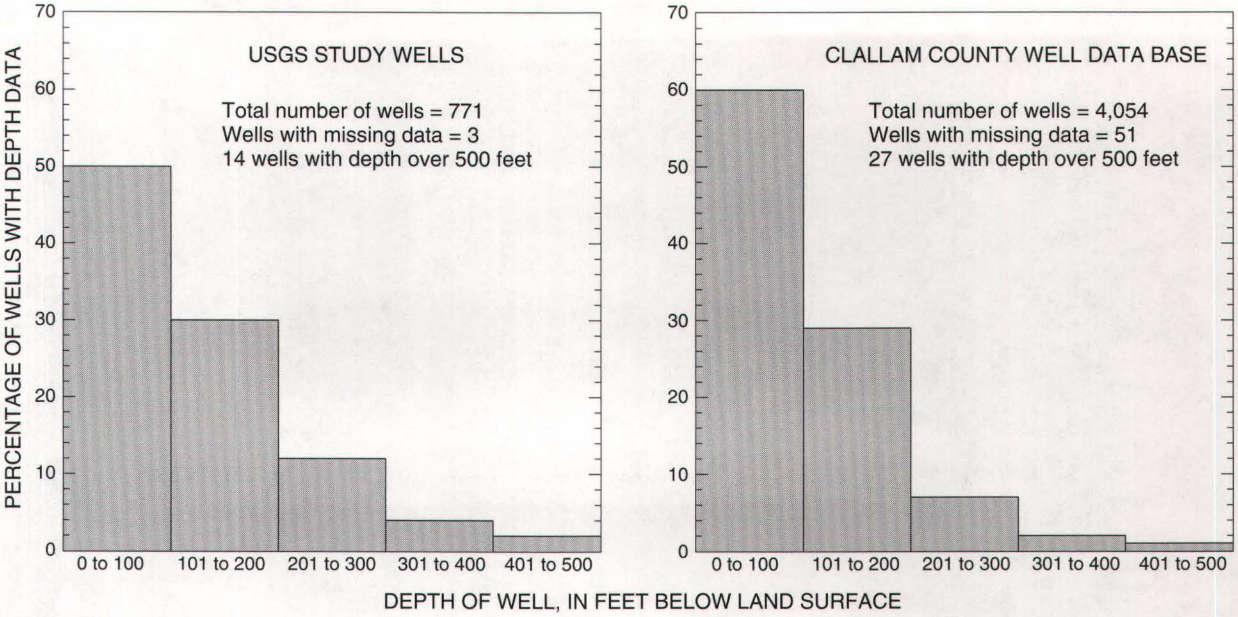


Figure 11. Distributions of depth of study wells and wells in Clallam County data base, Sequim-Dungeness area, Washington.

The principal source of information was lithology from drillers' logs for 608 field-checked wells in the USGS data base and published surficial geologic maps (Othberg and Palmer, 1980 a,b,c,d). The remaining 163 wells in the data base were not used in the analysis because 97 wells had no lithologic logs and 66 wells had redundant lithologic information. In addition to the drillers' logs, some interpreted lithology and geophysical information in geologic consultant reports were used to help define the framework (Associated Earth Sciences, Inc., 1991; Northwestern Territories, Inc., 1990; Pacific Groundwater Group, 1995a and 1995b; Sweet-Edwards/EMCON, 1991a). Much of the hydrogeologic analysis was performed using a geographic information system (GIS) that included locations and lithologic information for the 608 wells, land-surface altitudes at a 30-meter cell size resolution (digital elevation models (DEM's)), and surficial geology from Othberg and Palmer (1980, a,b,c,d).

The first step in the hydrogeologic analysis was to estimate the top-altitude boundary of each hydrogeologic unit in each lithologic well log. Starting with land surface (top of shallow aquifer), the descriptions of sand, silt, clay and combinations of such material were evaluated and boundaries of units were estimated by grouping adjacent material into units of similar hydrogeologic properties. General correlations are used, which results in a hydrogeologic unit that is mostly coarse or fine grained.

Hydrogeologic cross sections were constructed to provide a three-dimensional picture of the hydrogeologic framework and to provide data and information for the mapping of extent, thickness, and top altitudes of the hydrogeologic units. A total of 188 wells were selected to construct the 10 hydrogeologic cross sections. Four cross sections from Jones (1996b) were used to produce sections A-A', B-B', H-H', and I-I' in this report. One cross section from Jones (1996b) was extended in this study into two cross sections (C-C' and D-D'). New wells were incorporated in these cross sections where information was available; therefore, some minor modifications were made to the Jones (1996b) cross sections with the addition of new data. In addition to the Jones (1996b) cross sections, four new cross sections were constructed (E-E', F-F', G-G', and J-J').

Extent, thickness, and top altitude maps were constructed after the completion of the hydrogeologic cross sections. Data from the 10 cross sections were extrapolated and used in conjunction with the top altitude data from the remaining 420 wells to construct maps of the top altitude of the upper confining bed, middle aquifer, and lower confining bed. Thickness maps were constructed for the shallow aquifer, upper confining bed, and middle aquifer. The top surface of the shallow aquifer is land surface, and DEM data were used with the top surface of the upper confining bed to construct the thickness of the shallow aquifer. To construct the top surface and thickness of a unit, 50-ft contours of equal altitude or thickness were drawn on the basis of cross-section data and the altitude and thickness of the unit at a well. The thickness of unconsolidated deposits in the Puget Sound Lowland was estimated in a regional study by Jones (1996a). Those data were used in this study with some slight modifications on the basis of the additional information from this study. The top surface of bedrock was estimated by subtracting the thickness of all unconsolidated deposits (Jones 1996a and 1996b) from land surface derived from DEM's.

Ground-Water System

Boundaries and Directions of Flow

Ground-water flow boundaries of the hydrogeologic units were described using the data and information derived from the hydrogeologic analysis. Directions of ground-water flow were inferred from measurements of water levels in wells. In March 1996, water levels were measured in 214 wells for a synoptic picture of the potentiometric surfaces of the shallow and middle aquifers. In addition to the March 1996 water levels, water levels measured in another 425 wells were also used to augment the analysis, especially in areas of meager March 1996 data. The USGS, other government agencies, and drillers measured the 425 water levels. Thirty-seven water levels were measured during 1995–96, 323 water levels were measured during 1970–94, and 65 water levels were measured before 1970. All 639 water levels were plotted on a map, and 50-ft contours of equal water-level altitude were drawn through the point data. Priority was given to the March 1996 water levels. Using the 425 water levels measured at different times was reasonable because they were only used to augment the analysis, and the 50-ft contours have probably changed little during the past 30 years.

Clallam County made monthly water-level measurements in 47 wells during this study. Twenty-seven of those wells were measured monthly by the USGS during 1979-80. In addition, Ecology measured water levels once every 3 months in seven wells during this study, and all those wells were measured monthly during 1979-80.

Hydraulic Properties

Horizontal hydraulic conductivity of the hydrogeologic units was estimated in this study from specific-capacity data obtained from driller's logs of the study wells. The specific-capacity data were converted to hydraulic conductivity using one of two equations, depending on the method of well construction. Only data from wells with complete specific-capacity information (discharge rate, discharge time, drawdown, well-construction data, and lithologic log) were used, and all wells were pumped for a minimum of 1 hour.

For a well that had a screened, perforated, or open-hole interval (a section of a well in bedrock with no casing or screen), the modified Theis equation (Ferris and others, 1962) was used to estimate transmissivity. This equation, commonly solved for transmissivity using Newton's iterative method (Carnahan and others, 1969), is

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

where

T is transmissivity of a layer of the hydrogeologic unit (equal to the length of the open interval of the well), in square feet per day;

Q is discharge, or pumping rate, of the well, in cubic feet per day;

s is drawdown in the well, in feet;

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

r is effective radius of the well, in feet; and

S is storage coefficient, dimensionless.

The storage coefficients used in equation 1 were 0.12 for the shallow aquifer and 0.00001 for all other hydrogeologic units. Drost (1983) used 0.12 for the shallow aquifer, and the average of three values used by Drost (1983) for the middle aquifer is about 0.00001.

Horizontal hydraulic conductivity for the wells with screened, perforated, or open-hole intervals was computed using the transmissivity from equation 1 and the following equation:

$$K_h = \frac{T}{b} \quad , \qquad (2)$$

where

K_h is horizontal hydraulic conductivity of the hydrogeologic unit, in feet per day;

T is transmissivity, computed from equation 1; and

b is length of open interval of well as described in the driller's water well report.

A second equation was used to estimate hydraulic conductivity for wells having only an open end, and thus no vertical dimension to the opening. Bear (1979) provides an equation for hemispherical flow to an open-ended well that just penetrates the upper part of an aquifer. When modified for spherical flow to an open-ended well within an aquifer, the equation becomes

$$K_h = \frac{Q}{4\pi s r} \quad , \qquad (3)$$

where

K_h is horizontal hydraulic conductivity of the hydrogeologic unit, in feet per day;

Q is discharge, or pumping rate of the well, in cubic feet per day;

s is drawdown in the well, in feet; and

r is radius of the well, in feet.

The horizontal hydraulic conductivities computed from equations 1–3 have several limitations and biases, because all the assumptions of the equations are not met and because of the locations of the wells. The estimates of conductivities in this study, therefore, should only be considered as rough values. They are useful for relative comparisons within the study area, but should be used with caution in hydrologic calculations and for comparison with other study areas.

Equation 1 has many assumptions (Ferris and others, 1962), but a primary one is that all flow to the pumping well moves in a horizontal direction. The transmissivity and horizontal hydraulic conductivity computed from equations 1 and 2 are for a layer of the hydrogeologic unit that corresponds to the open interval of a well. The assumption of horizontal flow to this open interval is reasonable because the glacial hydrogeologic units in the study area are heterogeneous with horizontal layers of coarse and fine material, and the horizontal component of flow is generally much larger than the vertical component. This method results in a possible bias toward lower values of hydraulic conductivity, because the drawdown in a pumped well is usually greater than the drawdown in the adjacent aquifer due to well losses (turbulent flow near the screen or perforations).

Equation 3 is based on the assumption that ground water can flow at the same rate in all directions, and specifically that horizontal and vertical hydraulic conductivities are equal. As discussed above, this is not likely to be true for glacial material. This equation was still used assuming that the open end of the well is located in a layer of isotropic coarse material and the upper and lower boundaries of finer material have no appreciable effect on the pumping rate and drawdown.

The hydraulic conductivities computed in this study are generally biased toward higher values because of the nature of the statistical sample of inventoried wells. The ideal statistical sample of wells would represent all the horizontal and vertical variations of lithology and pore-size structure in the hydrogeologic units. The wells used in this study represent only the more productive parts of the units because they are primarily domestic wells that were drilled for water-supply purposes. When a driller installs a well, the depth, location, and construction of the well are determined to maximize the amount of water that can be pumped. Thus, the less productive fine-grained parts of the hydrogeologic units are bypassed until a coarse-grained productive part is found. The bias toward higher values of hydraulic conductivity is more acute for the confining units than for the aquifers. The overall hydraulic conductivity of the confining units is low, but the sample of inventoried wells is mostly located in the discontinuous coarse-grained lenses that have higher conductivities. The overall hydraulic conductivity of the aquifers is high because most parts of the aquifers are coarse-grained, and the sample of inventoried wells is likely to be located in the coarse material.

Because of the different methods and assumptions in equations 1 and 2, compared with equation 3, a possible bias in computed hydraulic conductivities from these two methods was investigated. In the shallow aquifer, computed conductivities from equations 1 and 2 were generally lower (median of 31 feet per day (ft/d) for 101 wells) than conductivities computed from equation 3 (median of 120 ft/d for 91 wells). The spread in data, however, was similar; the minimum values were 0.8 ft/d for equations 1 and 2 and 0.6 ft/d for equation 3, and the maximum values were 3,500 ft/d for equations 1 and 2 and 4,600 ft/d for equation 3. This bias in conductivities computed by different methods is not geographically distributed. Wells used for equations 1 and 2 are evenly distributed among the wells used for equation 3. There was no method bias in computed hydraulic conductivities for the middle aquifer; the computed median conductivities were 57 ft/d for equations 1 and 3 and 58 ft/d for equation 3.

Recharge

Sources of ground-water recharge in the study area are infiltration and percolation of precipitation, percolation of unconsumed irrigation water, leakage from irrigation ditches, subsurface inflow through the southern study-area boundary, and leakage from streams.

Recharge from infiltration and percolation of precipitation was estimated using a deep-percolation model (DPM) (Bauer and Vaccaro, 1987; Bauer and Mastin, 1997); a detailed discussion of the construction of the model is given in the section on recharge (pages 54-69). Data collected for the model are discussed here.

Data collected for the DPM include precipitation, soil water, and runoff. Daily precipitation was measured at five sites (Pre-1 to Pre-4, and Pre-6) by volunteers, and at a National Weather Service station near Sequim (Pre-5) (U.S. Department of Commerce, 1995-97) (fig. 12). Total volumetric soil-water content was measured at 16 sites once every six weeks using time domain reflectometry (TDR) (see Topp and others, 1980; and Bauer and Mastin, 1997). Runoff at a small, till-covered basin in the hills (Emery Creek) was estimated by periodic measurements of stream water levels at a staff gage, measurements of discharge and water level at the staff stage, and conversion of the stages to discharges using a rating curve. Streamflow in Emery Creek, an ephemeral stream, is a result of either overland flow or shallow subsurface flow through the soil. Other data used in the DPM include properties of soils and land-surface slope (Soil Conservation Service, 1975 and 1987), vegetation and land cover (fig. 4), air temperatures (U.S. Department of Commerce, 1995–97), and solar radiation (Matt Detlef, National Oceanic and Atmospheric Administration, written commun., 1998; H. H. Bauer, U.S. Geological Survey, written commun., 1998).

Percolation of unconsumed irrigation water and leakage from irrigation ditches were estimated using a water-budget approach, measured data on ditch-leakage rates, and the DPM. Informal agreements were made between the USGS, Clallam County, Washington State Department of Ecology (Ecology), Montgomery Water Group, Inc. and Jamestown S'Klallam Tribe, so that the collection and analysis of data for estimating irrigation recharge were shared between the USGS, Montgomery Water Group, Inc., Jamestown S'Klallam Tribe, and Clallam County. Montgomery Water Group, Inc. conducted a study for Ecology, concurrent with the USGS study, to develop a comprehensive water conservation plan for the agricultural water users of the Sequim-Dungeness area.

Diversions of water from the Dungeness River, discharge at intermediate points in the irrigation-ditch system, and discharge at most tailwaters (water returned from ditches to surface-water bodies) were estimated by the USGS with assistance from volunteers, Clallam County, and the Jamestown S'Klallam Tribe. Estimates were also made of irrigation-ditch water discharged to and diverted from McDonald Creek. Consumption of irrigation water by crops, leakage of water from irrigation ditches, and percolation of unconsumed irrigation water were estimated by Montgomery Water Group, Inc. using the ditch water-budget data collected by the USGS, crop-irrigation requirements, ditch-leakage rates from a previous study (Montgomery Water Group, Inc., 1993), and estimates of irrigation efficiencies. The USGS also used the DPM to independently estimate consumption of irrigation water by crops and percolation of unconsumed irrigation water; the methods used to estimate those components are described in the section on irrigation recharge (pages 69-74).

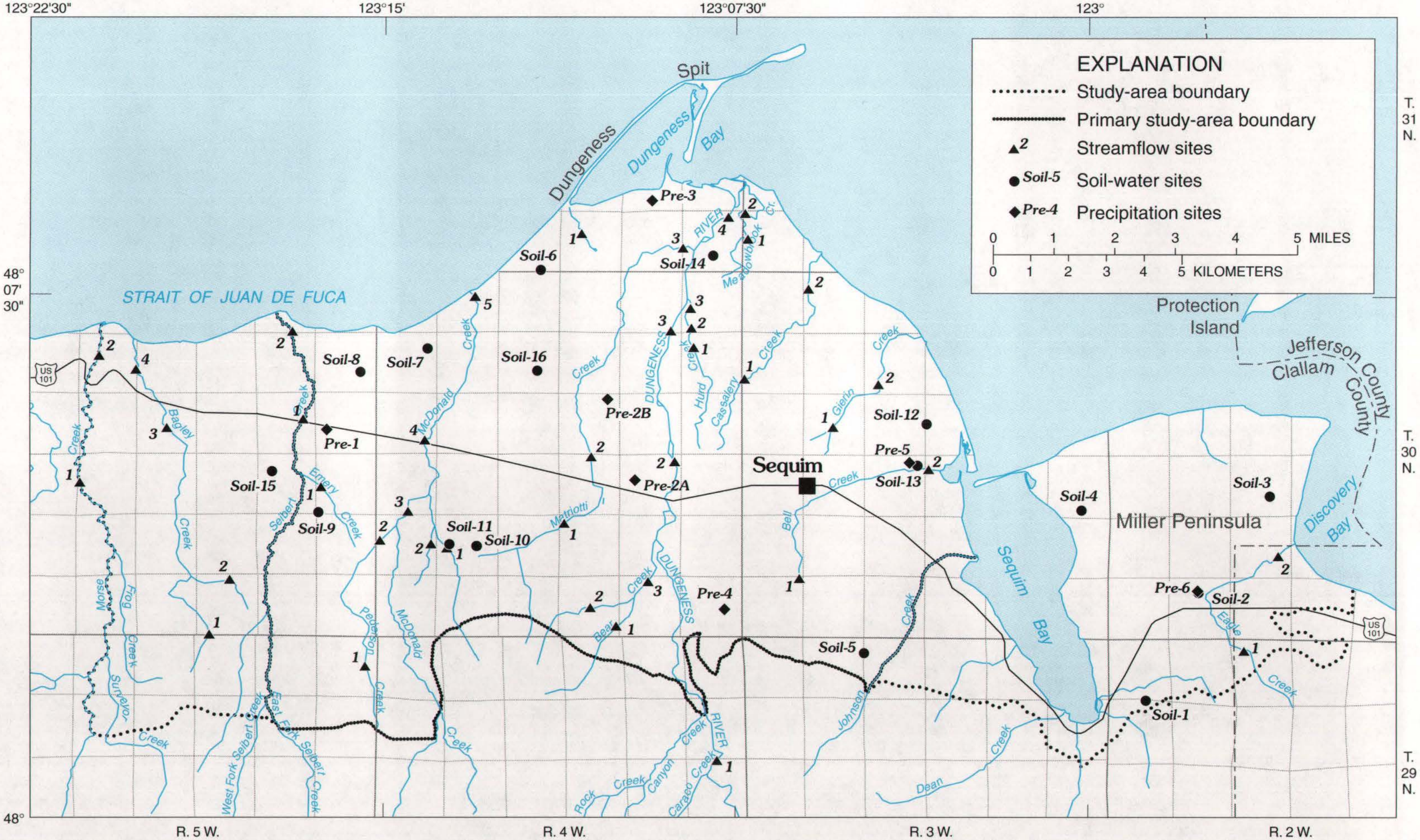


Figure 12. Locations of sites where soil water, streamflow, and precipitation data were collected.

Diversions of irrigation water from the Dungeness River and McDonald Creek, discharge at intermediate points in the ditch system, and discharge at tailwaters were estimated by making periodic measurements of water levels at 74 staff gages, developing rating curves by making discharge measurements at the staff-gage sites, and converting the gage heights to discharges.

About 35 volunteers were recruited to measure water levels at the 74 staff gages installed in the ditches (fig. 13). The average frequency of staff-gage measurements was 2-3 times per week at the outtake points for each irrigation company or district, once per week at intermediate points, and twice per week at most tailwaters. A total of 9,451 measurements were made between December 1, 1995, and September 30, 1997.

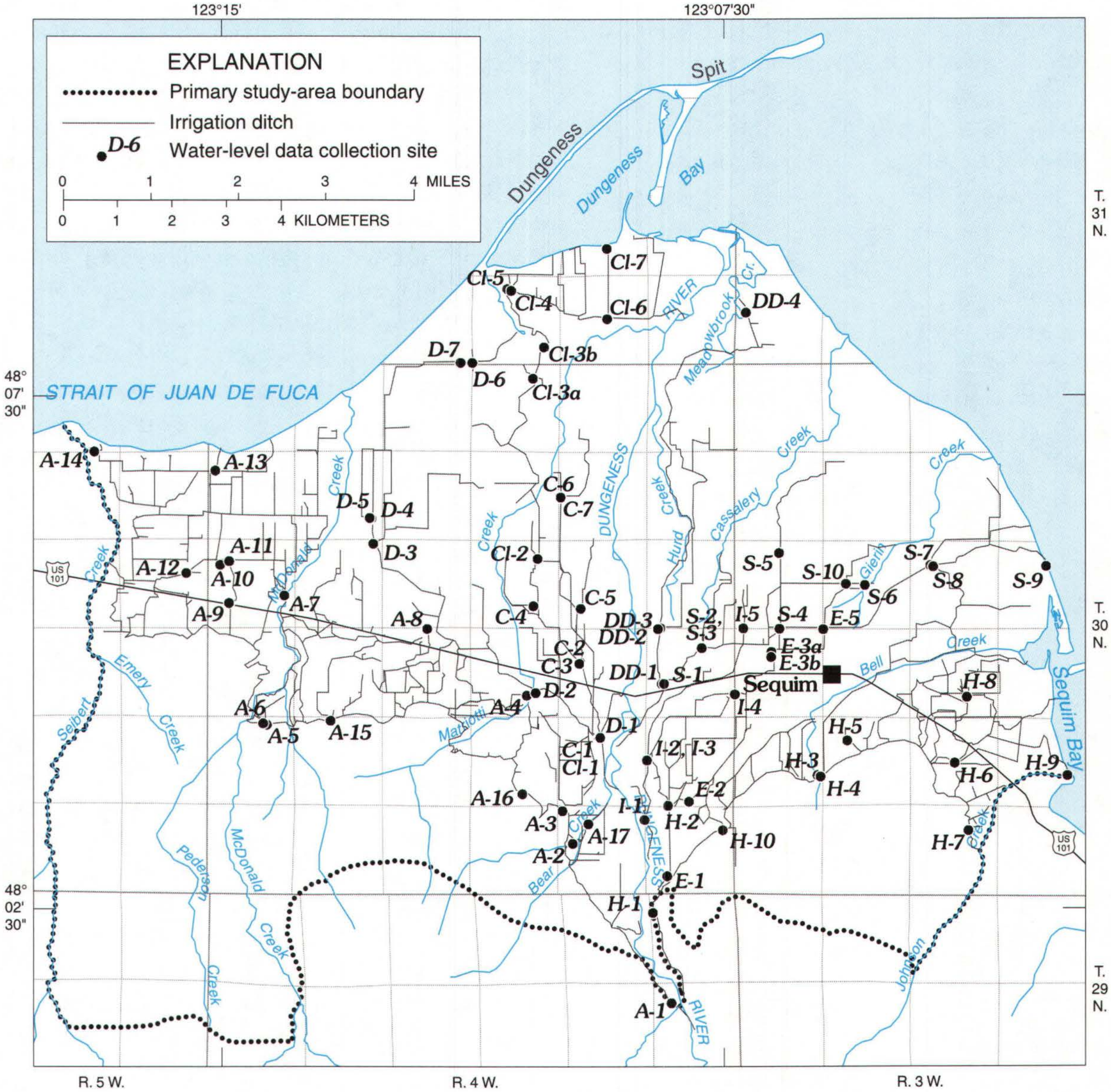


Figure 13. Irrigation ditches and locations of sites where water-level data were collected.

To estimate discharges at the staff-gage sites in the ditches, a minimum of three discharge measurements were made at each site, regression relations were developed between stage and discharge, and the staff-gage readings were converted to discharges using the regression relations. The resulting data were 9,451 estimates of daily discharge. These data are available in the USGS computer data base. The discharge measurements made at the staff-gage sites and the regression relations used to convert staff-gage heights to discharges are shown in appendix B.

Leakage from streams was estimated by measuring streamflow at the upstream and downstream ends of selected reaches in the Dungeness River and 15 other streams (fig. 12). The gains or losses in streamflow between the sites were assumed to be ground-water discharge (gain) or recharge (loss). The dates of streamflow measurements were May 3, 1996, and September 10, 1996, in the Dungeness River; September 29 and 30, 1997, in five streams outside the irrigated area; and October 6 and 7, 1997, in 10 streams inside the irrigated area. Because many irrigation tailwaters discharge into streams, the October measurements were made after the irrigation system was shut down on October 1, 1997. The streamflow measurements made in this study are expected to be within about 5 percent of the true value. If the magnitude of a gain or loss is less than the measurement errors of the bounding streamflows, then assumptions about ground-water recharge or discharge were made with caution.

Subsurface inflow through the southern boundary of the study area was estimated using Darcy's law with estimates of hydraulic conductivity, aquifer thickness, and hydraulic gradient. Darcy's law is:

$$Q = K_h bwi \quad , \qquad (4)$$

where

Q is discharge, in cubic feet per day;

K_h is horizontal hydraulic conductivity, in feet per day;

b is aquifer thickness, in feet;

w is width of section, in feet; and

i is hydraulic gradient, vertical difference in hydraulic head divided by horizontal distance, dimensionless.

Discharge

Ground water discharges as subsurface flow to saltwater bodies, flow to streams, and flow to springs. Subsurface flow to saltwater bodies and flow to springs were not estimated in this study. Discharge to streams was estimated using the stream-discharge data collected for the Dungeness River and 15 other streams in the study area.

Ground-water withdrawals during 1996 for the study area were estimated for the following water-use categories: domestic self-supplied, public supply, irrigated agriculture, golf courses, dairies, fish hatcheries, and commercial/industrial. As part of the same informal agreement for sharing the task of estimating irrigation recharge (see page 19), the task of estimating ground-water withdrawals was also shared among several parties. Pacific Groundwater Group, as a subcontractor to Montgomery Water Group, Inc., and Clallam County estimated the ground-water withdrawals. The USGS estimated the hydrogeologic units from which well water was withdrawn.

Total gross ground-water withdrawals for 1996 were estimated on the basis of average water use per connection (350 gallons per day (gal/d)) for domestic wells, metered withdrawals and average use per connection (350 gal/d) for public-supply wells, and a combination of metered withdrawals and average uses for the other categories (Peter Schwartzman, Pacific Groundwater Group, Seattle, Wash., written commun., 1998). In addition to the gross withdrawals, net withdrawals were also estimated. Net withdrawal is the amount of water actually consumed that does not return to the ground-water system. A large part of the domestic self-suppled water and public-supplied water is returned to the ground-water system by septic systems. A septic system returns water to the ground-water system by percolation of the water that leaves its drainfield. It was assumed that 70 percent of the water withdrawn from wells in houses with septic systems percolates to the water table. M. van Heeswijk (U.S. Geological Survey, written commun., 1998) estimated a value of 70 percent for part of Kitsap County, Wash., on the basis of public-supply data during periods of low evapotranspiration. Sapik and others (1988) also used a value of 70 percent in Island County, Wash. It was assumed that all domestic self-supplied withdrawals were at houses with septic systems. A comparison of public-supply systems and areas with sewers showed that about 70 percent of the homes served by public-supply systems had septic systems. Some of the water used for irrigated agriculture, golf courses, and dairies returns to ground water; however, the total amount was considered negligible and was not estimated.

Collection of Water Samples for Analysis of Nitrogen

To describe the magnitude and distribution of nitrogen in ground water, water samples were collected from 74 wells in July-August 1996 and were analyzed for concentrations of dissolved nitrogen species, including ammonia, ammonia plus organic nitrogen, nitrite, and nitrite plus nitrate. To facilitate the analysis of sources of nitrate, analyses were also made for dissolved iron and chloride, and field measurements were made for specific conductance, temperature, pH, and dissolved oxygen (DO) concentration. The principal method of estimating probable sources of nitrate was a loading analysis in which estimates were made of the amount of nitrogen that enters the ground-water system.

Methods used to collect and analyze water samples followed guidelines presented in several U.S. Geological Survey Techniques of Water-Resources Investigations Reports (TWRI) (Friedman and Erdmann, 1982; Fishman and Friedman, 1989; and Fishman, 1993). In addition, the field procedures outlined by M.A. Sylvester, L.R. Kister, and W.B. Garrett, eds. (U.S. Geological Survey, written commun., 1990) supplemented the TWRI guidelines.

All the wells selected for sampling had been inventoried as part of this study, were open to only one hydrogeologic unit, and had an existing pump that could be used for water sampling. Most of the selected wells are used for individual domestic supply, but some are used for public supply or irrigation. Most of the wells (64 wells) were selected from the primary study area, as this is the area of most concern for nitrogen contamination. Most are shallow (63 are less than 150 ft deep), because an objective of the study was to estimate sources of nitrogen in ground water, and shallow ground water is closer to the sources. Another objective was to assess changes in nitrogen concentrations since 1980, so water samples were collected from 35 wells that had also been sampled in 1980.

Water samples were collected from a faucet as near to the wellhead as possible and ahead of any water treatment such as disinfection, softening, or filtration (fig. 14). Some samples were also collected after a small (less than 50 gal) storage/pressure tank if a faucet was not present near the wellhead or in the water distribution system ahead of the tank. Nylon or polyethylene tubing connected the faucet to a stainless-steel manifold mounted in a mobile water-quality laboratory. The manifold allowed the sample water to be fed directly either to a flow chamber, whole-water line, or filtration unit. At the flow chamber, temperature, pH, specific conductance, and DO concentrations were monitored continuously while purging several casing volumes of water from the well (and the volume of any storage or pressure tank, if necessary).

When the flow-chamber measurements were stable for about 10 minutes (indicating that water was being drawn from the aquifer), whole- and filtered-water samples were collected from the appropriate manifold outlet. Stable measurements for 10 minutes were defined as less than a 5 percent change in specific conductance, temperature, and DO, and less than 0.2 pH units. Water for laboratory analysis of dissolved constituents was filtered through a 0.10-micron membrane filter. The 0.10-micron filter was used instead of a 0.45-micron filter commonly used for dissolved constituents because it is better for ground water that may have high iron concentrations (Wood, 1981). Water with high iron concentrations often contains colloidal particles of iron that are between 0.10 and 0.45 microns in diameter. In this report, concentrations determined from filtered-water samples are referred to as dissolved concentrations.

After collection, the water samples were preserved and chilled, if required, according to standard USGS procedures (Britton and Greeson, 1988; C.A. Watterson and A.T. Kashuba, U.S. Geological Survey, written commun., 1993). Samples to be analyzed by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., were sent by first-class mail the next day. Analytical procedures used at the NWQL are described by Fishman and Friedman (1989) and Fishman (1993).

All 74 ground-water samples were analyzed at the NWQL for concentrations of dissolved chloride, iron, and the nitrogen species (ammonia, ammonia plus organic nitrogen, nitrite, and nitrite plus nitrate). Specific conductance, temperature, pH, and DO concentration were measured in the field with meters, using standard USGS methods (Wood, 1981; M.A. Sylvester, L.R. Kister, and W.B. Garrett, eds., U.S. Geological Survey, written commun., 1990).

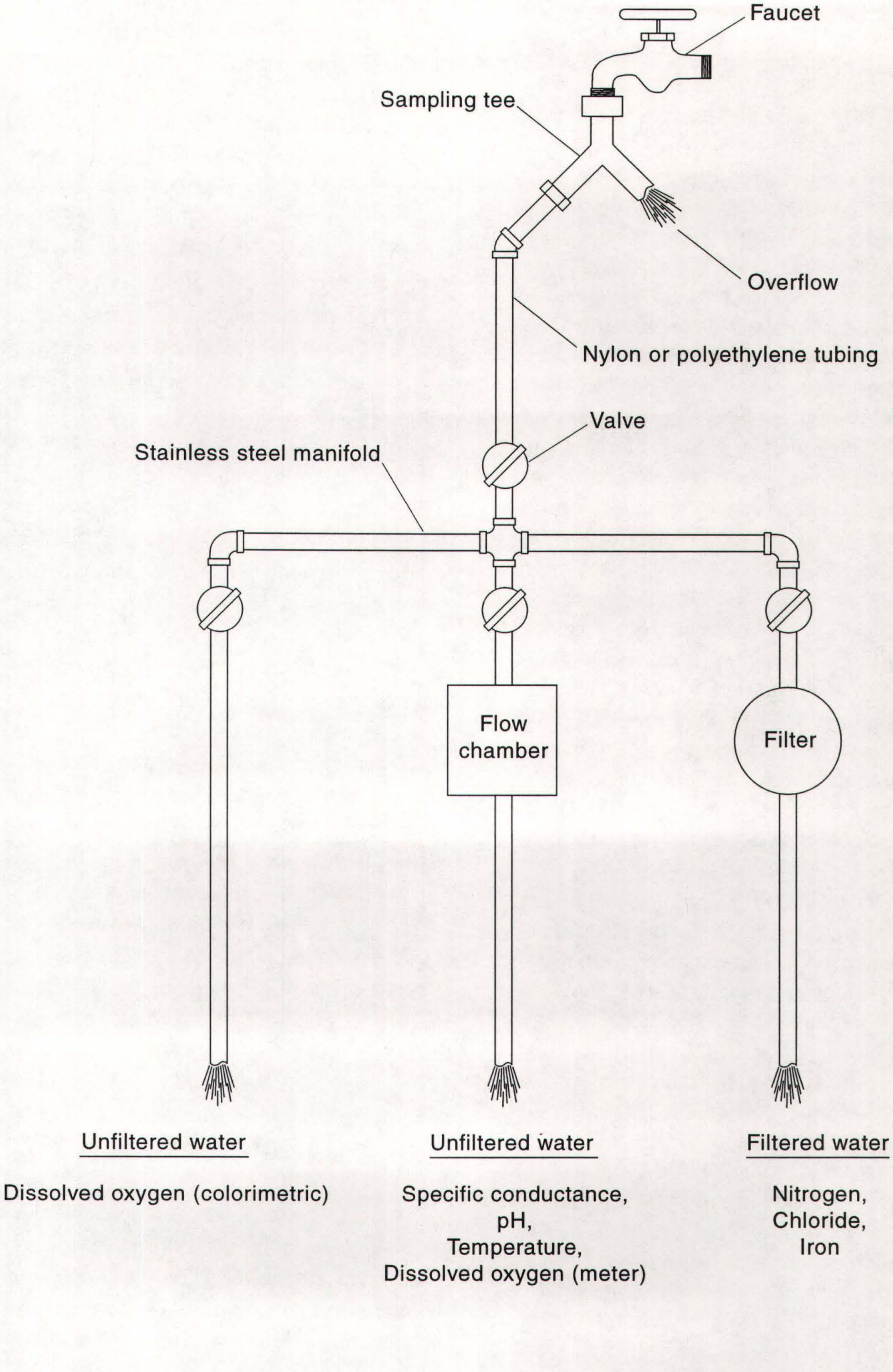


Figure 14. Ground-water sampling system for domestic wells.

Dissolved-oxygen concentrations of greater than 1.0 milligram per liter (mg/L) were determined with a meter, and DO concentrations of less than 1.0 mg/L were determined with a Rhodazine-D colorimetric method (White and others, 1990) developed by Chemetrics, Inc.

The study's quality-assurance program for water-quality data collected in the field included meter calibration, duplicate samples, and field-blank samples. To ensure the accuracy of field pH and specific-conductance measurements, meters were calibrated daily with known standards. Dissolved-oxygen meters were calibrated daily using the water-saturated air technique. Nine duplicate water samples were collected and analyzed for selected constituents. Nine field-blank samples were prepared for selected constituent analysis using laboratory-supplied inorganic-free water. Duplicates and field blanks were processed, treated, and submitted to the NWQL in the same manner as the regular field ground-water samples.

After review and acceptance of the sample analyses by the NWQL, the resulting analytical data were released to the USGS district office in Tacoma, Wash., by electronic transfer. District and project personnel further reviewed the data for quality and accuracy (see appendix C). The project quality-assurance plan (B.E. Thomas, U.S. Geological Survey, written commun., 1995), a general plan by Friedman and Erdmann (1982), and a quality control manual by Jones (1987) provide additional details concerning field and laboratory quality-assurance procedures and data review. The results of the quality-assurance practices and the analytical data for the samples collected and processed in the field are discussed in appendix C.

Methods of Statistical Hypothesis Testing

Hypothesis testing is a statistical method used in this study to make objective decisions about relations between data. Hypotheses are ideas or concepts that describe systems or populations. In order to test a hypothesis, data are collected to provide samples that represent the populations. Statistical tests are applied to such data, and results of the tests can be used to substantiate a hypothesis or to determine if a hypothesis must be modified or rejected.

Most of the hypothesis testing in this study was done to evaluate and compare groups of data. A null hypothesis is established, which states that there is no difference between the groups and they are from the same population. The alternative hypothesis (the groups are different) is the situation anticipated to be true if the evidence (data) show that the null hypothesis is unlikely. An example of a hypothesis test of two groups performed in this study was the comparison of nitrate concentrations in ground-water samples collected at two different times, in 1980 and in 1996. The null hypothesis is that the nitrate concentrations in both groups are the same, and therefore, 16 years of input of nitrogen to the ground water have had no effect on nitrate concentrations. If this hypothesis is rejected, then nitrate concentrations significantly changed between 1989 and 1996.

An important feature of the statistical methods used to test hypotheses is the computed probability or significance level (p-value), which is a measure of the strength of evidence (data) for supporting or rejecting the hypothesis. For example, a p-value of 0.03 means that there is a 0.03 probability or a 3 percent chance that the null hypothesis is correct. Before the test is made, a threshold significance level (α) is selected at which the null hypothesis is rejected or not rejected. For this study, the threshold level is 0.05; a computed p-value of less than 0.05 is significant and a computed p-value of more than 0.05 is not significant. Thus, using the example in the previous paragraph, if a test computes a p-value of less than 0.05; the null hypothesis is rejected, and we say that the two groups are significantly different and nitrate concentrations significantly changed over the past 16 years.

The threshold significance level (α) of 0.05 used in this study is for independent comparisons of groups of data. When multiple comparisons are made by splitting one set of data into several groups, the comparisons are dependent, and the threshold significance level must be decreased to account for this dependence. The equation (Sokal and Rohlf, 1981) used to compute the adjusted threshold level is

$$\alpha' = 1-(1-\alpha)^{\frac{1}{k}} \qquad (5)$$

where

α' is threshold significance level adjusted for dependence of comparisons;

α is original threshold significance level for independent comparisons; and

k is number of comparisons.

An example of dependent comparisons is when ground-water samples are collected from wells in a study area during a short period of time, the samples are split into three groups on the basis of land-use type, and then three comparisons are made between nitrate concentrations in the three groups. If the outcome of one comparison is significant, then the outcome of the other two comparisons are more likely to be significant.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework describes the physical boundaries and lithology of the hydrogeologic units in the study area. Hydrogeologic units are aquifers or confining beds, and they are a composite of the unconsolidated geologic units in the study area. In addition to a description of the boundaries and lithology of the hydrogeologic units, this section of the report also contains a brief description of the geologic history of the study area to provide the reader with background on how the geologic units were formed.

Geologic History

Many studies have contributed to our current understanding of the geologic history of the study area. The summary that follows is taken mostly from Noble (1960) and Vaccaro and others (1998). Other descriptions of the geologic history of the Puget Sound area include Armstrong and others (1965), Blunt and others (1987), Bretz (1913), and Thorson (1980). The reader is referred to those studies for more detailed descriptions.

Western Washington, including the Puget Sound Lowland, has been influenced throughout geologic time by tectonic events, but the present topography and distribution of unconsolidated geologic deposits are largely a result of the glacial events during the Tertiary and Quaternary periods (Vaccaro and others, 1998). The Puget Sound Lowland is a structural basin bounded on the north by the Fraser River in Canada, on the east by the drainage divide of the Cascade Range, on the west by the drainage divide of the Olympic Mountains, and on the south by a series of low hills just south of Olympia, Wash.. Three or more continental glaciers are believed to have advanced into Washington from the north during the Pleistocene Epoch (10,000 to 1,600,000 years before present). Repeated episodes of ice advance and recession, called glaciations, resulted in thick accumulations of glacial and interglacial deposits throughout the region (Noble, 1960).

The most recent glaciation, the Vashon Stade of the Fraser glaciation, originated in the coast range of British Columbia, Canada where the ice sheet moved southward into the Puget Sound Lowland about 18,000 years before present. The glacier advanced southward until it reached the Strait of Juan de Fuca, where it split into two lobes, the Juan de Fuca lobe and the Puget lobe. The Juan De Fuca lobe flowed west, blocking the Strait of Juan de Fuca, and the Puget lobe flowed south into the Puget Sound Lowland, blocking drainage to the north (Vaccaro and others, 1998). Approximately 13,500 years ago, the climate began to warm, causing the glacier to melt faster than it advanced, beginning the process of recession. As the glacier melted, the drainage to the north across the Puget Sound Lowland to the Strait of Juan de Fuca was eventually reestablished. Approximately 13,000 years ago, the ice of the final glaciation had thinned sufficiently to allow marine water back into the Puget Sound Lowland and float the remaining ice. Progressive melting of the ice resulted in the deposition of the last glacial deposit, the Everson drift (Noble, 1960).

Within the Sequim-Dungeness study area, the glacier flowed in a generally southward or westward direction to terminate at the foothills of the Olympic Mountains. The topography that existed before the Vashon advance is unknown, but was most likely a coastal shelf or plain that was derived from the ancestral Dungeness River. Glacial erratics have been found as high as 3,000 ft in the Olympic Mountains, indicating that the ice must have reached that altitude (Noble, 1960)

Geologic Units

The unconsolidated geologic units in the study area are glacial and nonglacial deposits of Quaternary age (Othberg and Palmer, 1980a,b,c). These deposits generally are heterogeneous and may be discontinuous in places. Beneath these unconsolidated deposits are Tertiary consolidated rocks that are referred to as bedrock in this report. The unconsolidated deposits generally are thin in the southern part of the study area where bedrock is at or near land surface and they thicken to the northeast, with a maximum thickness of about 2,500 ft (fig. 15).

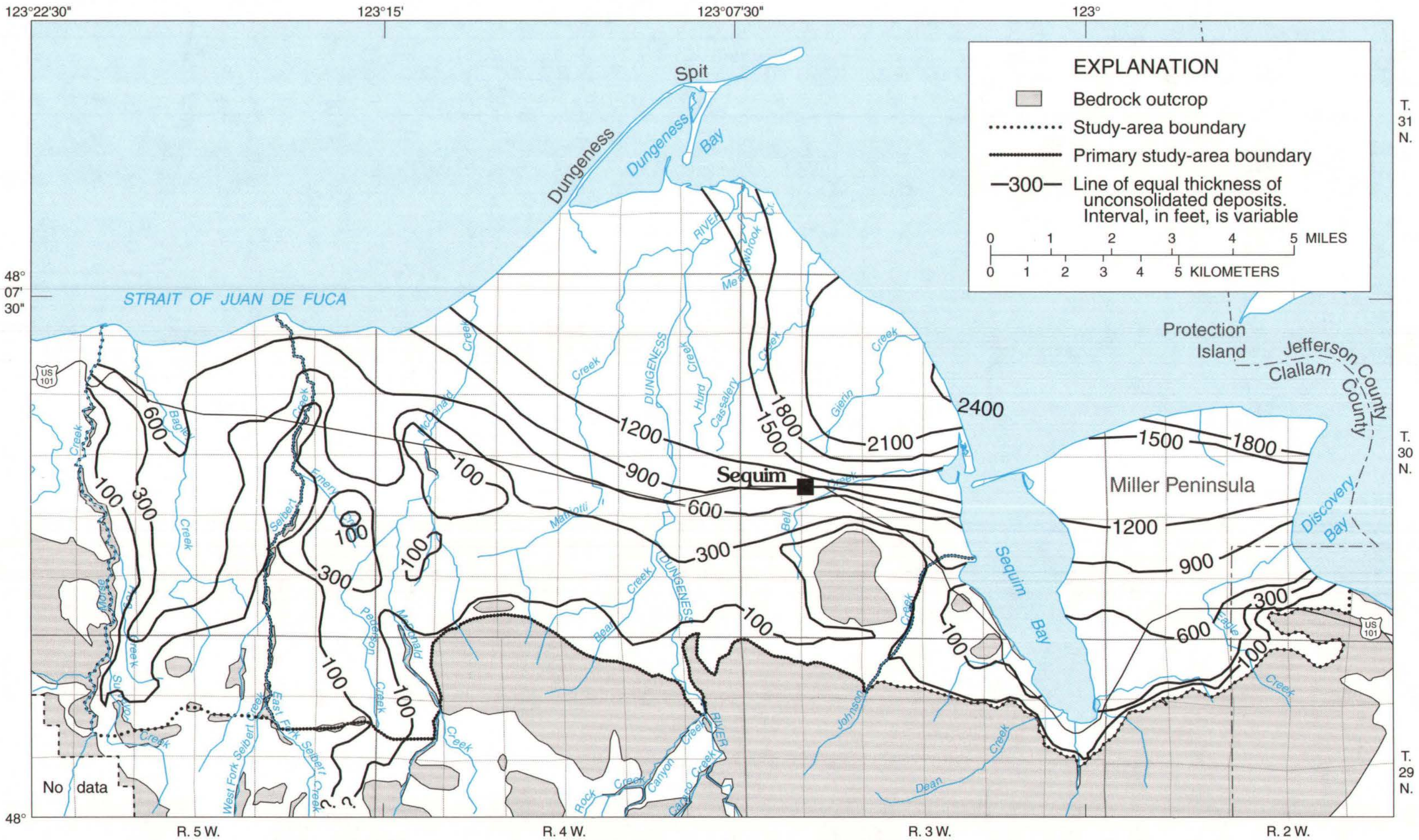


Figure 15. Thickness of unconsolidated deposits (Jones, 1996a).

The nonglacial surficial geologic units in the study area are alluvium, beach deposits, peat and marsh deposits, and older alluvium (fig. 16) (Othberg and Palmer, 1980 a,b,c,d). The alluvium was deposited along the present floodplain of the Dungeness River and varies in composition from gravels to finer-grained sands, silts and clays. Beach deposits of sand and gravel were deposited by longshore drift along the coastline. Peat and marsh deposits are scattered throughout the study area and were formed by the accumulation and decomposition of organic material in wet depressions and other areas of poor drainage. The older alluvium, found mostly east of the present Dungeness River, is a floodplain terrace deposit of the ancestral Dungeness River with a wide range of lithology from cobble gravels to progressively finer grain sizes.

The glacial surficial geologic units in the study area are Everson sand, Everson glaciomarine drift, Vashon recessional ice-contact and outwash deposits, Vashon till, Vashon reworked till, and Vashon advance outwash (fig. 16). Everson sand is sorted to stratified sand, located near the mouth of McDonald Creek. Everson glaciomarine drift is a poorly sorted, weakly stratified to massive deposit of pebbly silt and clay that is mostly in low-lying areas in the northern part of the study area. Vashon recessional ice-contact and outwash deposits, and Vashon advance outwash are primarily coarse-grained deposits in the north-central part of the study area. Vashon till is a lodgement till that is compact, poorly sorted nonstratified pebbly sandy silt with occasional boulders. It is generally quite hard as a result of compaction by thick glacier ice. Vashon till is found throughout the study area. Vashon reworked till is primarily sand and gravel stream deposits resulting from the washing and winnowing of Vashon till. The reworked till is found in the west-central part of the study area.

Bedrock units exposed within the study area include sedimentary and volcanic rocks. The sedimentary rocks are marine sandstone, siltstone, mudstone, and conglomerate of the Twin River Group, Aldwell Formation, and Blue Mountain Unit. The volcanic rocks are submarine basalt flows and breccias of the Crescent Formation (Tabor and Cady, 1978). Bedrock crops out in the foothills along the southern boundary of the study area and in the valleys along Canyon, McDonald, Siebert, and Morse Creeks. The bedrock shown on figure 16 includes areas mapped as Vashon till over bedrock by Othberg and Palmer (1980 a,b,c,d). The till in that mapping unit is generally less than 10 ft thick and is therefore not of sufficient thickness to be defined as an independent outcrop of unconsolidated material.

Hydrogeologic Units

Hydrogeologic units are the aquifers and confining beds that compose the ground-water system in the study area. In general, the aquifers are coarse-grained unconsolidated deposits and the confining beds are fine-grained unconsolidated deposits. Bedrock contains less water and has much lower permeability than the unconsolidated deposits. The top surface of bedrock, therefore, is considered the base of the ground-water system in this study. The seven defined hydrogeologic units are (from top to bottom) shallow aquifer, upper confining bed, middle aquifer, lower confining bed, lower aquifer, undifferentiated unconsolidated deposits, and bedrock.

The three-dimensional geometry of the hydrogeologic units is shown in 10 hydrogeologic cross sections (figs. 17a–k), and the geometries of the shallow aquifer, upper confining bed, and middle aquifer are shown in maps of the extent, top altitude, and thickness of those units (figs 18-23).

The lateral correlations of hydrogeology in the study area were difficult to make because of uneven areal distributions of data and possibly different depositional environments. The most accurate definitions of the hydrogeologic framework were made in the primary study area because the density of data was adequate. Defining the hydrogeology of Miller Peninsula and of the area west of Siebert Creek was more difficult because the data are meager and the thickness and lithology of the geologic deposits appear to be slightly different than in the primary study area. Nonetheless, the same hydrogeologic classification scheme was applied to the entire study area for consistency.

The shallow aquifer extends throughout the study area where bedrock is not present at land surface (fig. 18). It contains alluvium, older alluvium, Everson sand, Everson glaciomarine drift, Vashon recessional ice-contact and outwash deposits, Vashon till, Vashon reworked till, and Vashon advance outwash (fig. 16) (Othberg and Palmer, 1980a,b,c,d). Because of the complex and discontinuous nature of the surficial deposits, the shallow aquifer was not delineated into individual coarse- and fine-grained deposits.

The upper confining bed lies below the shallow aquifer. It is comprised mainly of pre-Vashon silts and clays and contains locally discontinuous lenses of water-bearing sand and gravel. The typical thickness of the upper confining bed is about 75 ft, with a range of about 30 to 110 ft (figs. 17a–j and 19). Its typical thickness decreases from about 110 ft in the west to about 60 ft in Miller Peninsula, and increases from about 60 ft in the south to 90 ft in the north. Three percent of the study wells (24) are completed in thin, discontinuous lenses of sand and gravel.

The middle aquifer, which underlies the upper confining bed, contains pre-Vashon glacial outwash deposits of sand and gravel and interglacial coarse deposits. The aquifer is present in the middle, northern, and eastern parts of the study area (fig. 21), but is not present in the southern and southwestern parts (figs. 17f–i). The middle aquifer has a typical thickness of about 40 ft and ranges in thickness from about 10 to 70 ft. Its typical thickness increases from about 35 ft in the west to 50 ft in the east, and from about 25 ft in the south to 50 ft in the north. Thirteen percent of the study wells (101) are completed in the middle aquifer.

The lower confining bed underlies the middle aquifer. This unit is composed of till and interbedded clay, silt, and fine-grained sand, but may contain locally discontinuous lenses of water-bearing sand. Few wells penetrate this unit, but its extent is thought to be similar to that of the middle aquifer. The typical thickness is about 100 ft and ranges from about 10 to 300 ft. Only one of the study wells was completed in this unit.

The lower aquifer, which underlies the lower confining bed, is composed of sand with thin lenses of sand and gravel, silt, and clay. Few wells are completed in this aquifer, so meager data are available. The aquifer is present in the northern and eastern parts of the study area where the unconsolidated deposits are thick and is absent in the southern and southwestern parts of the study area where unconsolidated deposits are thin. The typical thickness is about 90 ft, with a range from about 10 to 180 ft. Six percent of the study wells (44) were completed in the lower aquifer.

Undifferentiated unconsolidated deposits lie between the lower aquifer and bedrock. Data are too meager to adequately define aquifers and confining beds in this unit. The unit is thin in the southern part of the study area and more than 1,000 ft thick in the northern part (figs. 15, 17a, and 17i). There are potentially productive aquifers in this northern part of the unit.

The bedrock in the study area is Tertiary sedimentary and volcanic rocks exposed along the foothills in the southern and southwestern parts of the study area, and in the valleys along Canyon, McDonald, Siebert, and Morse Creeks. Bedrock is an unreliable source of ground water because it yields relatively small quantities of water to wells. Most of the 26 wells completed in bedrock are in the southern part of the study area.

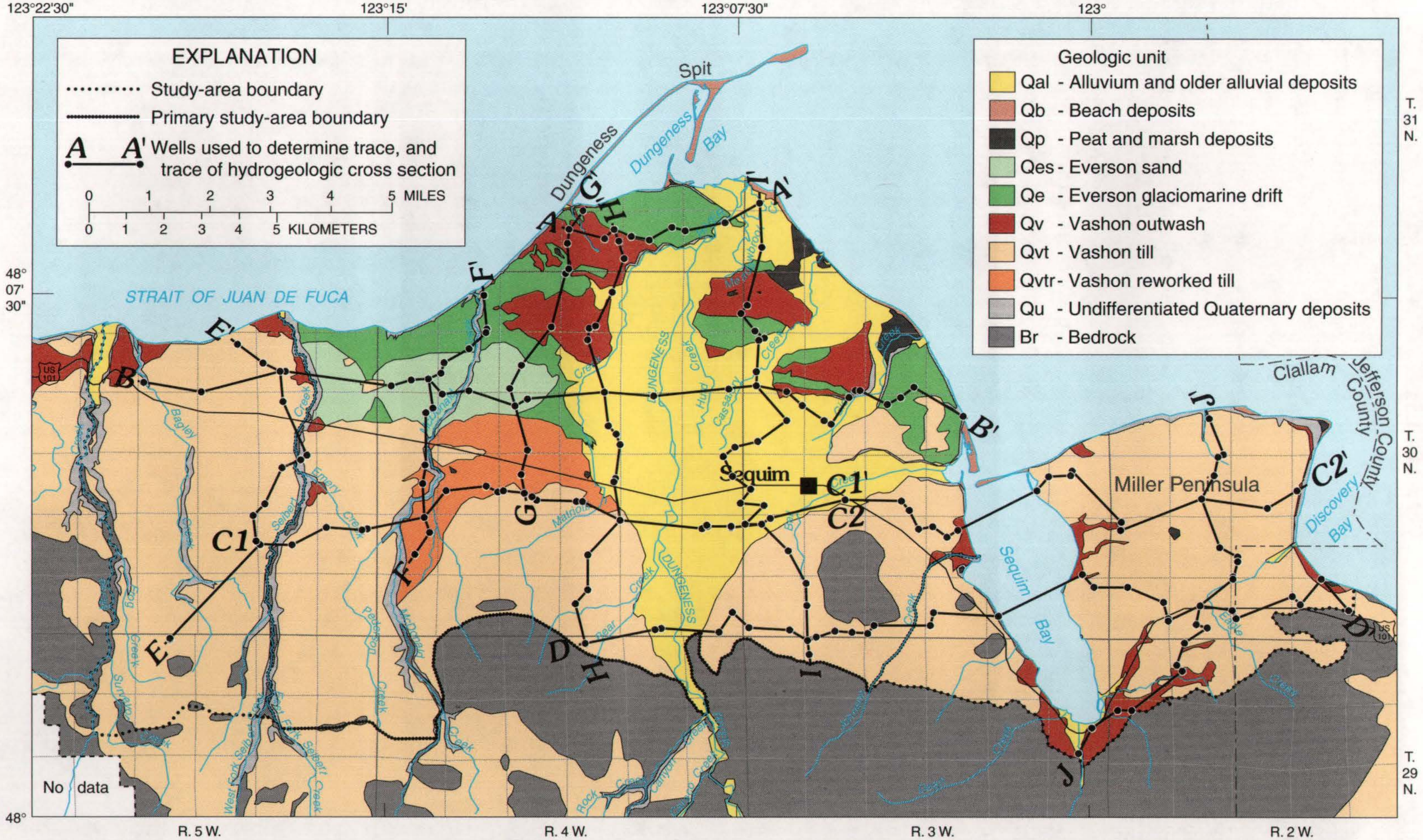


Figure 16. Generalized surficial geology and locations of hydrogeologic sections (Othberg and Palmer, 1980a,b,c,d).

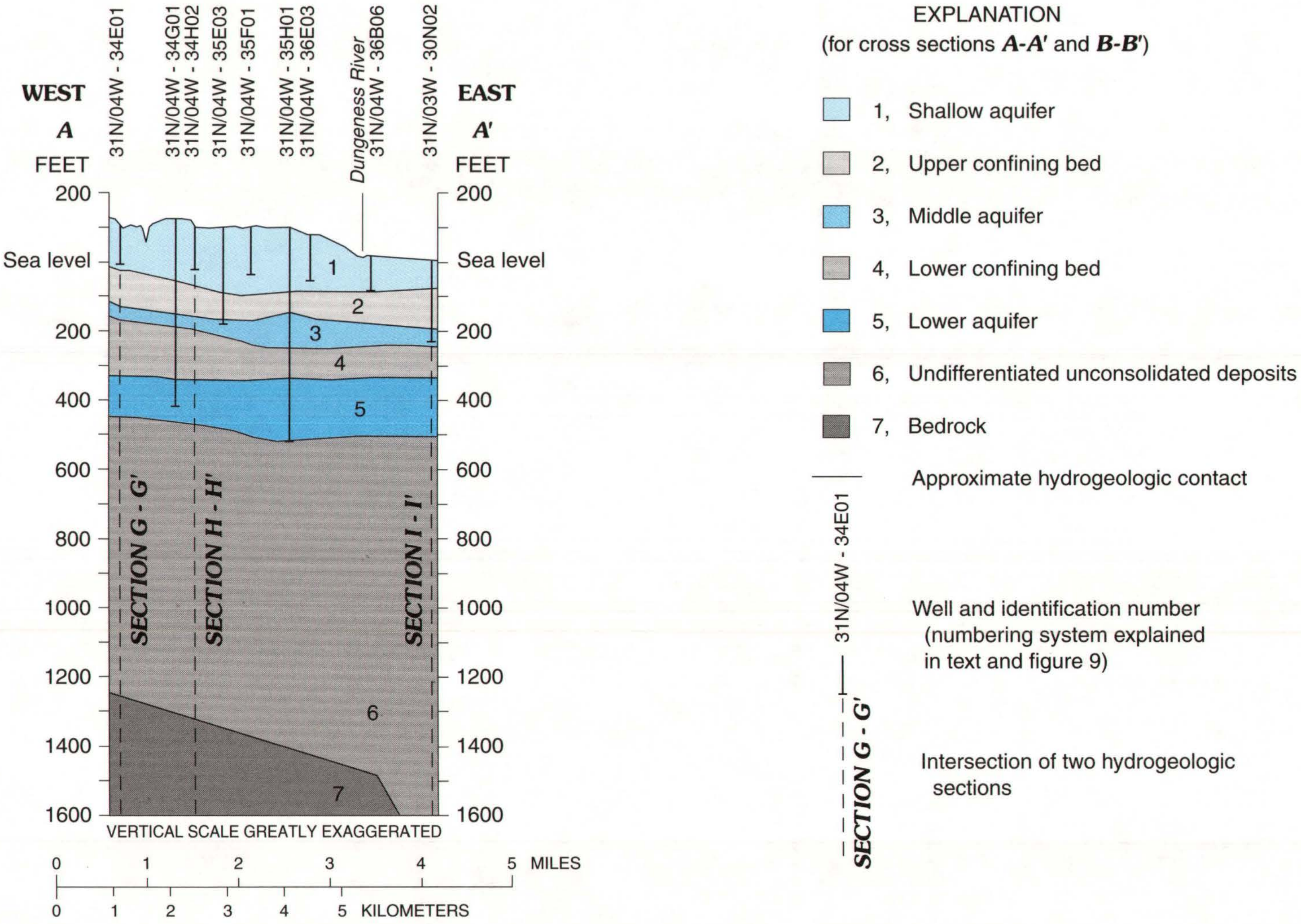


Figure 17a. Hydrogeologic cross section *A-A′*, Sequim-Dungeness area, Washington.

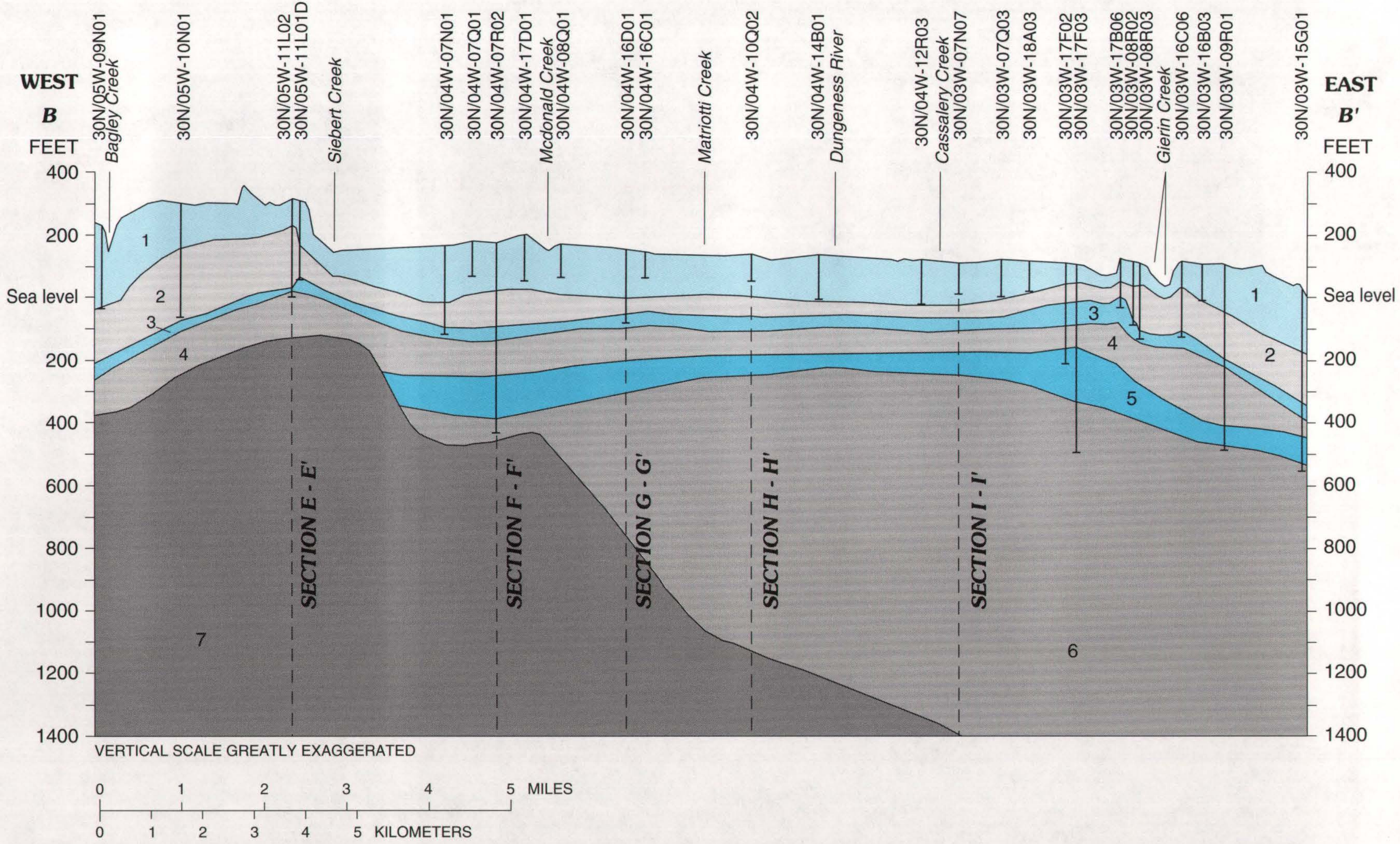


Figure 17b. Hydrogeologic cross section ***B-B'***, Sequim-Dungeness area, Washington.

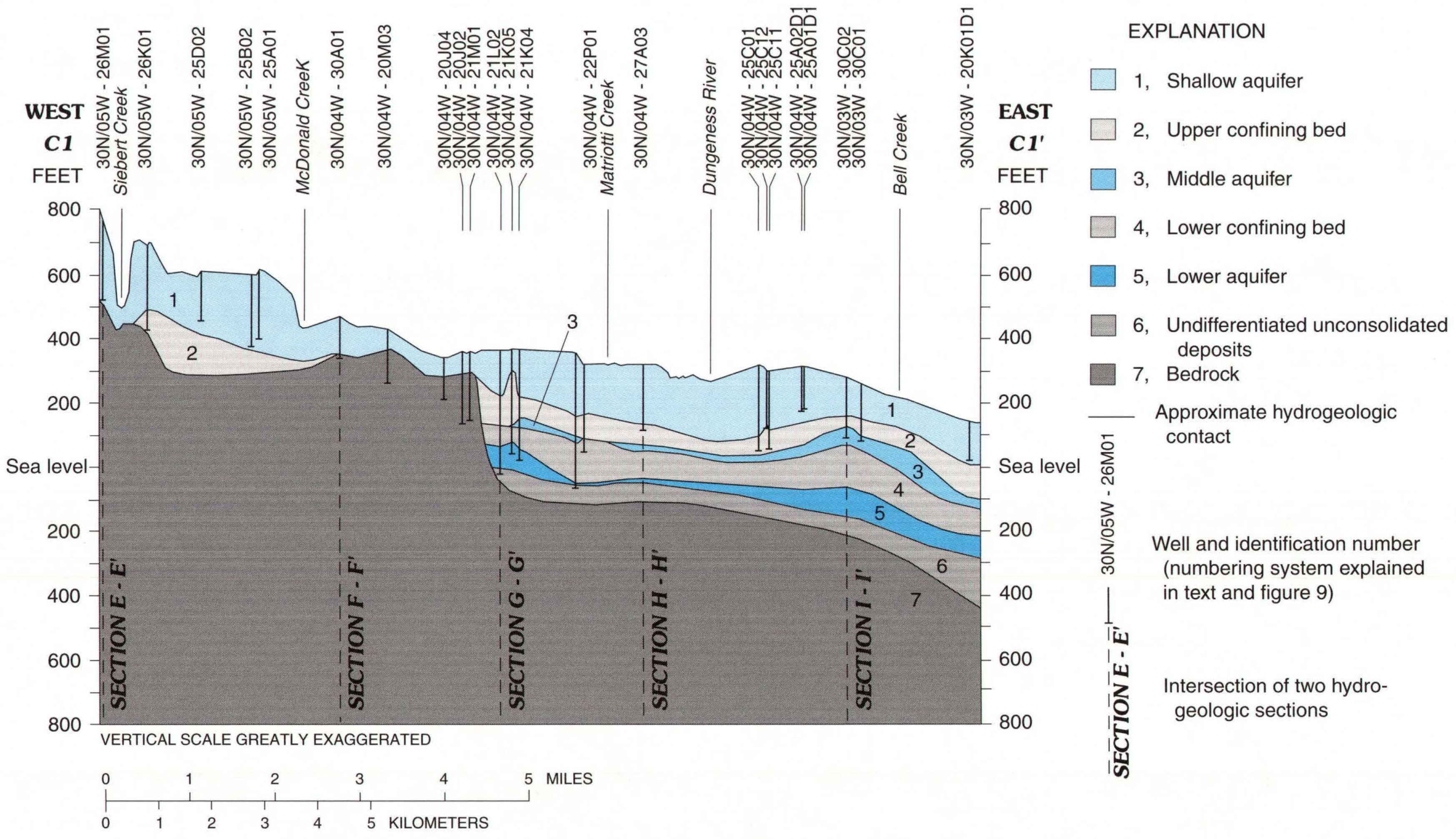


Figure 17c. Hydrogeologic cross section ***C1-C1'***, Sequim-Dungeness area, Washington.

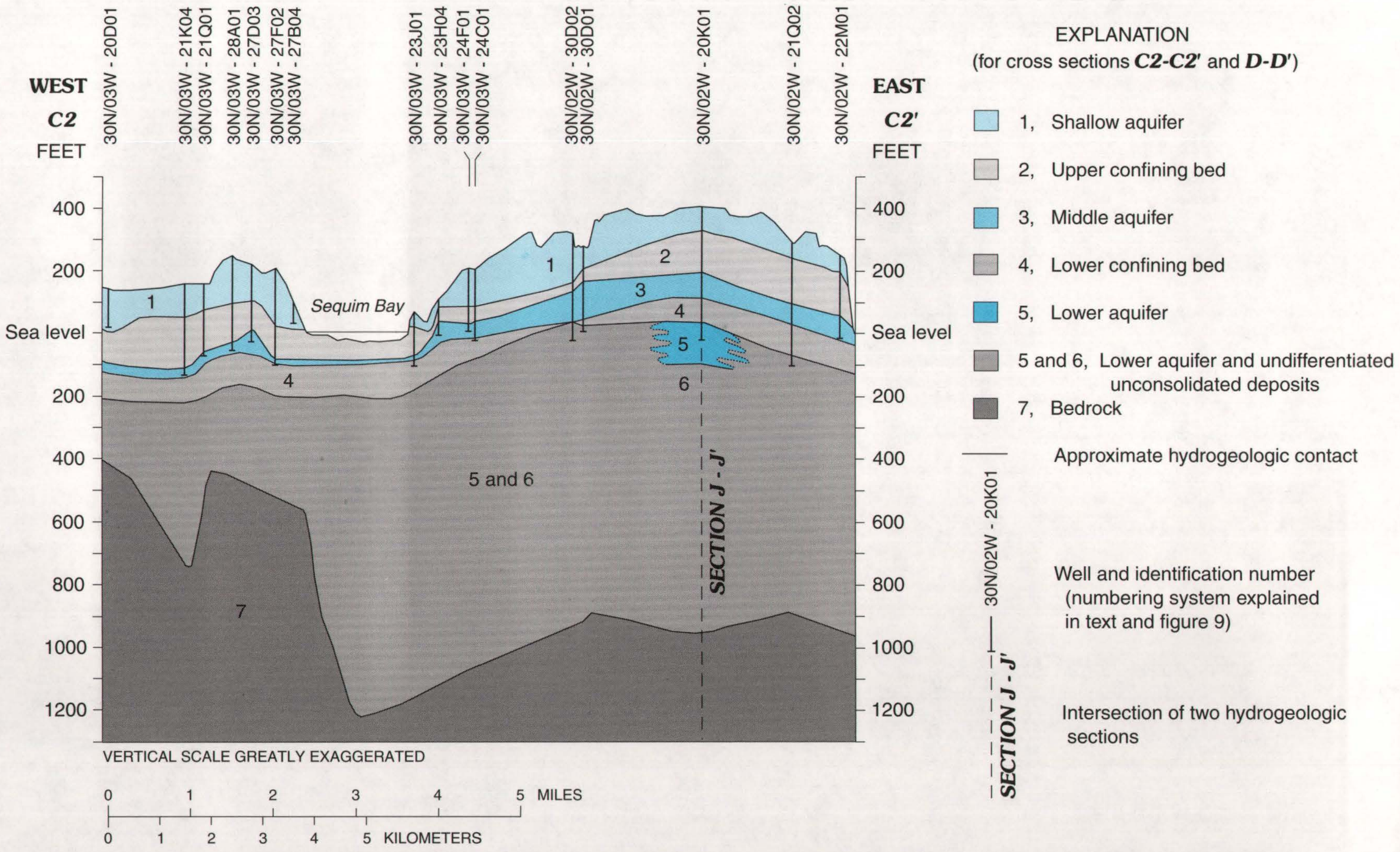


Figure 17d. Hydrogeologic cross section ***C2-C2′***, Sequim-Dungeness area, Washington

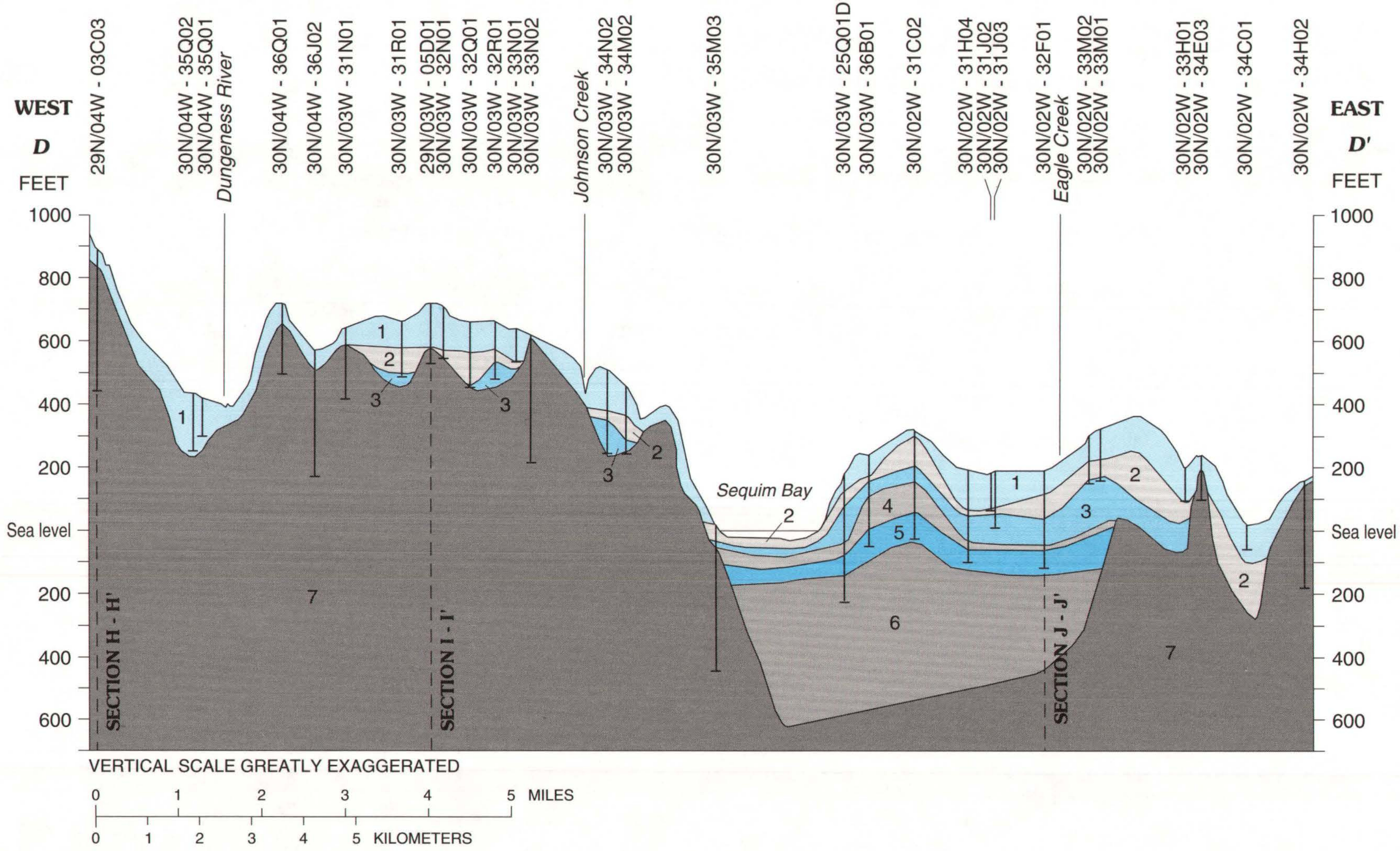


Figure 17e. Hydrogeologic cross section ***D-D'***, Sequim-Dungeness area, Washington.

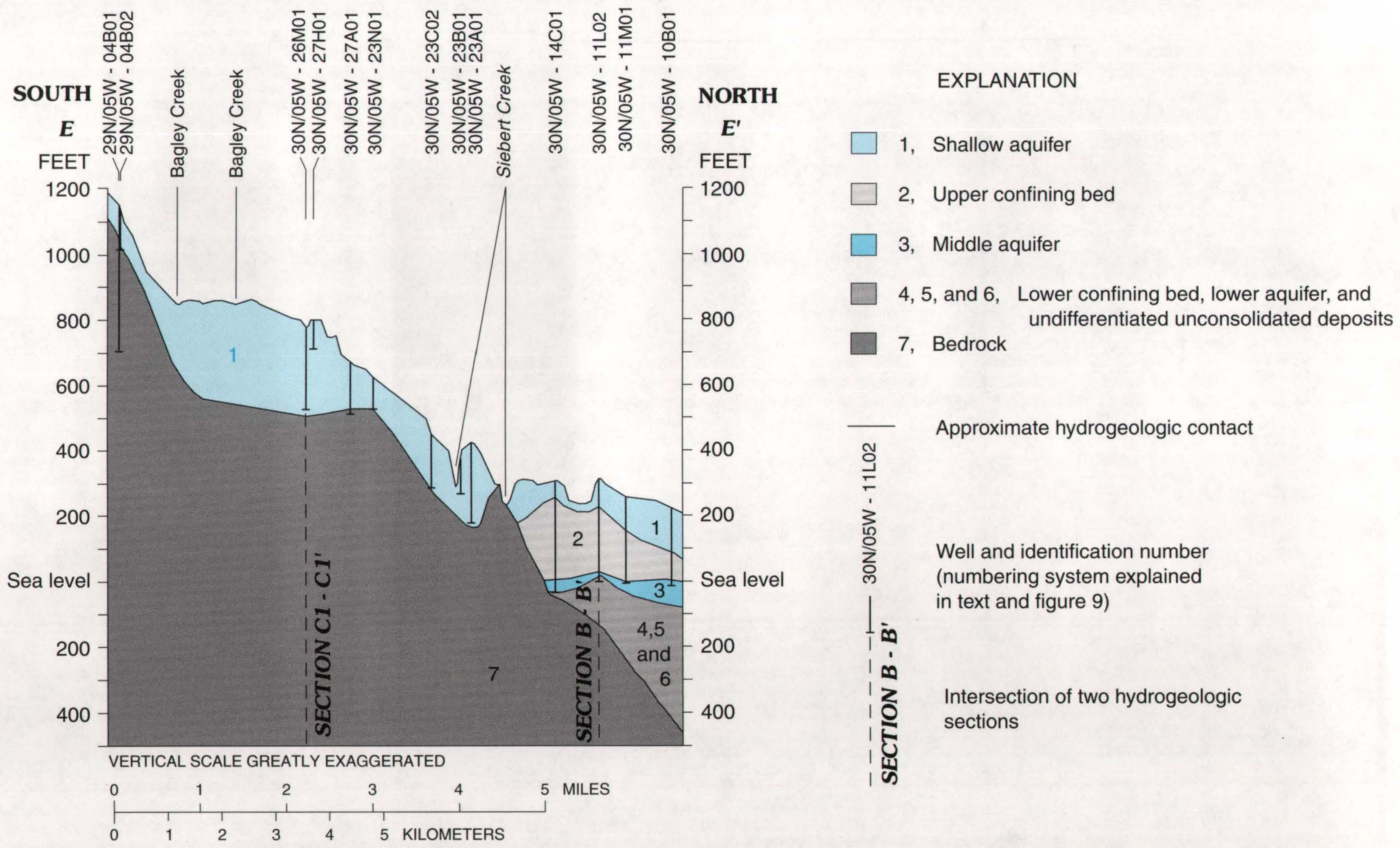


Figure 17f. Hydrogeologic cross section ***E-E'***, Sequim-Dungeness area, Washington.

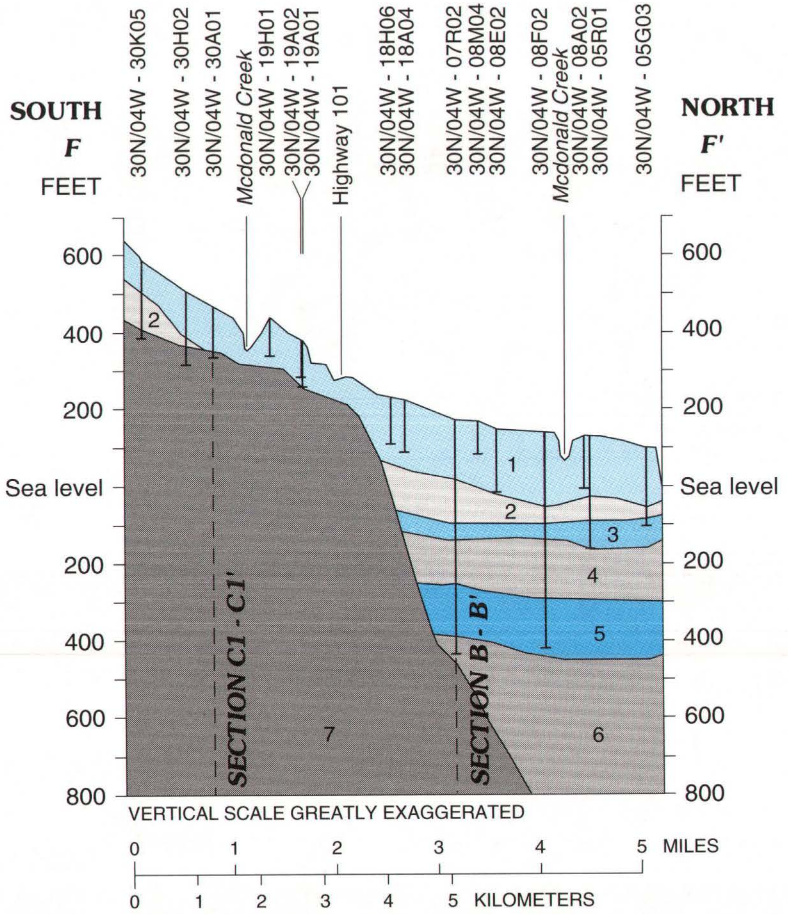


Figure 17g. Hydrogeologic cross section ***F-F'***, Sequim-Dungeness area, Washington .

EXPLANATION

▨ 1, Shallow aquifer

▨ 2, Upper confining bed

▨ 3, Middle aquifer

▨ 4, Lower confining bed

▨ 5, Lower aquifer

▨ 6, Undifferentiated unconsolidated deposits

▨ 7, Bedrock

— Approximate hydrogeologic contact

30N/04W - 07R02 Well and identification number (numbering system explained in text and figure 9)

SECTION B - B' Intersection of two hydrogeologic sections

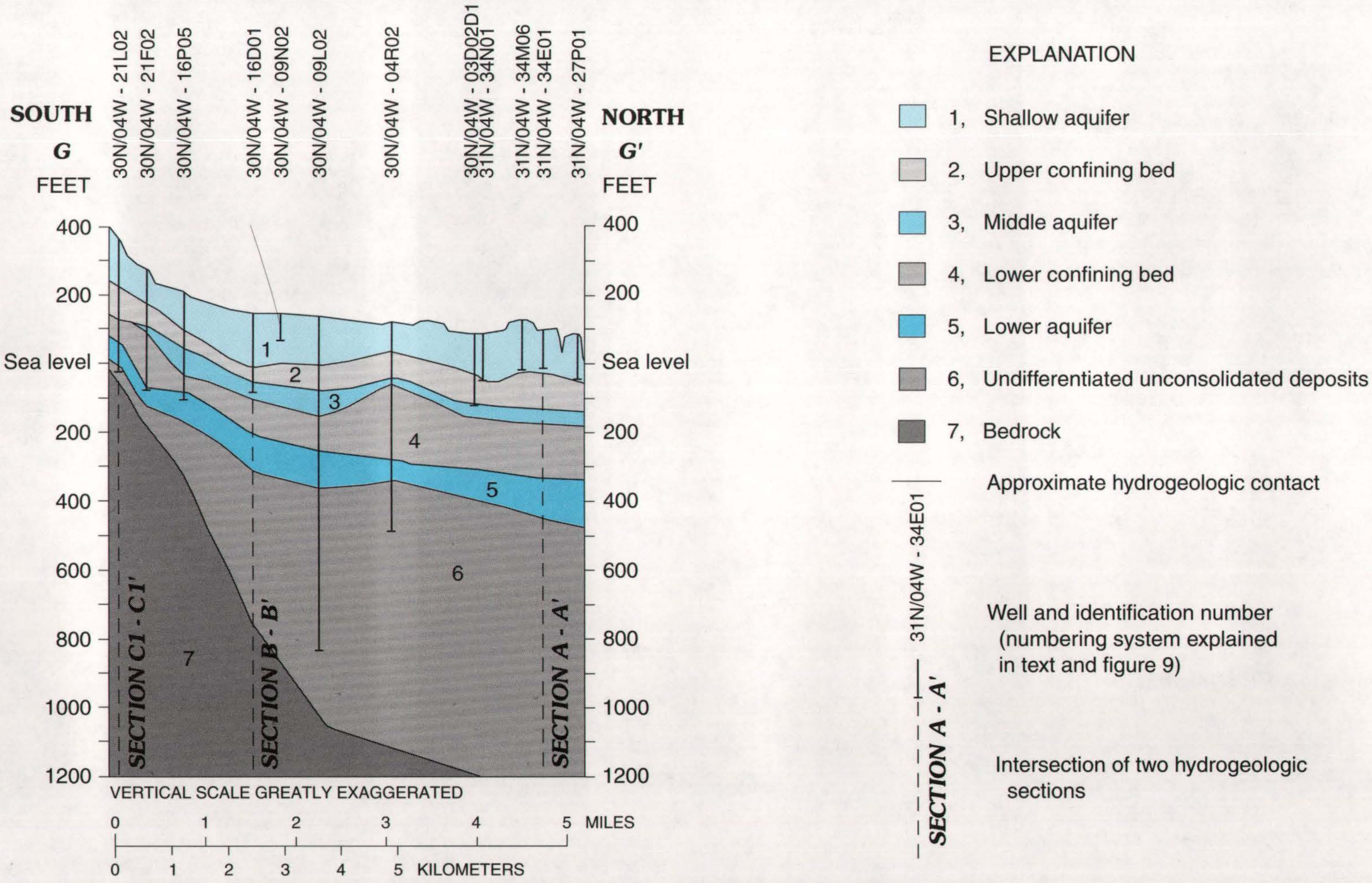


Figure 17h. Hydrogeologic cross section ***G-G'***, Sequim-Dungeness area, Washington.

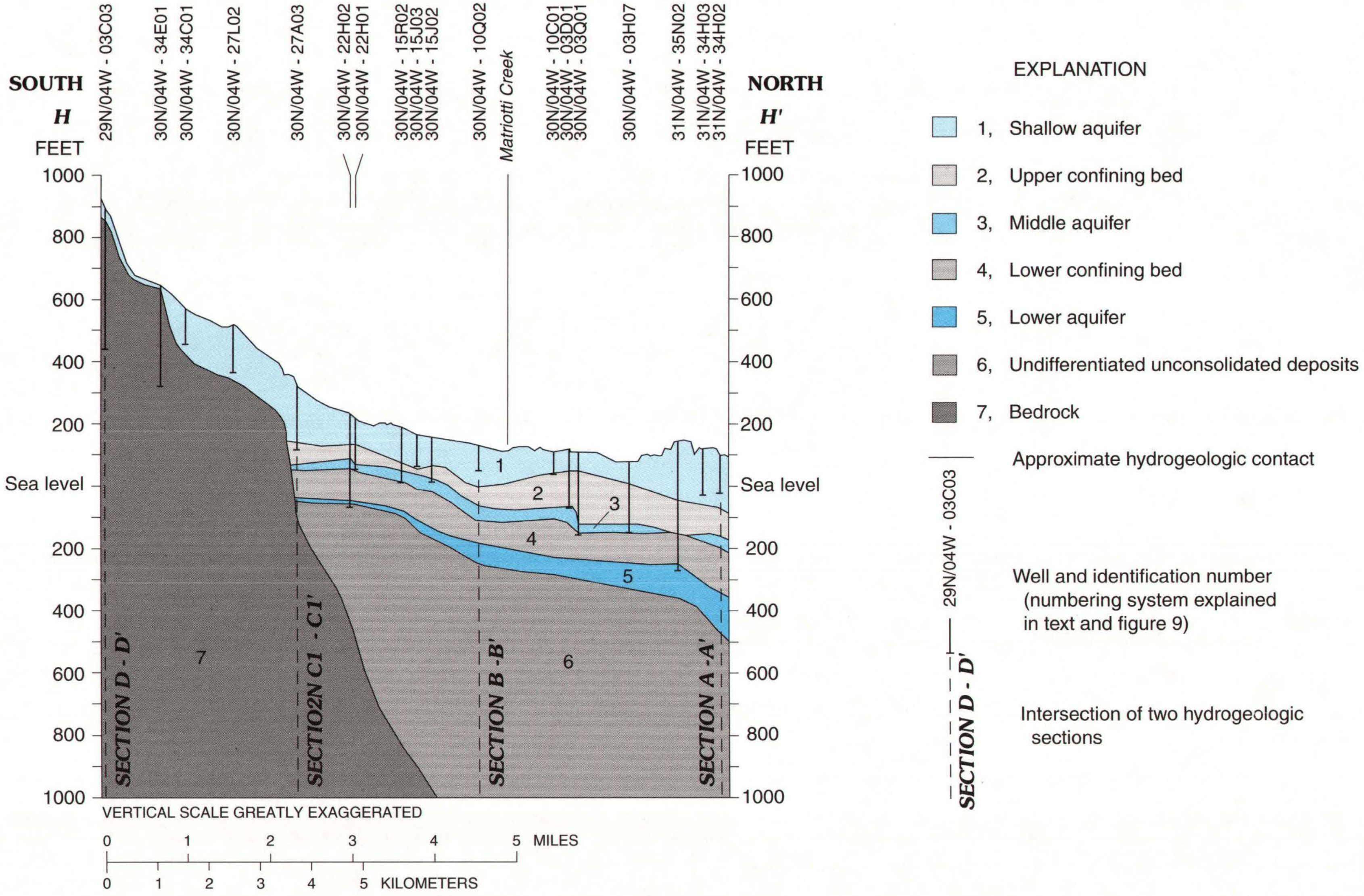


Figure 17i. Hydrogeologic cross section *H-H'*, Sequim-Dungeness area, Washington .

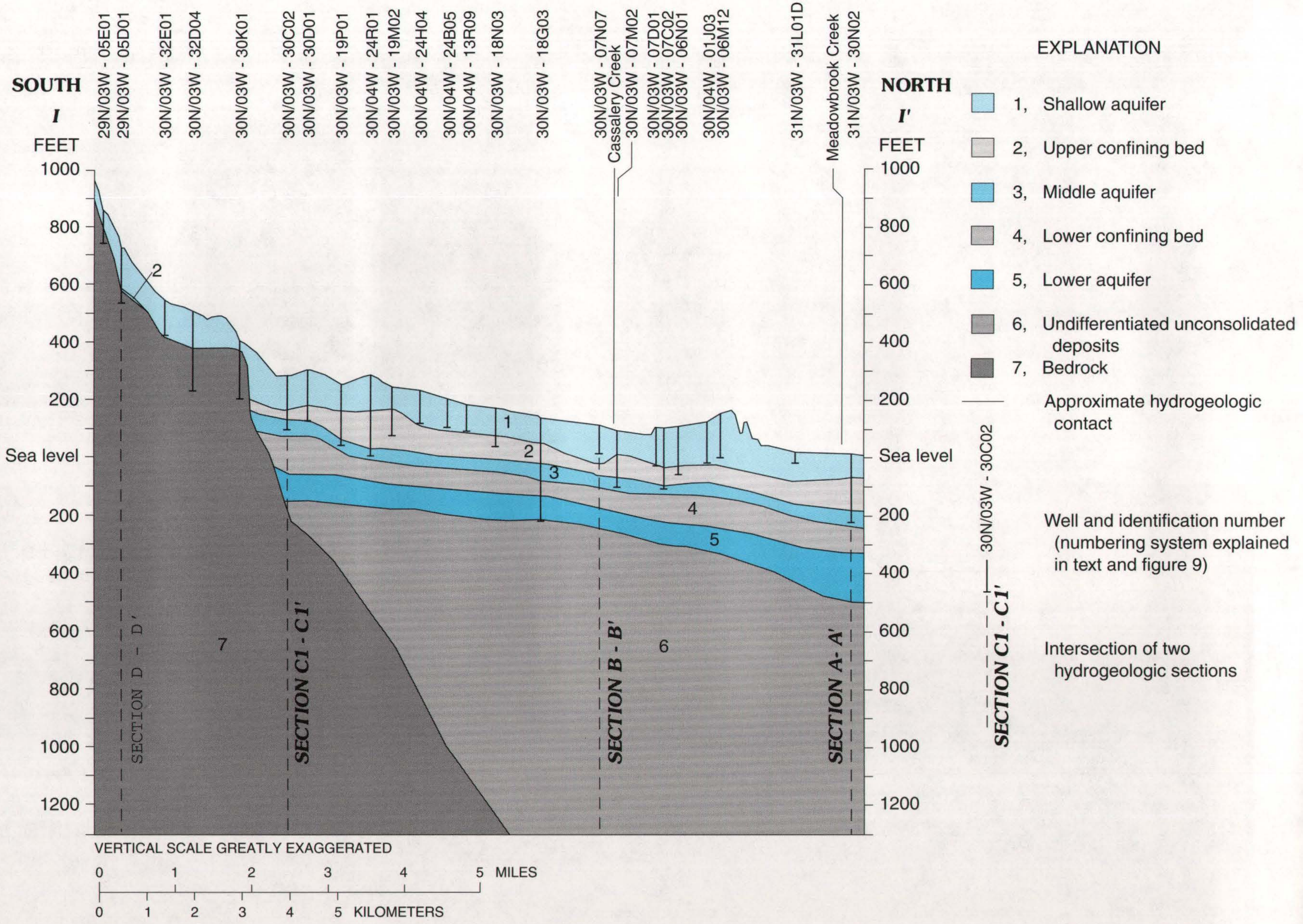


Figure 17j. Hydrogeologic cross section ***I-I'***, Sequim-Dungeness area, Washington .

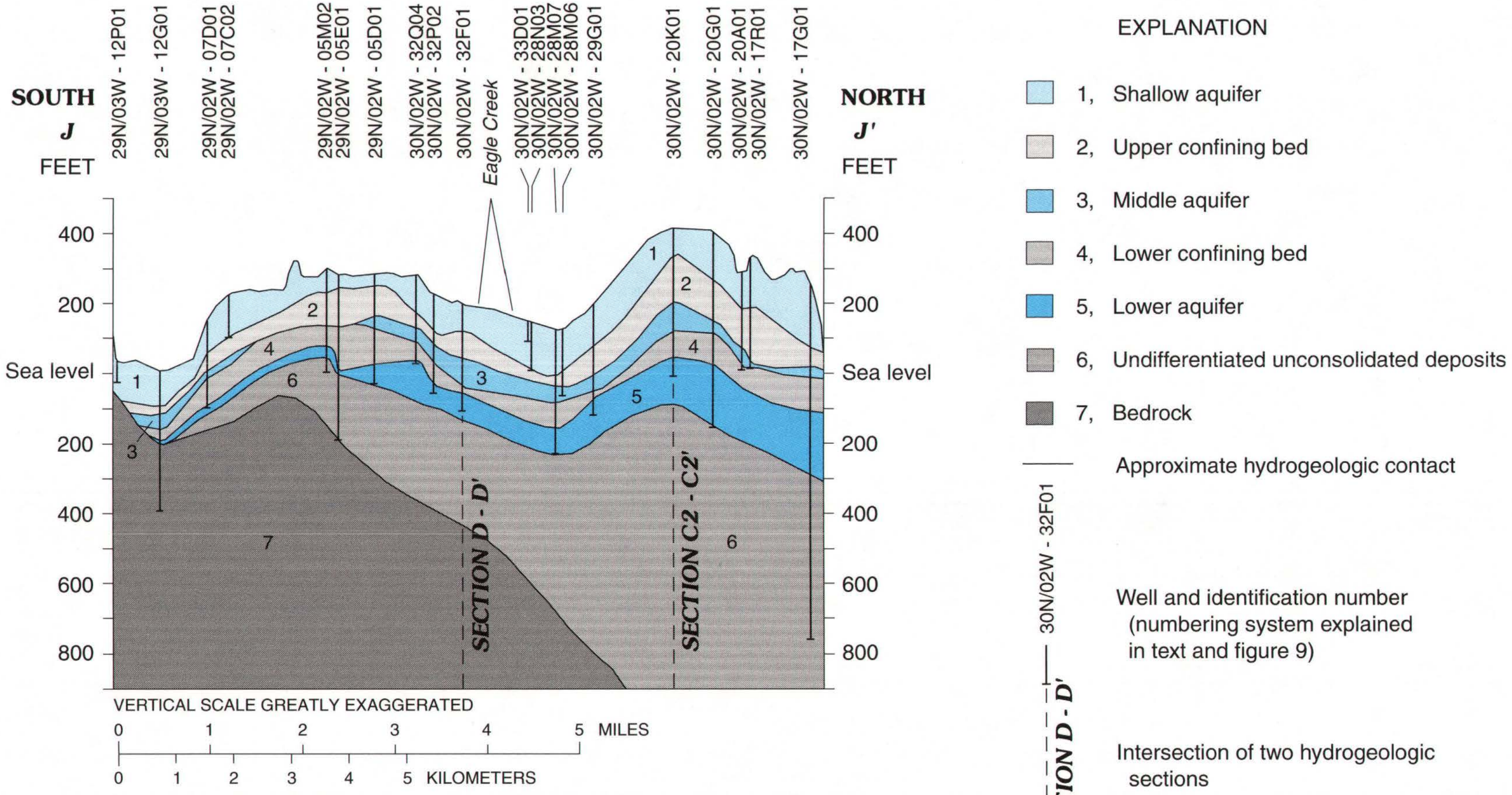


Figure 17k. Hydrogeologic cross section ***J-J'***, Sequem-Dungeness area, Washington.

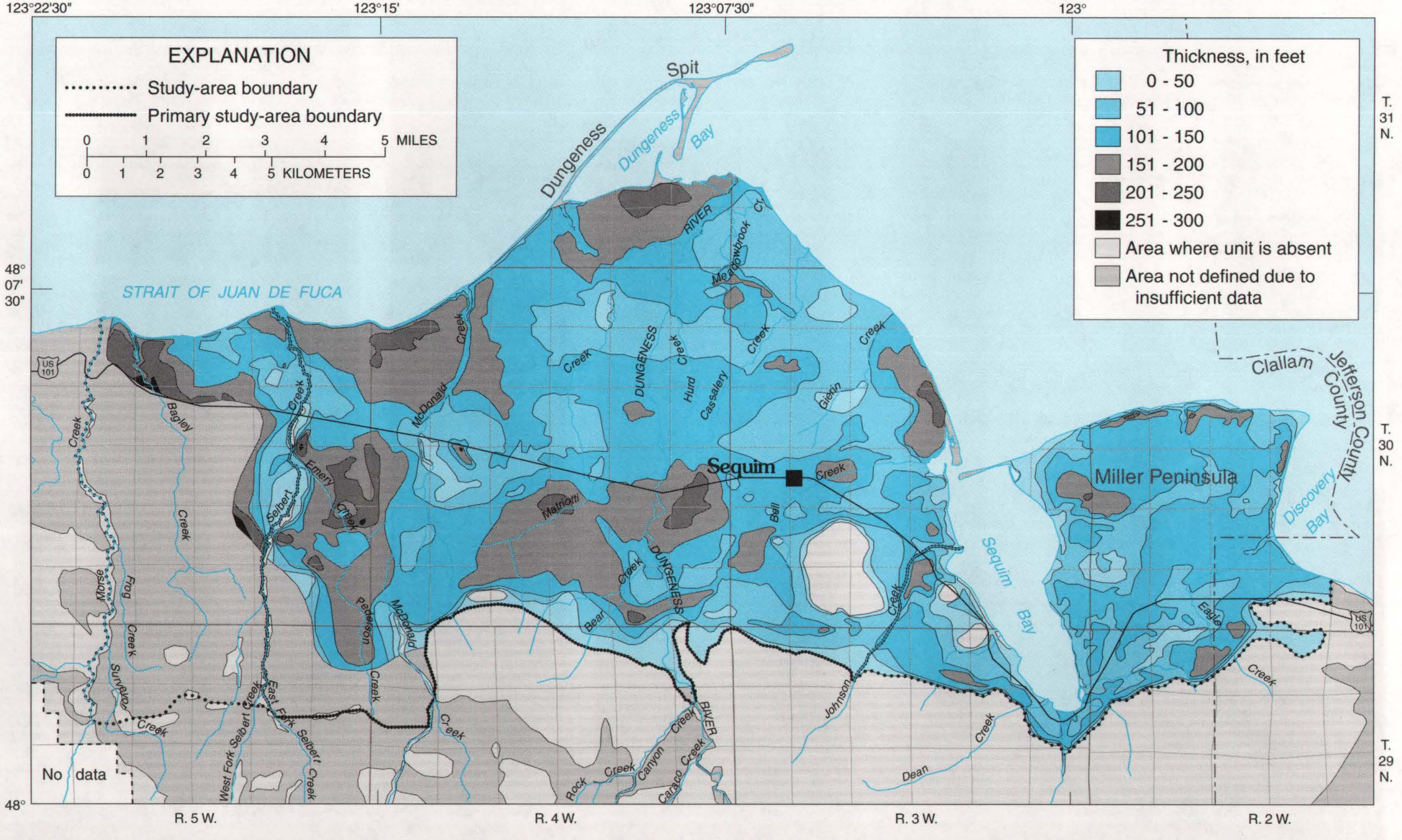


Figure 18. Extent and thickness of shallow aquifer.

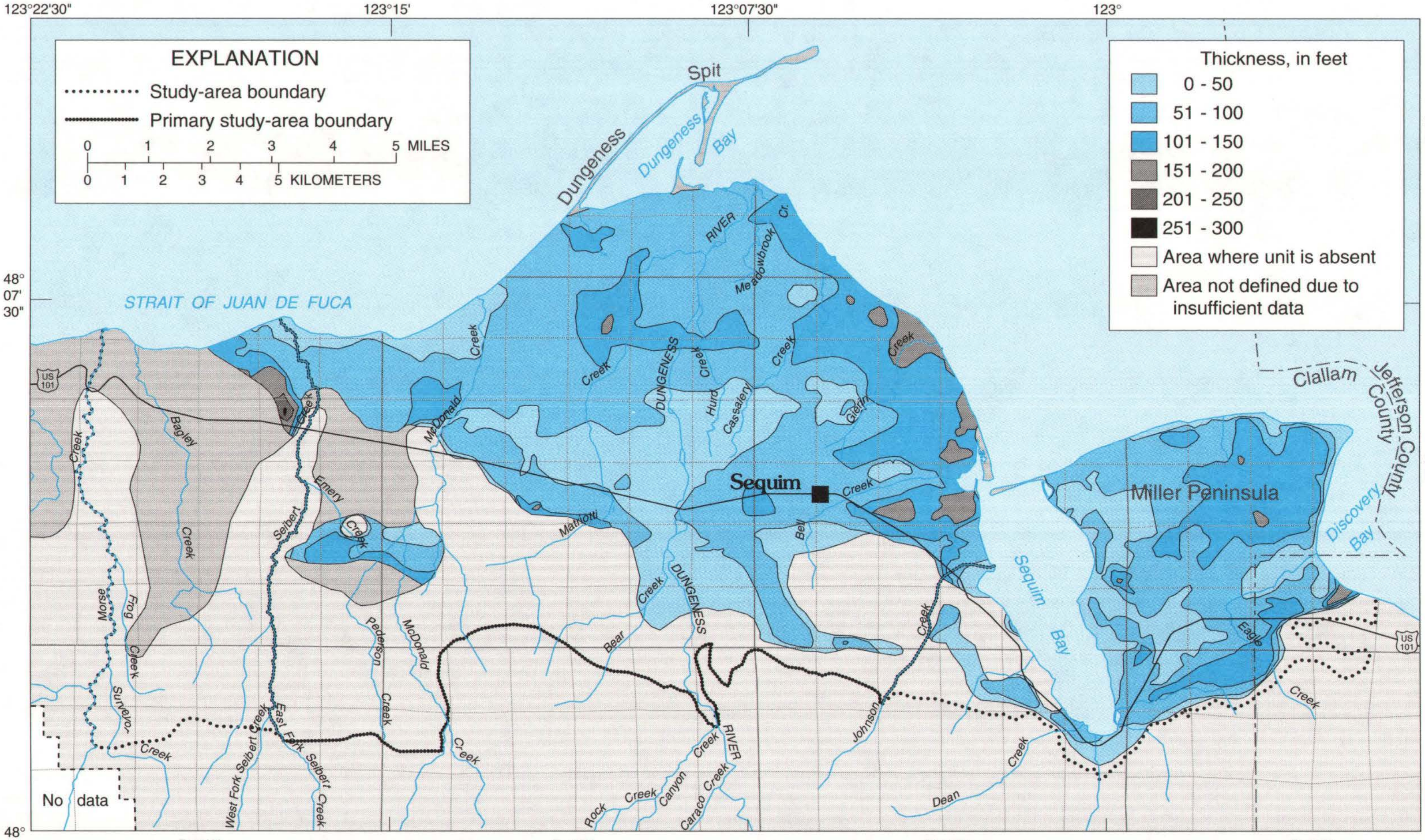


Figure 19. Extent and thickness of upper confining bed.

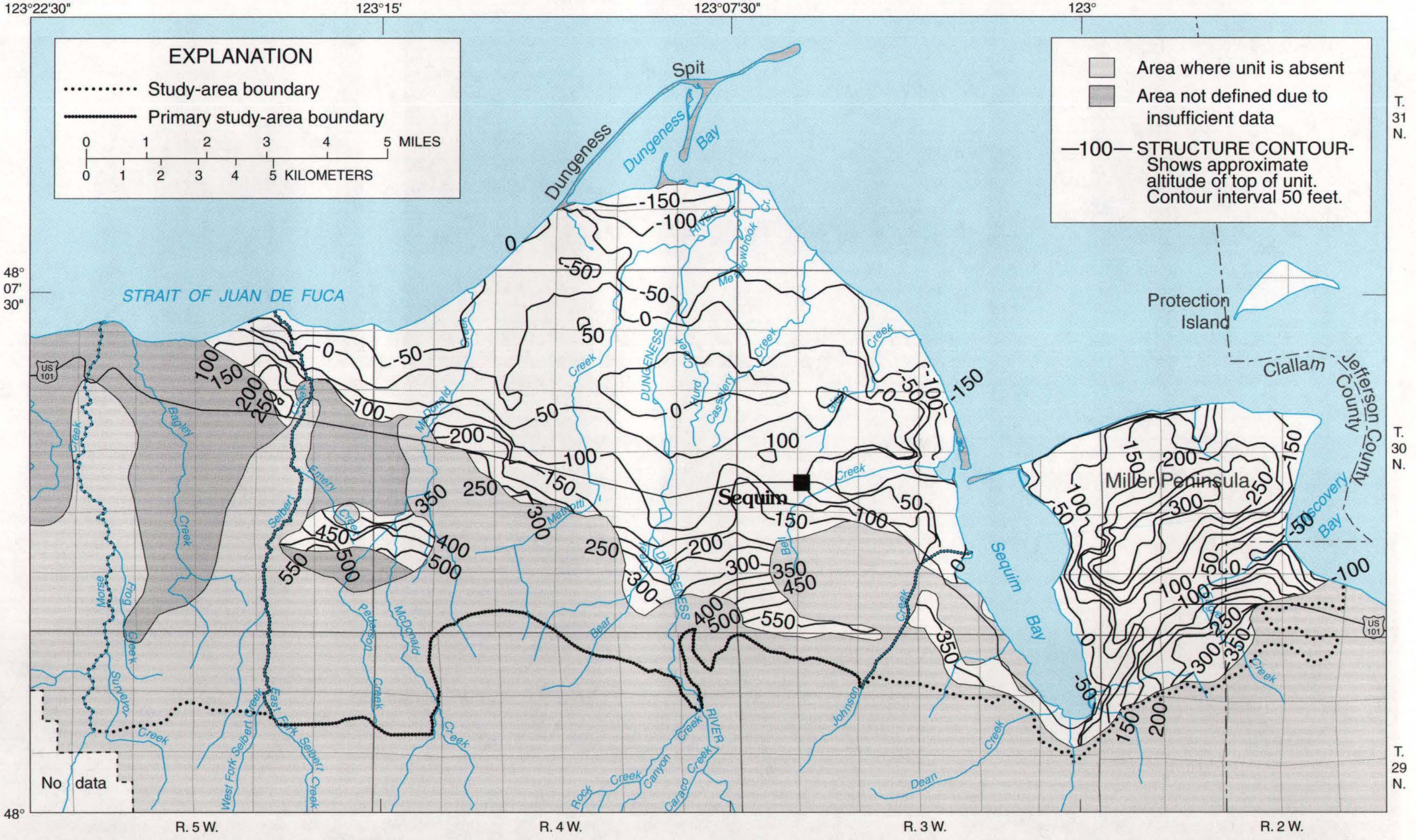


Figure 20. Altitude of top of upper confining bed.

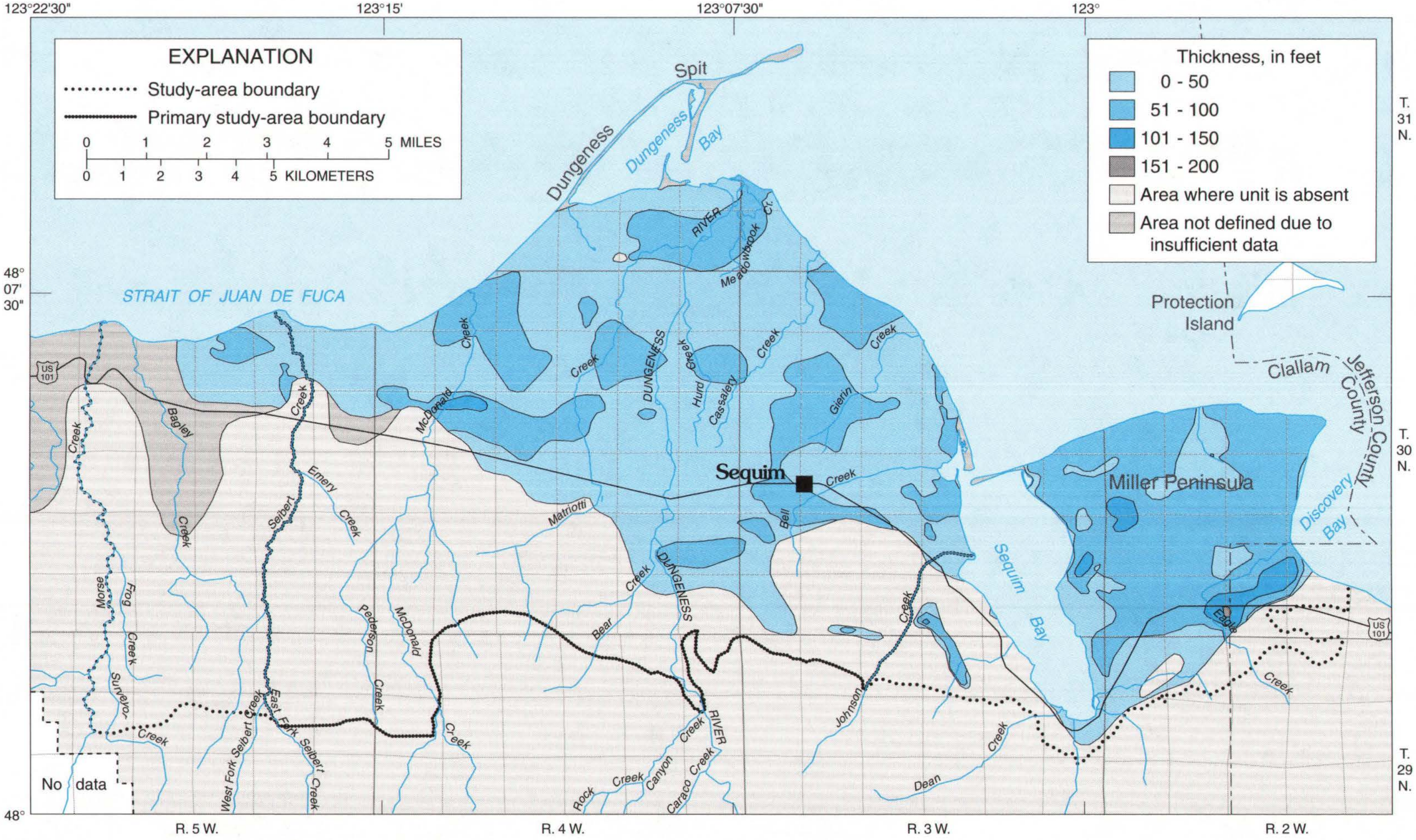


Figure 21. Extent and thickness of middle aquifer.

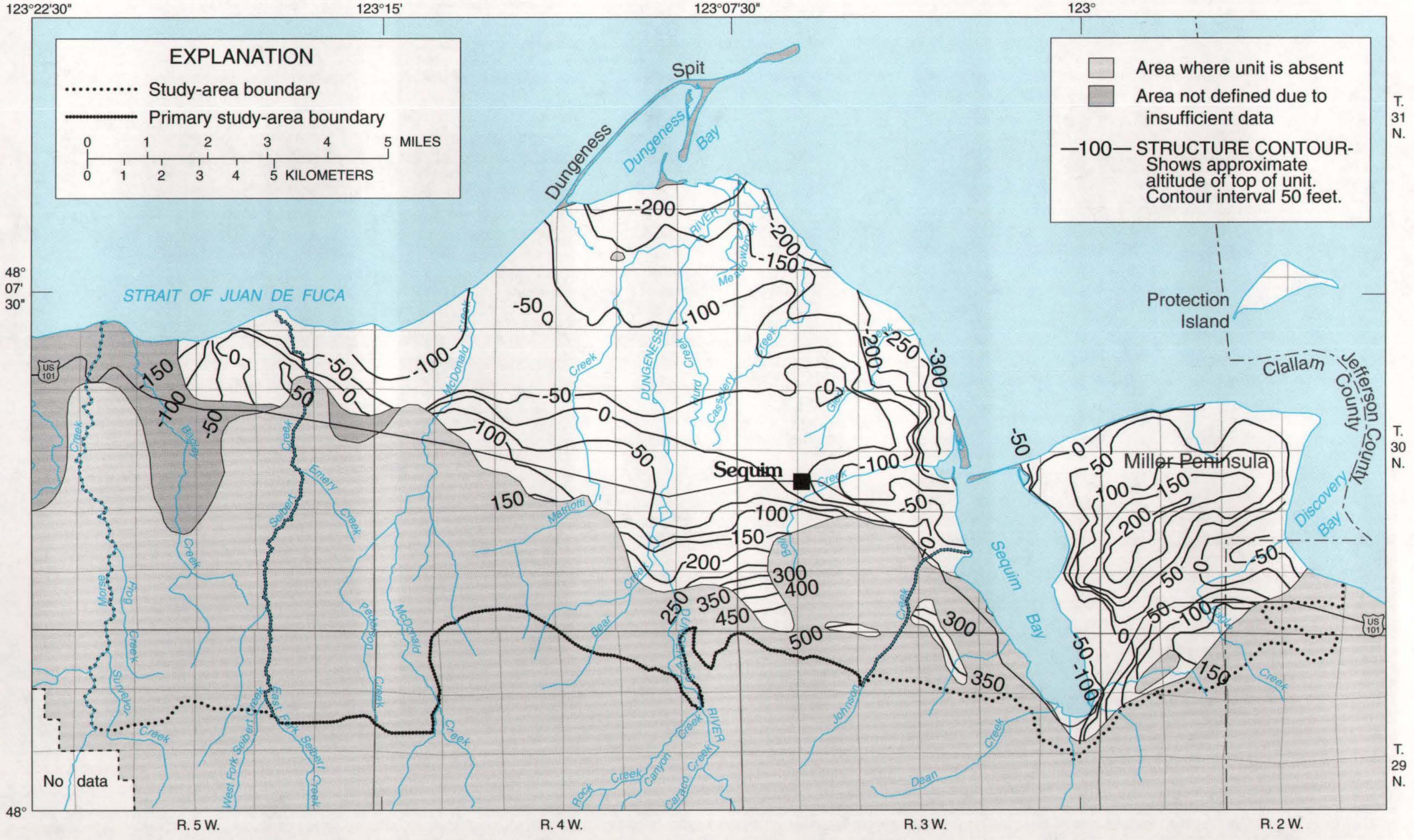


Figure 22. Altitude of top of middle aquifer.

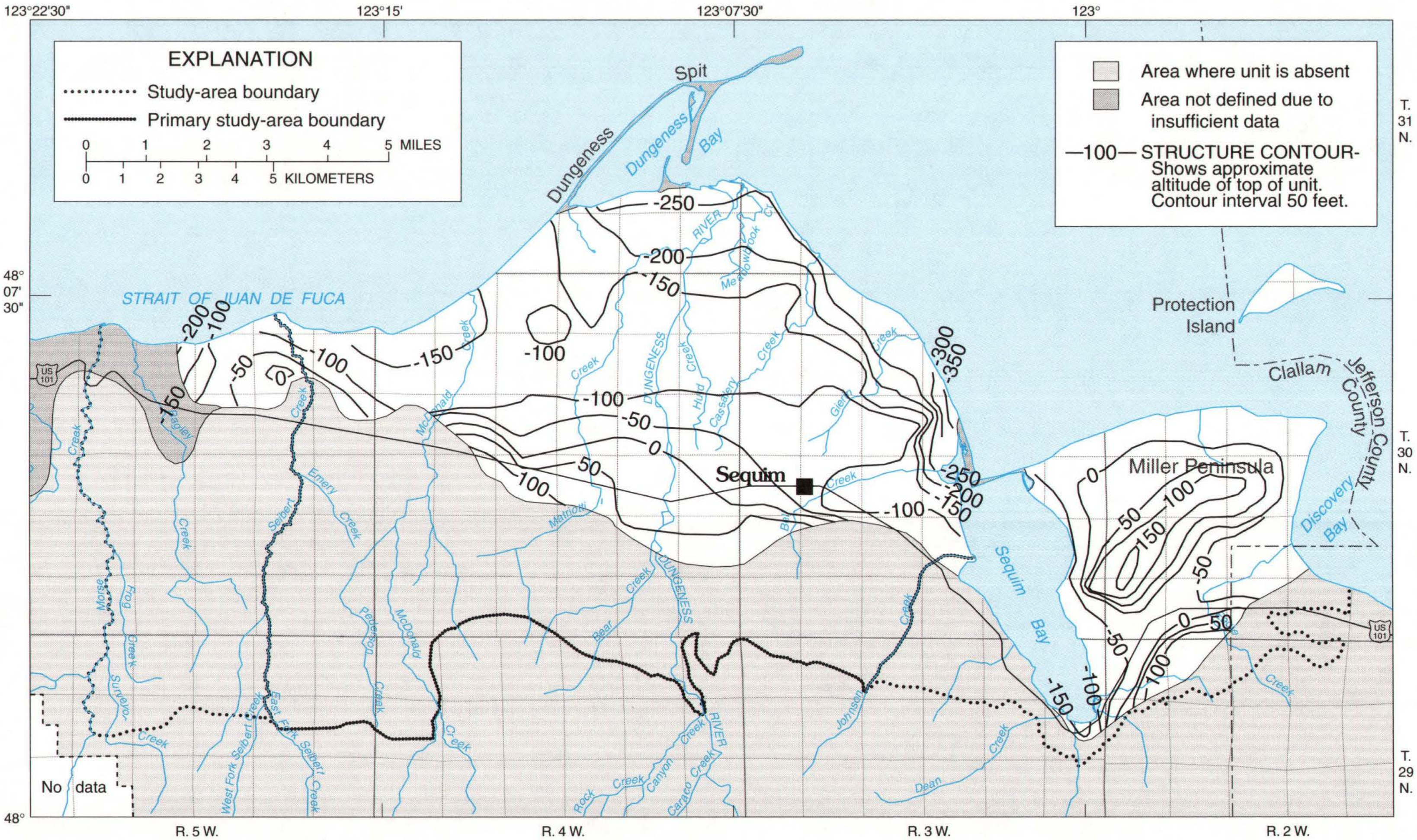


Figure 23. Altitude of top of lower confining bed.

GROUND-WATER SYSTEM

The ground-water system in the Sequim-Dungeness area contains several aquifers and confining beds. Some wells in the study area withdraw water from bedrock, but bedrock hydrogeologic units have small productivity. This study focused on the aquifers and confining beds in the unconsolidated deposits above bedrock.

The aquifers and confining beds have variable boundaries and hydraulic properties. Because of the heterogeneity of the deposits, considerable simplification was needed to describe this ground-water system. The aquifers are generally coarse-grained deposits, but local lenses of fine-grained clays or silts may affect the permeability and flow patterns within the aquifer. The confining beds are generally fine-grained deposits, but local lenses of coarse-grained sands or gravels can yield moderate amounts of water to individual wells. Because the confining beds are not impermeable, some ground water moves vertically across the confining bed.

Boundaries and Directions of Flow

Regional System in Unconsolidated Deposits

Ground water in the hydrogeologic units of the study area can be perched, unconfined, or confined. The thinner edges of a hydrogeologic unit may be unsaturated, but most parts contain at least some ground water.

The lower boundary of the regional ground-water system in unconsolidated deposits is the top of bedrock. Bedrock has very low permeability compared with the unconsolidated deposits of the ground-water system; however, some water does move into the system through this boundary. The upper boundary is the water table, which is mostly a recharge boundary. Sources of recharge to the water table are infiltration and percolation of precipitation, percolation of unconsumed irrigation water, and leakage from irrigation ditches or streams.

Lateral boundaries of the regional ground-water system are bedrock on the south, Morse Creek on the west, and saltwater boundaries at Sequim Bay, Discovery Bay, and the Strait of Juan de Fuca (fig. 16). Bedrock crops out in the southern hills at altitudes between about 500 and 1,000 ft. Ground water moves as subsurface inflow from bedrock through the southern boundary. Because Morse Creek roughly parallels the direction of ground-water flow, this boundary probably is a no-flow boundary, or it may have some ground-water discharge. Ground water discharges into the Strait of Juan de Fuca, Sequim Bay, and Discovery Bay.

Individual Aquifers

The shallow aquifer covers almost the entire study area; it is absent where there are outcrops of bedrock in the south (fig. 18). Most of the upper boundary is the water table. However, small parts of the aquifer throughout the study area are locally confined by shallow clay deposits. The water table is not static, but rises and falls seasonally. The water table can be a recharge, discharge, or no-flow boundary, depending on its closeness to land surface, the time of year, and nearby directions of ground-water flow. Water flows into the water table in most areas during the winter when precipitation is large enough to infiltrate land surface and percolate to the water table. Water can flow out of the water table if it is close to land surface, and water can move upward by capillary action to evaporate at land surface or be withdrawn by roots and transpired by plants.

In addition to infiltration and percolation of precipitation, other sources of recharge through the water table are leakage of water from irrigation ditches or streams, and percolation of unconsumed irrigation water. Recharge from ditches and streams is in areas where the water table is at a lower altitude than water in the ditch or stream. Recharge from unconsumed irrigation water is in areas where the amount of applied irrigation water exceeds the amount transpired by the plants, evaporated from the soil, or that runs off to nearby streams or ditches.

Most of the lower boundary of the shallow aquifer is the top of the upper confining bed. The lower boundary is bedrock in the southern parts of the study area where the aquifer directly overlies bedrock (figs. 17c, 17e, 17f, 17g, 17i, and 17j). A small amount of recharge might move into the shallow aquifer from the lower bedrock boundary in the south. The lower boundary with the upper confining bed has downward flow (discharge) in the south and upward flow (recharge) in the north (figs. 24 and 25).

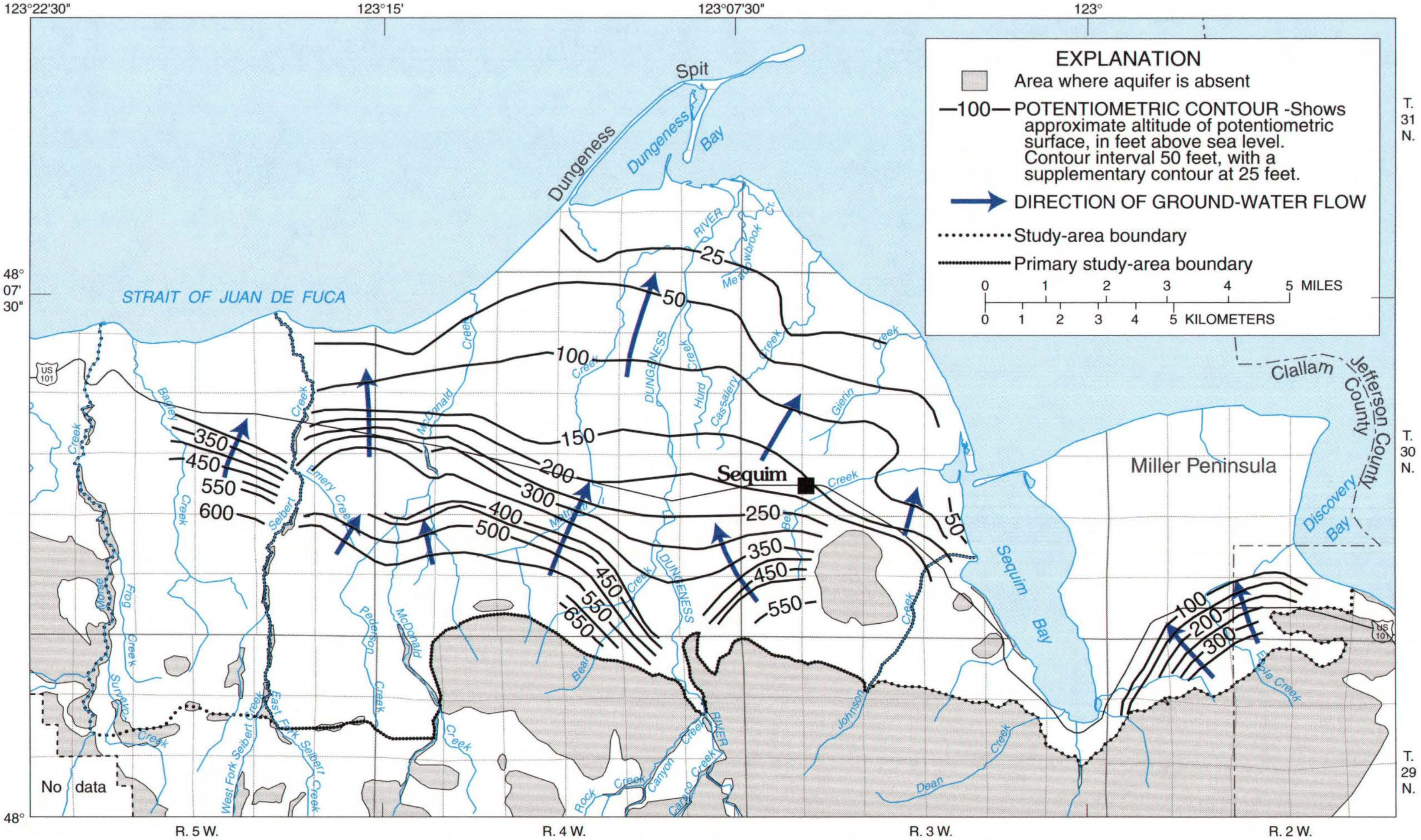


Figure 24. Potentiometric surface and inferred directions of flow in shallow aquifer, March 1996.

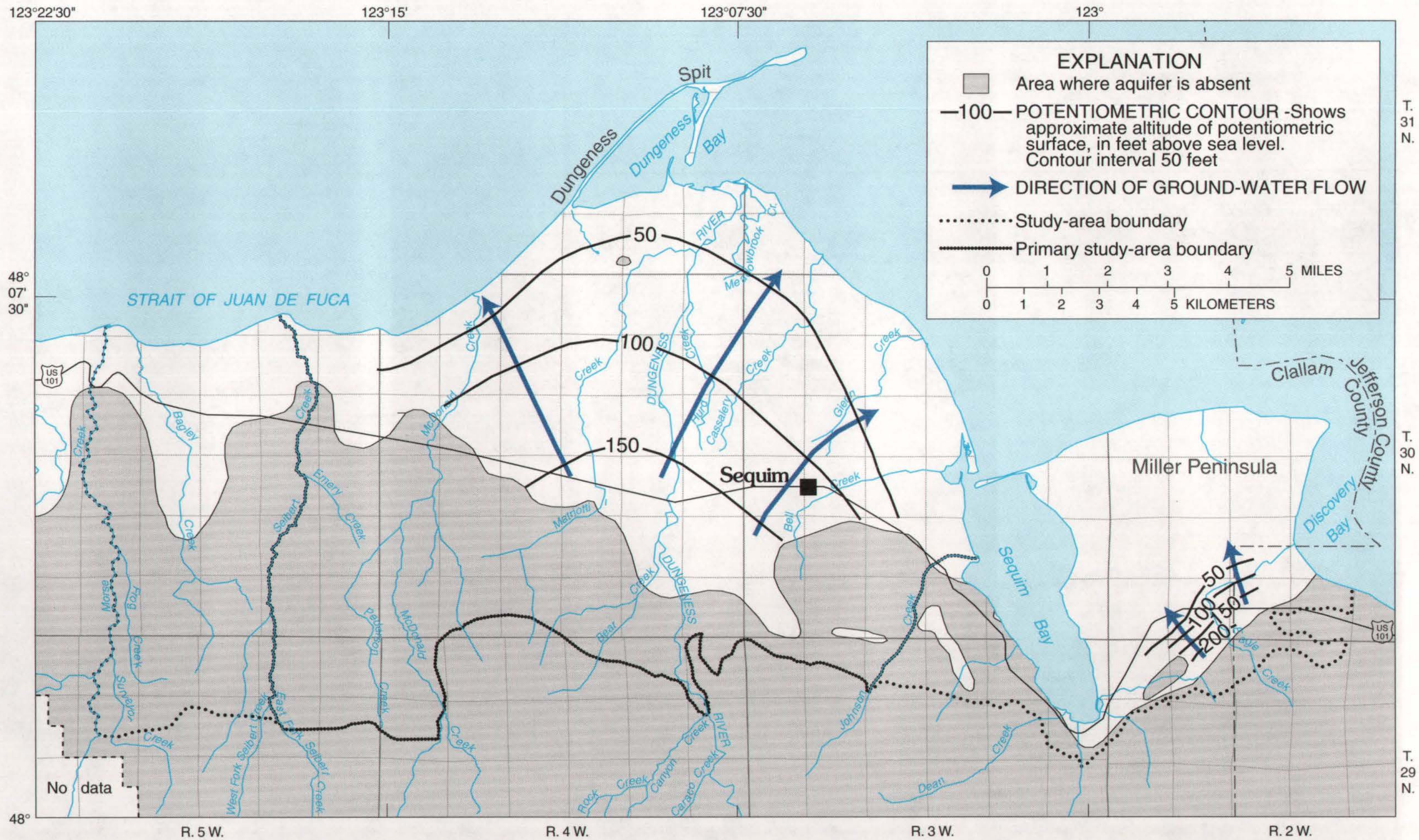


Figure 25. Potentiometric surface and inferred directions of flow in middle aquifer, March 1996.

Lateral boundaries of the shallow aquifer are bedrock on the south, Morse Creek on the west, Discovery Bay on the east, and Sequim Bay and the Strait of Juan de Fuca on the north (fig. 18). Ground water moves into the shallow aquifer through the southern boundary. Precipitation increases from north to south in the study area (fig. 2), so more water is potentially available for ground-water recharge in the southern part of the study area. There are two avenues for recharge through the southern boundary. Water moves downslope through the soil and veneer of unconsolidated deposits on top of bedrock and then through the boundary. Water also moves through fractures in the bedrock and into the ground-water system as subsurface inflow.

Morse Creek is a no-flow or discharge boundary. Discovery Bay, Sequim Bay, and the Strait of Juan de Fuca are discharge boundaries. Many of the streams within the study area are also discharge boundaries for the shallow aquifer.

Although there is a considerable range of depth to water in the shallow aquifer (about 20 ft above land surface where locally confined to more than 200 ft below land surface), most areas have depths of less than 100 ft. The average depth to water was 40 ft, and about 90 percent of the water levels measured in wells were less than 100 ft below land surface. Water levels in the shallow aquifer range from a few feet below sea level to over 700 ft above sea level.

Ground water in the shallow aquifer generally moves from recharge areas in the south to discharge areas in the north (fig. 24). The water-level gradient ranges from about 250 ft/mi in the south to about 40 ft/mi in the north. The average velocity of ground water for selected areas was estimated by multiplying the median hydraulic conductivity (fig. 26) by the water-level gradient (fig. 24), and then dividing that value by an estimated porosity of 0.35 (Heath, 1989, p. 25). Resulting average velocities ranged from about 1 ft/d in the southern hills, to about 4 ft/d near Sequim and in the north, to about 8 ft/d in the Dungeness River valley.

The middle aquifer covers the central, northern, and eastern parts of the study area (fig. 21). The upper boundary is the bottom of the upper confining bed. In the southern part of the study area, ground water moves downward through the upper boundary and into the aquifer, and in the northern part, ground water moves upward and out of the aquifer (figs. 24 and 25). The lower boundary is the top of the lower confining bed. Flow directions across the lower boundary are similar to those across the upper boundary, downward in the south and upward in the north. The aquifer is confined between Morse Creek and Sequim Bay, but parts of the aquifer are unconfined in Miller Peninsula.

Lateral boundaries of the middle aquifer are bedrock on the south, Morse Creek on the west, Strait of Juan de Fuca on the north, Sequim Bay in the middle, and Discovery Bay on the east. Morse Creek is mostly a no-flow boundary. The saltwater boundaries—Strait of Juan de Fuca, Sequim Bay, and Discovery Bay—are all discharge boundaries. The flow condition at the southern boundary with bedrock is uncertain; there may be some recharge, but it is probably small because of the small transmissivity of bedrock.

Depth to water in the middle aquifer ranges from about 30 ft above land surface to more than 300 ft below land surface. Depths to water in the primary study area are shallower than depths in Miller Peninsula. In the primary study area, the average depth to water was 90 ft and 60 percent of the water levels measured in wells were less than 100 ft below land surface. In Miller Peninsula, the average depth to water was 160 ft and 15 percent of the water levels measured in wells were less than 100 ft below land surface. Water levels in the middle aquifer range from about 30 ft below sea level to over 500 ft above sea level.

Ground water in the middle aquifer generally moves from south to north (fig. 25). The water-level gradient ranges from about 30 feet per mile (ft/mi) in the primary study area to about 200 ft/mi in the southern part of Miller Peninsula. The average velocity of ground water in the primary study area is about 1 ft/d.

The lower aquifer covers a similar area as the middle aquifer. Meager data are available, so maps of its areal extent, thickness, top altitude, and potentiometric surface were not constructed. The upper boundary is the bottom of the lower confining bed. Ground water flows downward through this boundary in the southern part of the study area and upward in the northern part of the study area (appendix A). The lower boundary is the top of undifferentiated unconsolidated deposits. Vertical flow directions through this boundary are unknown. Lateral boundaries and flow conditions of the lower aquifer are similar to those of the middle aquifer, but the lower aquifer does not appear to extend as far west as the middle aquifer (fig. 17b). Depth to water in the lower aquifer ranges from about 20 ft above land surface to about 400 ft below land surface. Depths to water in the primary study area are

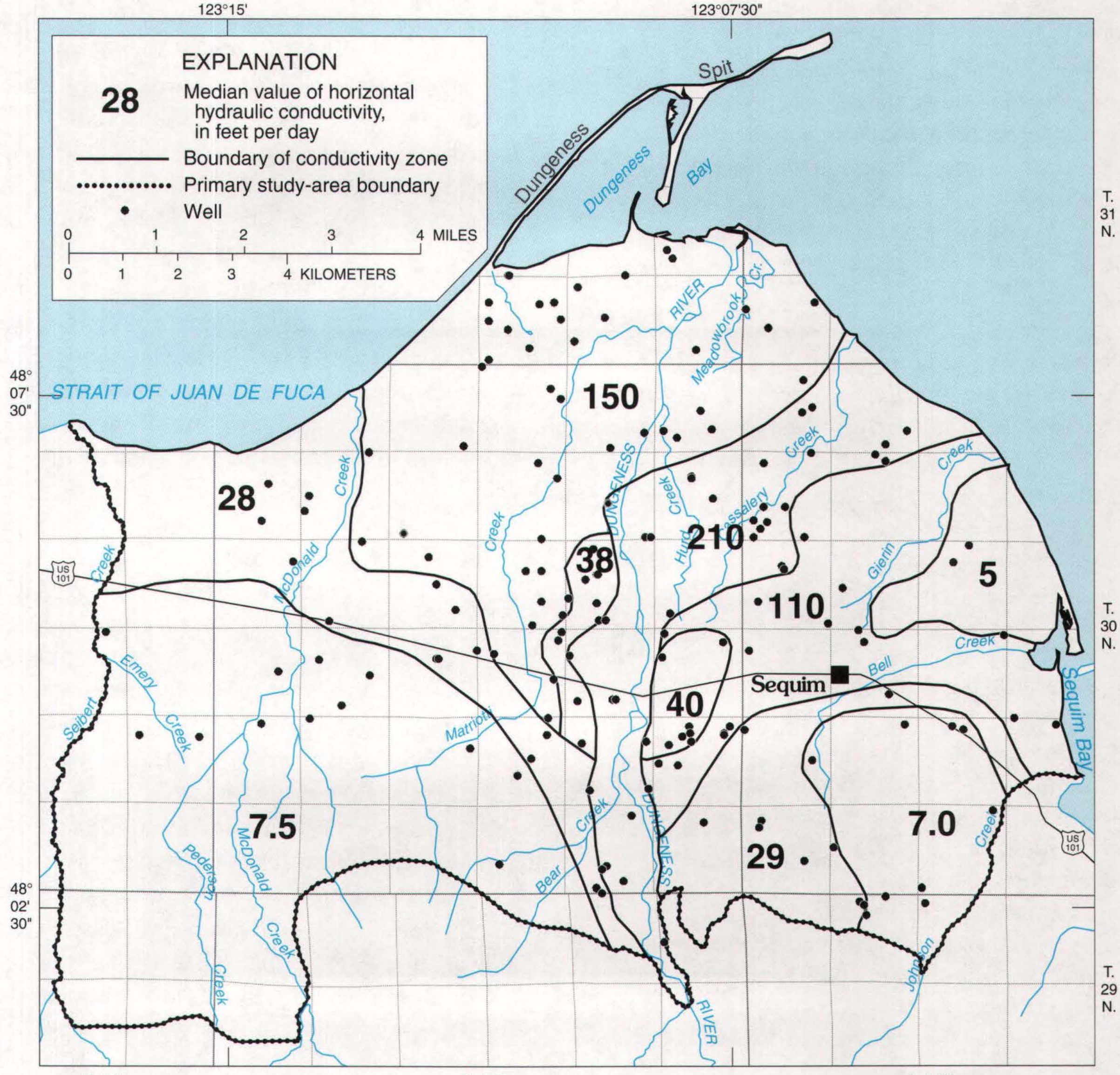


Figure 26. Zones of similar horizontal hydraulic conductivity of shallow aquifer. (see table 1 for details)

shallower than depths in Miller Peninsula. In the primary study area, the average depth to water was 110 ft, and 60 percent of the water levels measured in wells were less than 100 ft below land surface. In Miller Peninsula, the average depth to water was 240 ft, and none of the water levels measured in wells were less than 100 ft below land surface. Water levels in the lower aquifer range from about 50 ft below sea level to over 100 ft above sea level. Water-level data for the lower aquifer are insufficient to determine flow directions, but ground water probably flows from south to north as it does in the shallow and middle aquifers.

Hydraulic Properties

Horizontal hydraulic conductivity was estimated for hydrogeologic units using specific-capacity data from wells (table 1). Median conductivities decreased from 70 ft/d in the shallow aquifer to 44 ft/d in the lower aquifer to 0.039 ft/d in bedrock. There was a difference in conductivities of the units in Miller Peninsula, compared with the units west of the peninsula. In the shallow aquifer, conductivities were lower in the peninsula, compared with west of the peninsula, but in the middle and lower aquifers, conductivities were higher in the peninsula.

Table 1. Summary of horizontal hydraulic conductivity for hydrogeologic units, estimated from specific-capacity values of wells, Sequim-Dungeness area, Washington

Hydrogeologic unit	Area	Number of wells	Horizontal hydraulic conductivity, in feet per day				
			Minimum	25th percentile	Median	75th percentile	Maximum
Shallow aquifer	Entire unit	192	0.61	21	70	160	4,600
	West of Miller Peninsula	177	0.61	22	75	165	4,600
	Miller Peninsula	15	1.7	5.9	41	100	460
	See figure 26	12	1.0	3.0	7.5	30	96
	-do-	16	3.0	12	28	68	710
	-do-	47	9.0	77	150	250	1,800
	-do-	35	3.0	110	210	490	4,600
	-do-	8	19	28	40	54	77
	See figure 26	19	12	46	110	140	1,200
	-do-	[1]7	--	--	5.0	--	--
	-do-	9	4.0	22	29	60	160
	-do-	9	1.0	4.0	7.0	76	160
	-do-	10	7.0	18	38	60	79
Upper confining bed	Entire unit	10	6.3	14	24	94	200
Middle aquifer	Entire unit	51	2.8	15	57	150	2,600
	West of Miller Peninsula	42	2.8	15	50	128	1,900
	Miller Peninsula	9	4.3	7.8	110	425	2,600
Lower aquifer	Entire unit	29	0.67	11	44	92	430
	West of Miller Peninsula	17	0.67	7.9	42	68	260
	Miller Peninsula	12	9.9	14	73	178	430
Bedrock	Entire unit	8	0.012	0.016	0.039	1.3	6.2

[1] Only two study wells available in this area. The median of 5.0 is the value Drost (1983) used for the same area, based on seven wells.

A map of 10 zones of similar horizontal hydraulic conductivity was constructed for the shallow aquifer in the primary study area on the basis of well values and surficial geology (fig. 26). The median value for the wells in each zone is assumed to represent the most typical value. One zone on the eastern side had only two wells located in it, so a median hydraulic conductivity (5 ft/d) from Drost (1983) for the same area was used. To determine if the zones of equal conductivity are valid, statistical tests were made on nine zones together (omitting the zone with two wells) and on eight adjacent pairs of zones. A Kruskal-Wallis test determined that the nine zones have significantly different ($p < 0.01$) median values of hydraulic conductivity. Rank-sum tests determined that the median conductivities for six adjacent pairs of zones were different at an overall threshold significance level of 0.15 and a dependence-adjusted significance level of 0.02 (see page 25). The adjacent pair of zones with median conductivities of 7.5 ft/d and 28 ft/d had a rank-sum p-value of 0.04, and the adjacent pair of zones with median conductivities of 7.0 ft/d and 29 ft/d had a rank-sum p-value of 0.10. These adjacent zones did not meet the dependence-adjusted significance level of 0.02; however, they were kept separate because the surficial geology in each zone is quite different.

The zones of equal hydraulic conductivity relate to surficial geology (figs. 16 and 26) with smaller values of 7.0 ft/d to 7.5 ft/d in the southern till-covered foothills and larger values up to 210 ft/d in the coarse alluvium of the present-day and ancestral floodplains of the Dungeness River.

No areal patterns were apparent in the horizontal hydraulic conductivity and transmissivity computed for the middle aquifer; therefore, no maps of these properties were constructed.

Recharge

Ground water in the study area is recharged from infiltration and percolation of precipitation, percolation of unconsumed irrigation water, leakage from irrigation ditches, subsurface inflow through the southern boundary of the study area, and leakage from streams. Depending on the location within the study area, one of these sources may dominate. Recharge to the shallow aquifer was estimated in this study; the quantity of vertical flow between aquifers was not estimated.

Infiltration and Percolation of Precipitation

Infiltration and percolation of precipitation recharges ground water throughout the study area. Generally, the greater the precipitation, the greater the recharge. Other factors influencing amounts of recharge are soil type, surficial geologic material, vegetation, land-surface slope, and changes to land cover caused by human activities, such as streets, parking lots, houses, commercial buildings, and so forth. Estimated average annual recharge for the study period (December 1995 to September 1997) was 8.6 in. (74 ft^3/s), and estimated long-term average annual recharge was 5.4 in. (46 ft^3/s).

General Description of Deep-Percolation Model

A deep-percolation model (DPM) developed for eastern Washington (Bauer and Vaccaro, 1987) and modified for western Washington (Bauer and Mastin, 1997) was used to estimate recharge from precipitation. The DPM uses a daily water-budget approach to estimate recharge. In this method, daily fluxes of water into and out of a volume extending from the top of foliage to the bottom of the root zone are simulated and changes in water content are accounted for. Ground-water recharge is assumed to equal deep percolation, which is the water moving vertically downward from the bottom of the root zone. In general, deep percolation is computed as precipitation minus evapotranspiration minus direct runoff minus the change in soil moisture in the root zone.

Data required for the DPM include daily values of precipitation, air temperature, solar radiation, and surface-water runoff; and properties of soils, vegetation, and land surface. Areal variation in soils, vegetation, and land surface are accounted for in the DPM by dividing a study area into a grid of uniform cells and assigning varying properties to each cell. Areal variation in precipitation, temperature, and solar radiation can be accounted for by using different data-collection stations spread throughout the study area. The DPM computes values of precipitation, temperature, and solar radiation for each model cell by interpolating between values at the stations.

The DPM is usually calibrated by repeated trial-and-error runs of the model. In each run, one or more of the properties of soils, vegetation, and land surface are changed, and the simulated results are compared to measured data. During calibration the more certain properties are not changed or kept close to initial estimates, and uncertain or unknown properties are adjusted within larger, but realistic, limits. The model is considered calibrated when simulated and measured values of runoff and soil water are in good agreement. Some soil-water data were collected during this study, but those data were not considered sufficient for calibration of the DPM, so only measured runoff was used for calibration in this study.

Five steps were employed to estimate recharge from precipitation in this study: (1) all the data needed for applying the DPM to the study area were assembled; (2) the DPM was calibrated for a 1.0-mi^2 basin (Emery Creek) using runoff data; (3) the DPM was applied to the entire study area using results of the Emery Creek calibration and other data assumptions; (4) recharge was adjusted for urban areas; and (5) long-term average annual recharge was estimated using results of steps three and four.

Assemblage of Data for Deep-Percolation Model

The study area was divided into a uniform grid of 7,378 cells each with 660 ft on a side and an area of 0.0156 mi^2 (10 acres). Daily values of atmospheric data were assembled for a 22-month period (December 1, 1995 to September 30, 1997). Precipitation data were collected in this study, temperature data were obtained from the U.S. Department of Commerce (1995–97), and solar radiation data were obtained from Matt Detlef (National Oceanic and Atmospheric Administration, written commun., 1998) and H.H. Bauer (U.S. Geological Survey, written commun., 1998).

Most properties of soils, vegetation, and land surface were obtained from previous studies of the Sequim-Dungeness area. However, a few properties are difficult to measure and were not available from previous studies of the area. Those properties were estimated from values used in two previous applications of the DPM to areas of western Washington. Bauer and Mastin (1997) estimated recharge in till-covered areas, and W.R. Bidlake (U.S. Geological Survey, written commun., 1998) estimated recharge in areas covered by till and glacial outwash. Those two studies used locally measured meteorologic data and extensive calibration data, including runoff, soil water, and ground-water levels. Using properties from those two studies in this study is considered reasonable because all three study areas have similar climate, vegetation, geology, and topography.

Six stations with measured daily precipitation were used (fig. 12 and table 2), and two dummy stations of estimated precipitation were added in an area of no precipitation data. These stations were placed at the southern boundary of the study area: one near Morse Creek and one near Siebert Creek (fig. 1). Daily precipitation at the two dummy stations was estimated by multiplying daily values at site Pre-1 by 1.75, which is the ratio of average annual precipitation at the two sites to average annual precipitation at site Pre-1 (fig. 2 and 12).

The record at the National Weather Service station near Sequim (Pre-5, fig. 12) was used for daily minimum and maximum temperatures (U.S. Department of Commerce, 1995–97). No solar radiation data were available for the study area, so data from two stations outside the study area were used. The DPM interpolates solar radiation for the study area on the basis of the locations of these two sites. One site, about 50 mi southeast of the study area, is the National Weather Service station at Sandpoint near Seattle (Matt Detlef, National Oceanic and Atmospheric Administration, written commun., 1998). The other site is on Lopez Island about 30 mi northeast of the study area (H. H. Bauer, U.S. Geological Survey, written commun., 1998). The Sandpoint station had data for the entire study period (December 1, 1995 to September 30, 1997). However, the Lopez site only had data for September 29, 1996, to September 30, 1997. A synthetic record for the missing period at the Lopez site was created by constructing regression relations with daily solar radiation at Lopez as the response variable and daily solar radiation at Sandpoint as the explanatory variable. The concurrent data for September 29, 1996, to September 30, 1997 were used and two regression relations were created; one for August–February and one for March–July. The two regression relations provided a better fit to the data than one relation. R-square values were 0.91 for the August–February relation and 0.79 for the March–July relation.

Table 2. Monthly precipitation at gaged sites, Sequim-Dungeness area, Washington

[See figure 12 for locations of sites]

		Precipitation at indicated site, in inches					
Month	Year	Pre-1 (West)	Pre-2 (West central)	Pre-3 (North)	Pre-4 (South)	Pre-5 (East central)	Pre-6 (East)
December	1995	[1]2.91	[1]2.67	[1]1.87	[1]2.83	2.10	[1]3.49
January	1996	4.50	3.74	2.87	3.22	3.44	3.32
February		4.06	3.26	3.17	3.22	2.55	2.94
March		0.87	0.58	0.64	0.82	0.65	0.70
April		3.11	1.86	1.38	1.81	1.37	[2]2.11
May		1.16	1.69	1.15	2.29	2.09	2.63
June		0.91	0.63	0.50	1.00	0.91	0.96
July		[3]0.43	0.42	0.42	0.55	0.52	[3]0.44
August		[3]0.12	0.12	0.14	0.26	0.13	0.14
September		2.36	1.77	1.33	2.04	1.68	2.64
October		3.31	2.60	1.82	2.41	1.65	1.35
November		3.66	3.12	3.10	3.07	3.27	2.89
December		6.61	[1]5.44	3.28	5.38	4.47	6.17
Total	1996	31.10	25.23	19.80	26.07	22.73	26.29
January	1997	4.45	[1]4.45	3.00	4.09	3.94	2.24
February		1.53	[1]1.10	1.07	1.10	0.85	0.85
March		2.22	1.37	1.18	1.97	1.25	1.89
April		1.42	0.98	0.93	1.48	1.23	[2]1.52
May		1.00	0.90	0.85	1.82	1.51	1.65
June		1.67	1.58	1.24	2.33	2.60	1.63
July		0.40	0.48	0.33	0.66	0.58	0.82
August		0.72	0.62	0.61	0.70	0.71	0.83
September		1.87	1.47	1.58	1.65	1.14	1.79
January-September	1997	15.28	12.95	10.79	15.80	13.81	13.22

[1] Partial record at site. Precipitation for the missing days was estimated by multiplying the average ratio of monthly precipitation for winter months (December–February) at indicated site and site Pre-5 times precipitation for the missing days at site Pre-5.

[2] Partial record at site. Precipitation for the missing days was estimated using same procedure as described in footnote (1), but using spring months (March–May).

[3] Partial record at site. Precipitation for the missing days was estimated using same procedure as described in footnote (1), but using summer months (June–August).

Initial estimates of soil properties were obtained from the Soil Survey of Clallam County (Soil Conservation Service, 1987) and the Soil Survey of Jefferson County (Soil Conservation Service, 1975). The 26 soil series in the study area were combined into eight composite soil groups (table 3 and fig. 27). Properties of a group were computed as area-weighted averages of the properties of the soil series in the group. The principal soil properties used in the DPM are available water capacity, horizontal hydraulic conductivity, specific yield, depth, and texture. Horizontal hydraulic conductivity was not available in the soil surveys, so vertical hydraulic conductivities were compiled for reference. Ranges of the properties for each of the eight composite soil groups are 0.04 to 0.32 inch per inch for available water capacity, 0.4 to 40 ft/d for vertical hydraulic conductivity, 14 to 60 in. for depth, and silt loam to gravelly sandy loam for soil texture.

Estimates of specific yield for soils were not available in the soil surveys, nor from any other source for the study area. A value of 0.20 was used for all soils in the model. This is about the average of the specific yields used by Bauer and Mastin (1997) and is the same value used by W.R. Bidlake (U.S. Geological Survey, written commun., 1998) for all the soils in his study. A rough estimate of specific yield was made for this study area using typical values of specific yield and average soil properties for the study area. A typical value of specific yield for all soils is 0.40 (Heath, 1989), and a typical value for specific yield of the surficial unconsolidated deposits in the study area is 0.12 (Drost, 1983). For all soils in the study area, it was assumed that the A and B horizons had a specific yield of 0.40, and the C horizon had a specific yield equal to that of the surficial unconsolidated deposits (0.12). About 40 percent of an average soil in the study area contains the A and B horizons and 60 percent contains the C horizon (Soil Conservation Service, 1975 and 1987). The estimate of specific yield, weighted by specific yields of horizons and percentages of soil containing the horizons, is 0.23.

An important and usually unknown property used in the DPM is the vertical hydraulic conductivity of the subsoil. The calibrated models in Bauer and Mastin (1997) had a range of 0.0009 to 0.009 ft/d for three till-covered watersheds and the calibrated model by Bidlake (U.S. Geological Survey, written commun., 1998) had 0.006 ft/d for till and 0.2 ft/d for outwash and other coarse grained deposits.

Vegetation and land cover for the DPM were obtained from the GIS data base as shown on figure 4. All the vegetation was grouped into either grassland or forest. The irrigated areas shown on figure 4 were classified as grassland for the model simulations without irrigation. Residential areas were classified as grassland. It was assumed that runoff from the impervious parts of residential areas (streets and roofs) is directed onto undisturbed land where it can infiltrate the ground. An urban land cover was specified for about 0.6 mi^2 in the central part of Sequim and for about 0.1 mi^2 at an airport in the northeast part of Miller Peninsula. The DPM was run initially with grassland specified for the urban areas. After recharge was computed, it was assumed that impervious areas and storm sewers decreased the recharge by 30 percent.

Vegetation plays an important role in ground-water recharge by intercepting precipitation and by removing water from the soil by transpiration. Intercepted precipitation returns to the atmosphere by evaporation from the vegetation surface and thus is not available for recharge. The amount of interception of water depends on the cover characteristics of the vegetation. In this study, all vegetation was classified into either grassland or forest. No data were collected in this study on interception, so forests were assigned an average interception value of 20 percent (Bauer and Mastin, 1997; W.R. Bidlake, U.S. Geological Survey, written commun,. 1998). Grassland was assumed to have no interception of precipitation.

A property used in the DPM that is dependent on both soil and vegetation is the root depth. The root depth was assumed to equal the soil depth in this study.

Properties of land surface used in the model are land-surface slope and a measure of the density of small drainage channels in the basin (EFFLNGTH) (Bauer and Mastin, 1997). Land-surface slope was obtained from the mapping units of soil series (Soil Conservation Service, 1975 and 1987). The EFFLNGTH is defined as one-half the average spacing between the smallest drainage channels in the modeled basin (cells) (Bauer and Mastin, 1997). This property is difficult to measure or estimate, so it was assumed to be 100 ft for all cells in the model. W.R. Bidlake (U.S. Geological Survey, written commun,. 1998) used 100 ft for EFFLNGTH in all cells in his study.

Table 3. Properties of soil series and composite soil groups, Sequim-Dungeness area, Washington

[Source: C, Soil Conservation Service (1987); J, Soil Conservation Service (1975); <, less than; --, not applicable]

Soil series or composite soil group	Area (square mile)	Average available water capacity (inch per inch)	Vertical permeability (feet per day)			Average depth (inches)	Source
			Minimum	Average	Maximum		
Glaciomarine sediments or very fine alluvium							
Agnew silt loam	3.93	0.18	0.12	0.5	1.2	60	C
Bellingham silty clay loam	1.81	.22	.12	0.26	0.4	60	C
Casey silty clay loam	0.42	.15	.12	0.12	1.2	60	C
Cassolary fine sandy loam	3.65	.16	.4	1.7	4.0	60	C
Lummi silt loam	1.62	.16	1.2	2.6	4.0	60	C
Puget silt loam	4.65	.20	.4	0.8	4.0	60	C
Belfast silt loam Bk	0.03	.19	.4	0.8	1.2	60	J
Belfast silty clay loam Bm	<0.01	.16	.4	1.7	4.0	60	J
Area-weighted average							
Silt loam	--	.18	.4	1.0	2.8	60	--
Fine alluvium							
Dungeness silt loam	3.71	.14	1.2	2.6	4.0	60	C
Glacial outwash or coarse alluvium							
Carlsborg gravelly sandy loam	9.31	.03	4.0	26	40	60	C
Dick loamy sand	3.63	.06	12	26	40	60	C
Dystric xerorthents	.34	.05	1.2	8.0	12	60	C
Hoypus gravelly sandy loam	13.39	.04	12	26	40	60	C
Neilton very gravelly sandy loam	5.38	.04	12	26	40	60	C
Sequim very gravelly sandy loam	4.36	.03	12	26	40	60	C
Area-weighted average							
Gravelly sandy loam	--	.04	9.9	26	40	60	--
Glacial till, shallow depth							
Catla gravelly sandy loam	11.95	.09	1.2	2.6	4.0	14	C
Glacial till, moderate depth							
Clallam gravelly sandy loam	22.94	.08	1.2	2.6	4.0	28	C
Elwha gravelly sandy loam	13.08	.10	1.2	2.6	4.0	33	C
McKenna gravelly silt loam	.88	.12	.12	0.26	4.0	32	C
Yeary gravelly loam	5.51	.12	.4	0.8	4.0	38	C
Tukey gravelly loam	0.87	.14	.12	1.7	4.0	56	J

Table 3. Properties of soil series and composite soil groups, Sequim-Dungeness area, Washington—Continued

Soil series or composite soil group	Area (square mile)	Average available water capacity (inch per inch)	Vertical permeability (feet per day)			Average depth (inches)	Source
			Minimum	Average	Maximum		
<u>Area-weighted average</u>							
Gravelly sandy loam	--	.09	1.1	2.3	4.0	31	--
<u>Bedrock, moderate depth</u>							
Terbies very gravelly sandy loam	.54	0.05	1.2	2.6	4.0	45	C
Cathcart gravelly silt loam	0.01	.14	1.2	2.6	4.0	38	J
<u>Area-weighted average</u>							
Gravelly sandy loam	--	.05	1.2	2.6	4.0	45	--
<u>Bedrock, deep depth</u>							
Louella gravelly loam	.63	.12	1.2	2.6	4.0	60	C
Schnorbush loam.	12	.16	.4	0.8	4.0	60	C
<u>Area-weighted average</u>							
Gravelly loam	--	.13	1.1	2.3	4.0	60	--
<u>Organic material</u>							
Mukilteo muck	1.12	.32	1.2	2.6	4.0	60	C

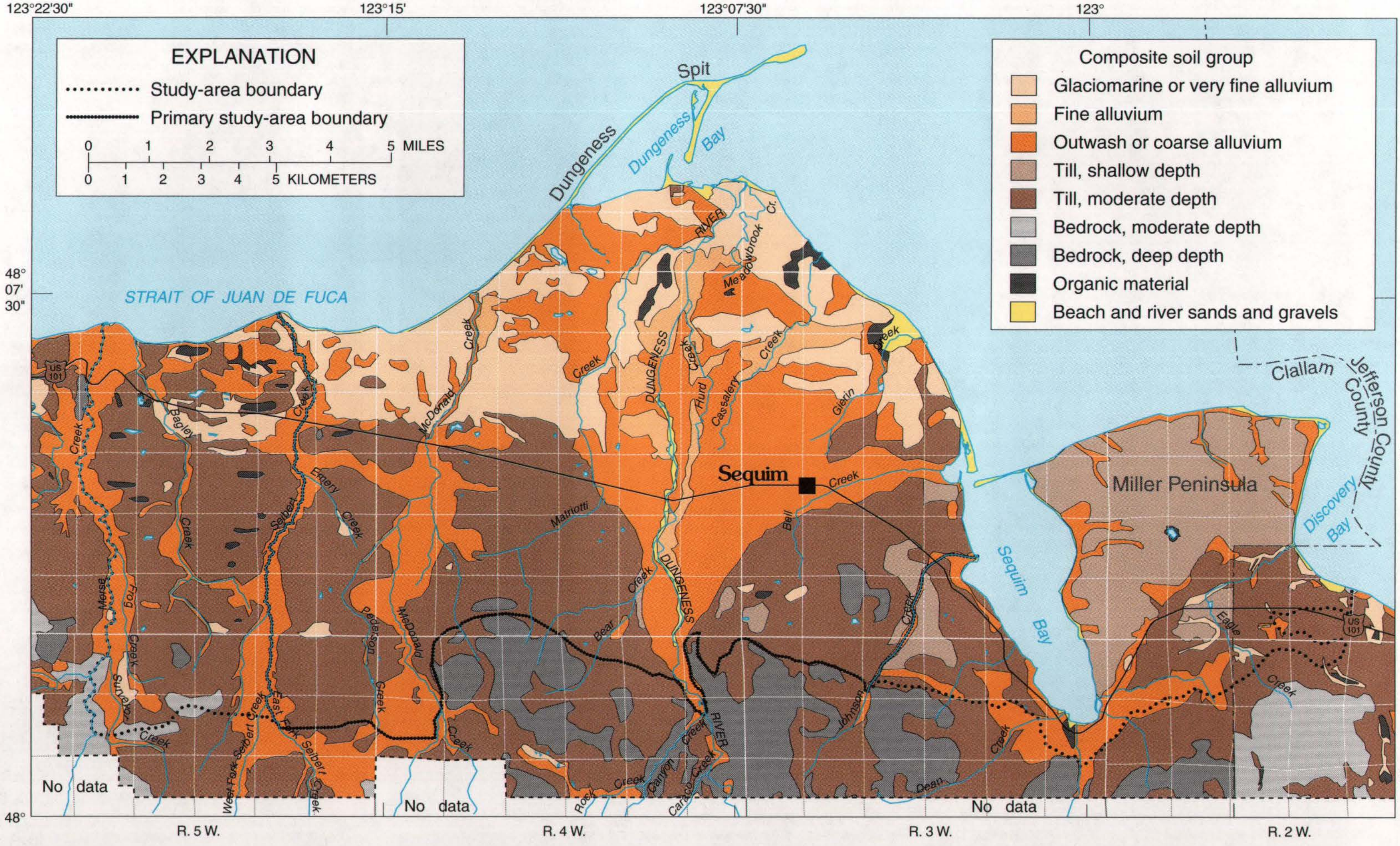


Figure 27. Composite soil groups used for recharge analysis.

Several other properties of atmospheric variables and vegetation are used in the DPM. Values of these properties were not available from any sources for the study area, so values used by Bauer and Mastin (1997) were used in this study. These properties are SBLRATE, sublimation rates for snowpack; SNMCOEF, snowmelt coefficient; SLRXFMX, monthly ratios for solar radiation values; FCMAX, maximum foliar cover; and MAXINT, maximum interception storage capacity.

Calibration of Deep-Percolation Model to Emery Creek Basin

Step (2) in the recharge analysis was to apply the DPM to Emery Creek Basin. The purpose of calibrating the DPM to the Emery Creek Basin was to obtain estimates of the two most uncertain variables in the DPM: horizontal hydraulic conductivity of the soil and vertical hydraulic conductivity of the subsoil. Emery Creek Basin was used because it was the only basin in the study area with measured runoff data (March 1, 1996 to August 31, 1997). Emery Creek is an ephemeral stream, and all streamflow is runoff, either overland flow or shallow subsurface flow through the soil.

The Emery Creek Basin is in the east-central part of the study area (fig. 1). It was divided into three variable-size model cells: (1) forested, glacial till soil of moderate depth, and 0.682 mi^2; (2) grassland, till soil of moderate depth, and 0.256 mi^2; and (3) grassland, glaciomarine sediments or very fine alluvium soil, and 0.058 mi^2. Till soils cover 94 percent of the basin; therefore, the emphasis of calibration was to adjust and obtain estimates of till-soil properties. The daily precipitation record at station Pre-1 was used for precipitation. Temperature data at station Pre-5 were used, and the two solar radiation stations described earlier were used.

To run the DPM, initial water contents of the soils must be specified. The amount of soil water is expressed as a fraction of the available water capacity (unsaturated soil) and as a fraction of specific yield (saturated soil). The start of the Emery Creek Basin simulation was March 1, 1996. Initial water contents were estimated by evaluating measured water contents of nearby soil-water sites in till soils, and by running the DPM for a dummy year to determine a simulated water content for March 1. Measured water contents at soil-water sites 9, 11, and 15 (fig. 12) appeared to become saturated in early December and remain saturated until the end of March. The DPM was run from March 1, 1996, to March 1, 1997, with initial water contents of 100 percent of available water capacity and zero percent of specific yield. Ending water contents of the two soils in the basin were 100 percent of available water capacity and about 30 percent of specific yield. Those ending water contents were, therefore, used as the initial water contents for the Emery Creek simulation. To determine the sensitivity of initial water contents, the model was run with 10 percent and 50 percent of specific yield. The resulting simulated recharges were 6 percent and 8 percent different than the simulated recharge for the initial water content of 30 percent of specific yield.

The DPM was calibrated by adjusting values of the horizontal and vertical conductivities of the till soil and subsoil until simulated runoff had a good agreement with measured runoff. All other properties of the composite soil groups, vegetation, and land surface were considered fairly reliable and were not changed from the initial estimates described earlier in this section. The calibrated model had a good agreement between measured (6.8 in.) and simulated (7.1 in.) runoff (fig. 28). Calibrated values were 4.83 ft/d for horizontal hydraulic conductivity of the till soil and 0.0043 ft/d for vertical hydraulic conductivity of the subsoil. The 4.83 ft/d is slightly larger than the initial maximum estimate of 4.0 ft/d for hydraulic conductivity of the till soil with moderate depth. The 0.0043 ft/d for vertical conductivity of the subsoil is within the 0.0009 to 0.009 ft/d range used by Bauer and Mastin (1997).

The simulated average annual water-budget components for Emery Creek basin during March 1996 to September 1997 are 28.9 in. for precipitation, 7.2 in. for recharge, 7.1 in. for runoff, 14.2 in. for evapotranspiration, and 0.4 in. for change in soil water. Actual runoff was 6.8 in. Average annual values were computed for a 19-month simulation by computing 19 individual monthly values, computing average monthly values using 2 months when available and 1 month when only 1 month was available, and adding the 12 average monthly values.

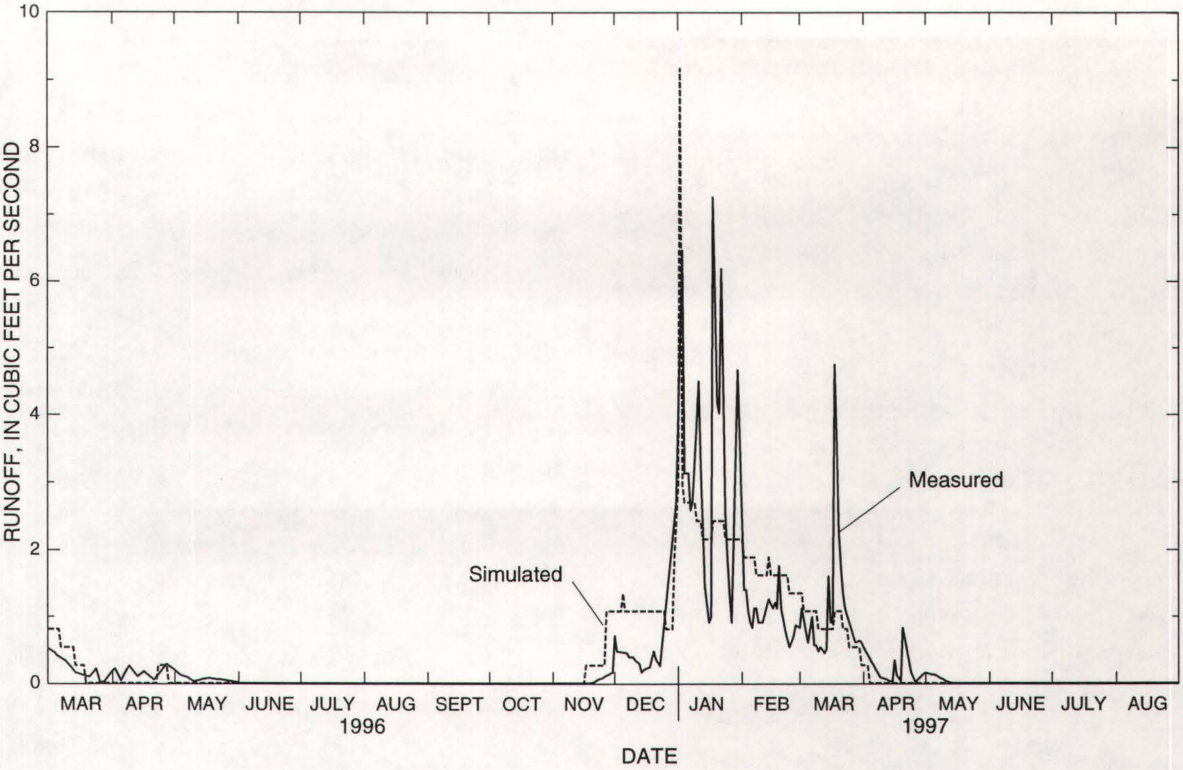


Figure 28. Comparison between measured runoff from Emery Creek watershed and runoff simulated by deep-percolation model, Sequim-Dungeness area, Washington.

Application of Deep-Percolation Model to Entire Study Area

Step (3) in the recharge analysis was to apply the DPM to the entire study area. The 7,378 cells were assigned one of two vegetation types and one of nine soil types or water. Forests cover 59 mi^2 and grassland covers 55 mi^2. The nine soil types include the eight composite soils and beach and river gravels. Till soils (two composite groups) cover 55 mi^2, glacial outwash or coarse alluvium cover 36 mi^2, glaciomarine sediments and very fine alluvium cover 16 mi^2, and the other four composite soil groups cover 6 mi^2 (fig. 27). Beach and river gravels cover about 2 mi^2, and they were assumed to have zero recharge because infiltrating precipitation would runoff rapidly into the adjoining salt water or river. Water covers less than 1 mi^2, and these areas were assumed to have zero recharge.

Estimates of horizontal and vertical conductivity for the eight composite soil groups were made using the Emery Creek calibrated estimates of horizontal and vertical conductivity for the till soil and ratios of the average vertical hydraulic conductivity from Soil Conservation Service (1975 and 1987) for the pertinent soil and for till (table 3). For example, the estimate of horizontal conductivity for the glaciomarine sediments and very fine alluvium soil was 2.10 ft/d (table 4), which is equal to 4.83 ft/d (table 4) times 1.0/2.3 (table 3). The resulting values for horizontal conductivity used in the DPM range from 2.10 to 54.6 ft/d (table 4). Values of vertical conductivity range from 0.00019 to 23 ft/d (table 4). The large value of 23 ft/d for outwash and coarse alluvium was not determined from the ratio method. These soils are very permeable and do not saturate; therefore, it was assumed that precipitation does not runoff from these soils, and the vertical conductivity was set at a large value to prevent any runoff.

The initial water contents specified for the DPM of the entire study area were 100 percent of available water capacity and zero percent of specific yield. Measured water contents at most soil water sites (fig. 12) appeared to become saturated near the beginning of December. In addition, the DPM was run from December 1, 1995, to December 1, 1996, and ending water contents were near 100 percent of available water capacity for most soils in the model.

Table 4. Summary of properties of composite soil groups used in deep-percolation model, Sequim-Dungeness area, Washington

Composite soil group	Total area (square mile)	Available water capacity (inch per inch)	Horizontal permeability (feet per day)	Vertical permeability of subosil (feet per day)	Soil texture	Depth (inches)	Land surface slope (foot per foot)	Number of soil series
Glaciomarine sediments or very fine alluvium	16.1	0.18	2.10	0.0019	Silt	60	0.01-0.08	8
Fine alluvium	0.7	.14	5.46	.0048	Silt	60	.02	1
Glacial outwash or coarse alluvium	36.4	.04	54.6	23	Sand	60	.02-.85	6
Glacial till, shallow depth	12.0	.09	5.46	.0048	Sand	12	.08-.48	1
Glacial till, moderate depth	43.3	.09	4.83	.0043	Sand	30	.02-.50	5
Bedrock, moderate depth	0.6	.05	5.46	.0048	Sand	42	.48-.75	2
Bedrock, deep depth	0.8	.12	4.41	.0043	Sand	60	.20-.38	2
Organic material	1.1	.32	5.46	.0048	Clay	60	.01-.08	1
Beach and river gravels	2.0	--	--	0	--	--	--	2

To determine sensitivity of initial water contents, the model was run with 80 percent of available water capacity, and with 100 percent of available water capacity and 20 percent of specific yield. The resulting simulated recharges were 2 percent and 6 percent different than the simulated recharge for 100 percent of available water capacity and zero percent of specific yield, respectively.

The DPM was run for the entire study area with the soil properties shown in table 4. No additional calibrations were performed because no runoff data were available, and the soil-water data collected at 16 sites during this study were considered insufficient for calibration purposes. Soil properties can change appreciably over distances of tens or hundreds of feet. A previous application of the DPM in western Washington (Bauer and Mastin, 1997) showed considerable variability in soil properties and in hydrographs of soil water in small basins of 0.05 to 0.2 mi^2. At least three measurement sites would be needed to accurately represent soil water in one soil type in the cell size for this model (0.0156 mi^2). The 16 soil-water sites in this study are all located in different cells.

Step (4) in the recharge analysis was to adjust the recharge for urban areas. Urban areas were assumed to have 30 percent effectively impervious surfaces. Computed recharge for five cells representing the Miller Peninsula airport and 40 cells representing the City of Sequim was, therefore, manually decreased by 30 percent. This 30 percent value was estimated using the average amount of effective impervious surfaces in three urban catchments in Bellevue, Wash. (Prych and Ebbert, 1986). Those three urban catchments were assumed to have density characteristics similar to the urban parts of the Sequim-Dungeness area. Effective impervious surfaces are roofs, streets, parking lots, and other paved areas that eventually drain to storm drains, stream channels, or irrigation ditches. The urban adjustment decreased total recharge by 0.2 percent.

The simulated average annual water-budget components for the study area during December 1995 to September 1997 are 27.9 in. for precipitation, 8.6 in. for recharge, 3.7 in. for runoff, 15.4 in. for evapotranspiration, and 0.2 in. for change in soil water. Simulated recharge for the primary study area was 8.0 in. The areal distribution of recharge (fig. 29) reflects precipitation (fig. 2) and soil types (fig. 27). Recharge increases to the south and west where precipitation increases and recharge is larger in areas of glacial outwash or coarse alluvium soils. There are large amounts of recharge in the upper valleys and side slopes of Morse Creek, Siebert Creek, and McDonald Creek because precipitation is higher (fig. 2), and those areas are covered by soils formed in coarse deposits of glacial outwash (fig. 27). This recharge, however, probably moves quickly through shallow deposits and discharges into the streams. Thus, this recharge would have little effect on the shallow aquifer in the northwest part of the study area.

The relations between recharge and precipitation for the composite soil groups reflect the soil properties of the composite soil group (fig. 30). In the soils with small infiltration rates (glaciomarine sediments and very fine alluvium, and till), recharge increases gradually with increased precipitation because the small vertical hydraulic conductivities only allow so much recharge regardless of the amount of precipitation. In outwash and coarse alluvium soils, recharge increases rapidly with increased precipitation because there is no runoff and the maximum precipitation of 50 inches per year (in/yr) is much less than the specified vertical conductivity of 23 ft/d. In the soils with small infiltration rates, the influence of land-surface slope on recharge is shown in separate curves in the plot of precipitation and recharge (fig. 30).

Average annual recharge ranged from 11 percent of average precipitation in areas with glaciomarine sediments and very fine alluvium to 48 percent in areas with outwash and coarse alluvium. The average recharge through till soils was 25 percent of precipitation, which is between the average of 12 percent for three simulated basins in Bauer and Mastin (1997) and 34 percent for 27 previous investigations in the Puget Sound area (Bauer and Mastin, 1997, table 1). The average recharge of 48 percent of precipitation for outwash and coarse alluvium is similar to the average of 52 percent for 27 previous investigations (Bauer and Mastin, 1997, table 1).

Some other comparisons were made to evaluate the results of the DPM. The all-area DPM simulated a recharge of 8.0 in. for the Emery Creek Basin (65 cells) and the DPM simulation of Emery Creek basin by itself (3 cells) simulated a recharge of 7.2 in. Simulated soil water was compared with measured soil water at seven sites in till soils. Simulated water contents were generally larger than measured water contents in the winter and smaller than measured in the summer (fig. 31). However, there was a large spread in the data for the seven sites, and the average differences between measured and simulated soil water for the seven sites were all within plus or minus 1.3 in. of zero. Comparisons of simulated to measured soil water were not made for the other nine soil water sites. Soil wilting points and available soil water could not be determined for six of the nine sites. The remaining three sites represented two soil types, and little information would be gained by comparing simulated and measured soil water contents for those sites.

Estimation of Long-Term Average Annual Recharge

Step (5) in the recharge analysis was to estimate long-term average annual recharge. Average annual precipitation during the study period was about 1.35 times greater than the long-term average annual precipitation; therefore, the average annual recharge estimated for the study period is larger than would be expected over a long time period. To estimate long-term average annual recharge, regression relations were developed for the composite soil groups with simulated annual recharge as the response variable, and annual precipitation and land-surface slope as explanatory variables (table 5). The data used to develop the regression relations were the values of recharge, precipitation, and land-surface slope for the 7,378 cells in the DPM (fig. 30). Long-term average annual precipitation from figure 2 and land-surface slope were then used in the equations to estimate long-term average annual recharge. The DPM was not used to estimate long-term average annual recharge for a long period of time (more than 20 years) because no solar radiation data were available, and precipitation data were only available for one site.

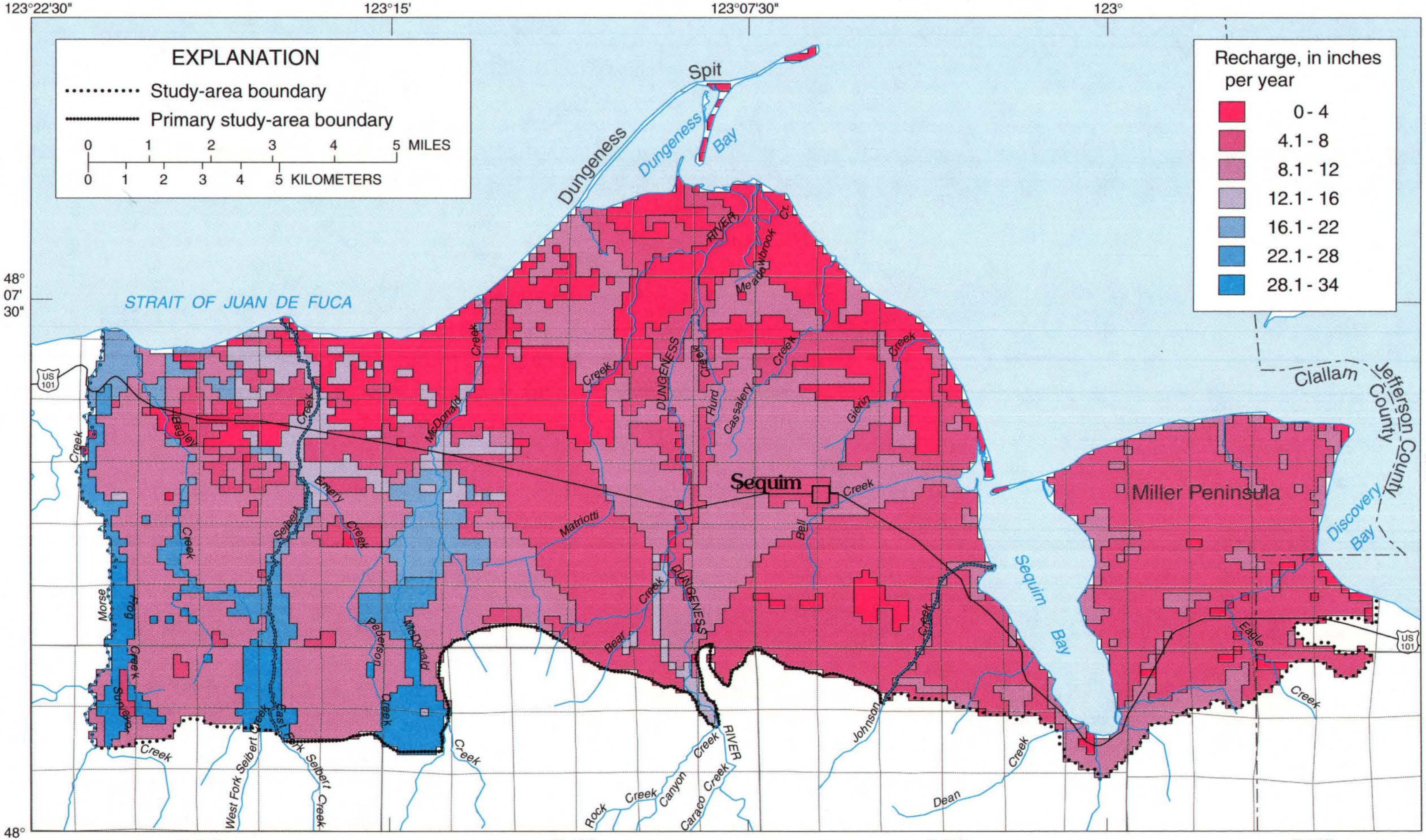


Figure 29. Average annual ground-water recharge from infiltration and percolation of precipitation during December 1995 to September 1997.

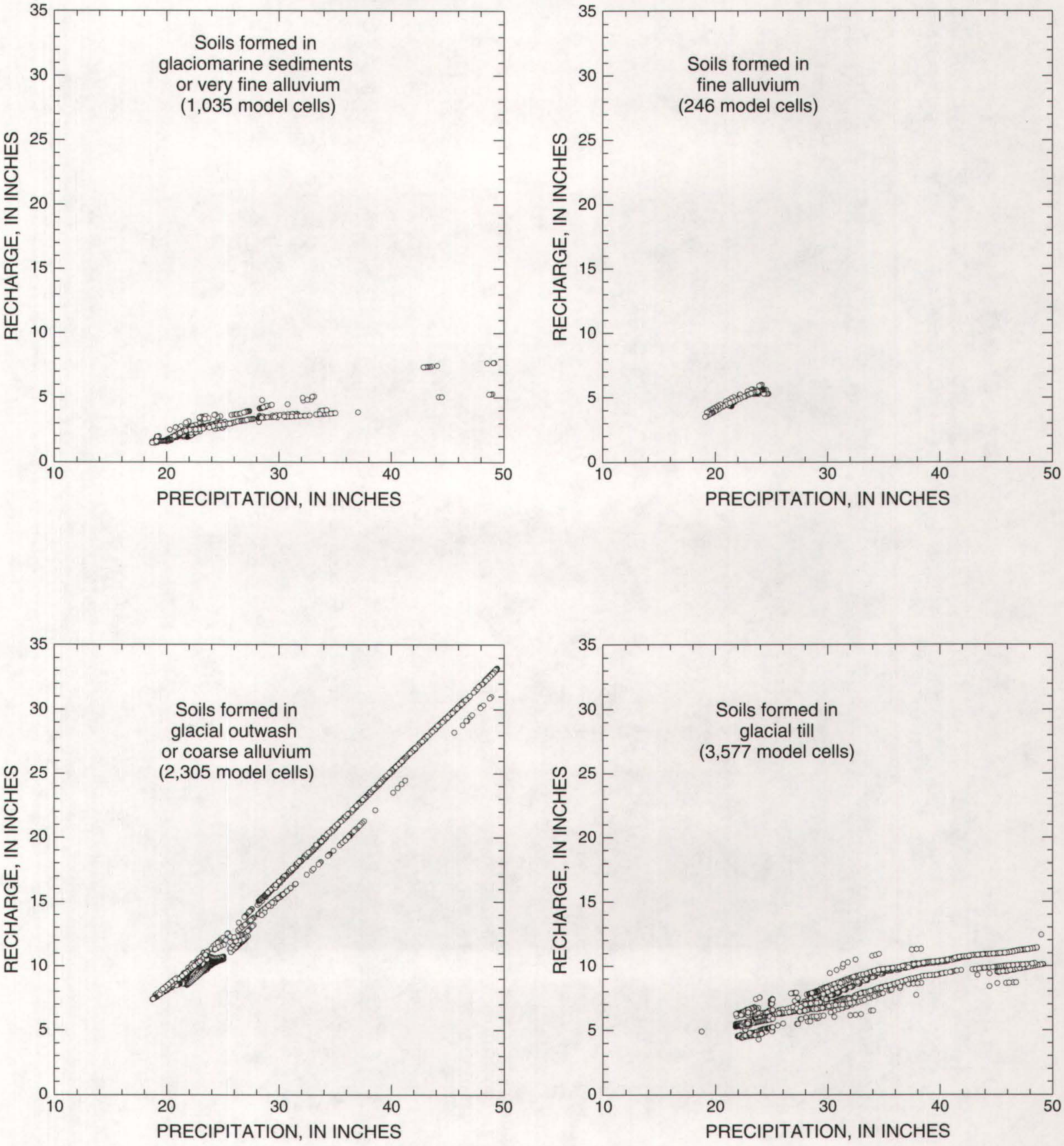


Figure 30a. Relations between annual ground-water recharge simulated by deep-percolation model and measured annual precipitation for selected composite soil groups, Sequim-Dungeness area, Washington.

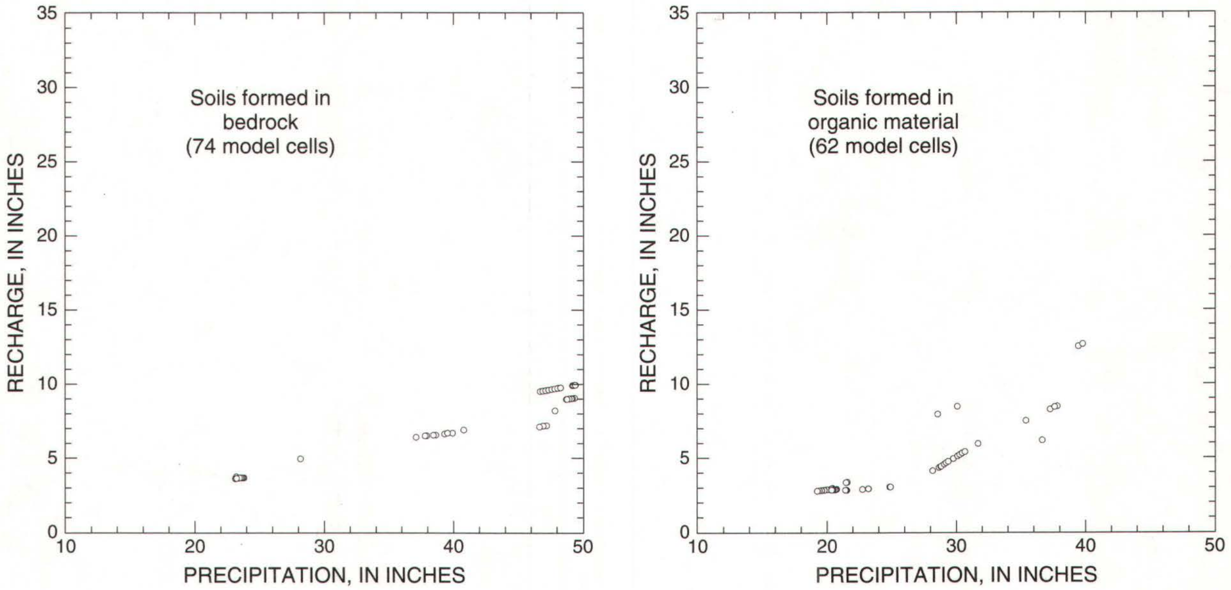


Figure 30b. Relations between annual ground-water recharge simulated by deep-percolation model and measured annual precipitation for selected composite soil groups, Sequim-Dungeness area, Washington.

Table 5. Regression equations for estimating annual ground-water recharge from annual precipitation and land-surface slope, Sequim-Dungeness area, Washington

[Data are from deep-percolation model applied to study area; Composite soil group, see table 3 for individual soil series in each group; *Rech*, ground-water recharge in inches; *P* , precipitation, in inches; *S* , land-surface slope, in fraction of vertical to horizontal distance]

Composite soil group	Number of model cells	Equation	Coefficient of determination (R^2)	Root-mean-square error (inches)
Glaciomarine sediments or very fine alluvium	1,035	$Rech = -3.87 + 0.348P - 0.00271P^2 - 6.26S$	0.88	0.32
Fine alluvium	46	$Rech = -3.95 + 0.398P$	.93	.15
Glacial outwash or coarse alluvium	2,305	$Rech = -10.06 + 0.872P$	.99	.58
Glacial till	3,577	$Rech = -2.22 + 0.457P - 0.00358P^2 - 5.02S$	.92	.56
Bedrock	74	$Rech = -1.60 + 0.222P$	.95	.59
Organic material	62	$Rech = -4.30 + 0.340P$	.81	.99

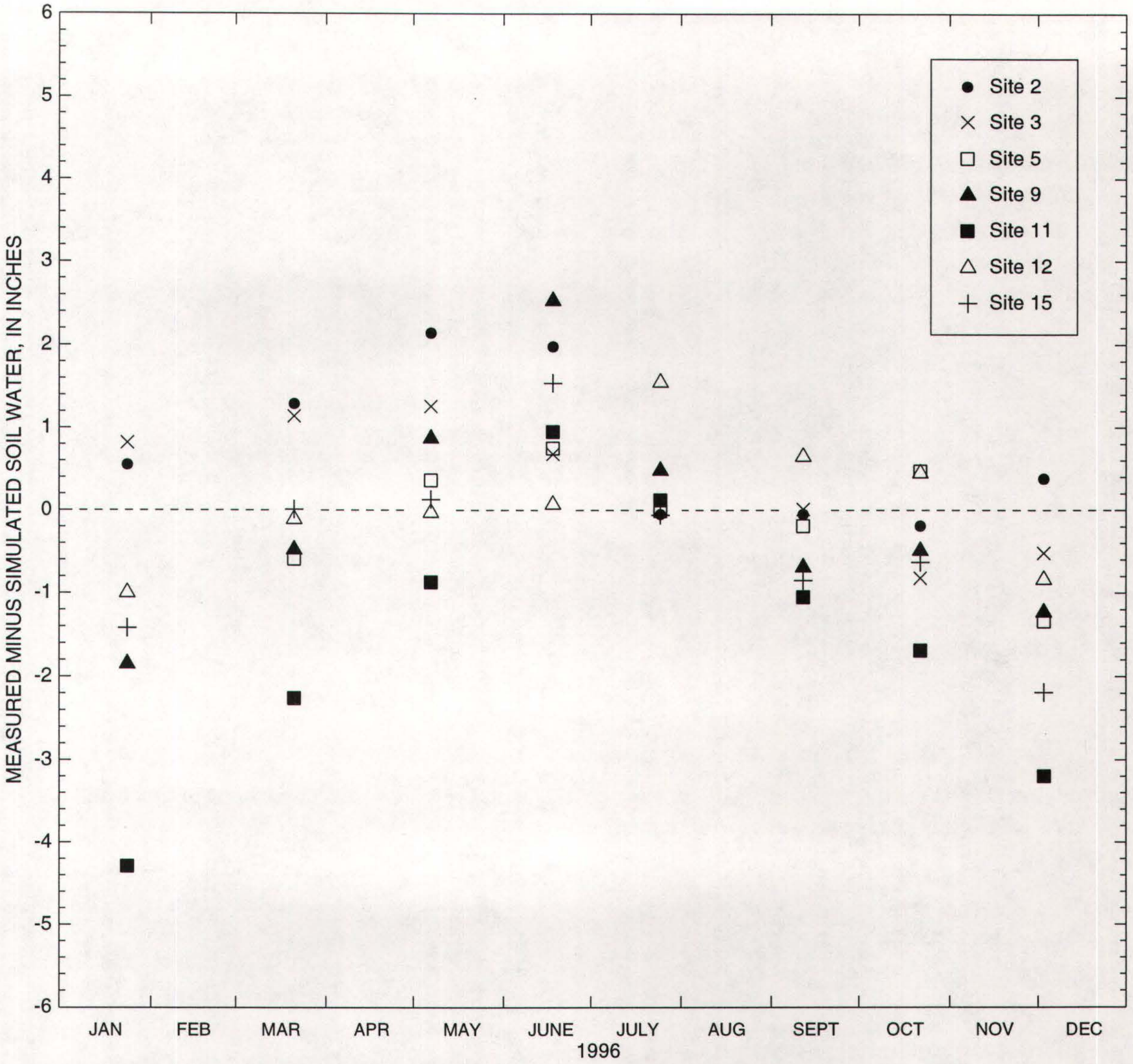


Figure 31. Comparison between measured soil water and soil water simulated by deep-percolation model at seven sites with till soils, Sequim-Dungeness area, Washington.

Six regression relations were developed for the eight composite soil groups (table 5). The two composite till soils were combined, and the two bedrock soils were combined. Linear relations were developed for fine alluvium, glacial outwash or coarse alluvium, bedrock, and organic material. The relations for glaciomarine sediments or very fine alluvium, and till are curvilinear, so a precipitation-squared term was added to create a curvilinear regression relation. Land-surface slope was tested with all the regressions, but it was only significant for the glaciomarine sediments or very fine alluvium and till groups.

Separate regressions were made within the soil groups for areas of grassland and areas of forests. The difference in estimated recharge for the vegetation groups was mostly less than 5 percent and was always less than 10 percent; therefore, no separate regression relations for vegetation groups were used. The precipitation data used to develop the regression relations ranged from 19 in. to 49 in. Long-term average annual precipitation for the study area ranges from 14 in. to 39 in. Regression relations are usually only applied within the range of data used to develop them. For this application, it was necessary to extend the relations beyond the lower limits of the data and assume that the slope of the regression relations did not change at the smaller precipitation values.

The regression relations were applied to 7,299 DPM cells using average annual precipitation from figure 2 and land-surface slope from DPM input data (the study area has 7,378 cells, but 79 of those cells have no recharge because they represent water, river gravels, or beaches). The resulting average annual recharge was 5.4 in. for the entire study area and 4.8 in. for the primary study area (fig. 32). The 4.8 in. for the primary study area is about 40 percent higher than the 3.4 in. estimated by Drost (1983) for his study area, which covered an area similar to this study's primary study area.

The recharge estimated in this study is probably more accurate than the recharge estimated in Drost (1983). The DPM used in this study accounts for daily changes in a water budget and includes measured precipitation, temperature, and solar radiation. The DPM also accounts for areal variation in soil properties, vegetation, and land-surface slope. Drost (1983) estimated recharge using a monthly water-budget approach; the method did not account for areal variation in soils, vegetation, or land-surface slope.

The last step in the recharge analysis was to add values for irrigation water to the DPM, resulting in recharge from both precipitation and percolation of unconsumed irrigation water. The method of estimating quantities of irrigation water and the application of such water to the DPM are explained in the following section on irrigation recharge.

Percolation of Unconsumed Irrigation Water and Leakage from Irrigation Ditches

Most of the water applied to irrigate fields of pasture, alfalfa, and row crops is taken up by the plants or is evaporated from the plant or soil surface, but the unconsumed water percolates to the water table and becomes ground-water recharge. In addition, leakage from irrigation ditches contributes a substantial amount of recharge near the ditches. Most of the ditches in the study area were constructed in the natural surficial soils or sediments, so leakage is controlled by the permeability of these materials, the size of the ditches, and the depths of water in the ditches. Estimated average annual recharge for the study period (December 1995 to September 1997) was 2.8 in. (23.7 ft^3/s) for ditch leakage and 0.3 in. (2.8 ft^3/s) for percolation of unconsumed irrigation water (the values in inches were obtained by dividing the rates by the entire study area, 116 mi^2).

The amount of percolation of unconsumed irrigation water was estimated using the DPM with values for applied irrigation water added to precipitation. The quantity of water applied to fields was estimated using total monthly diversions from the Dungeness River (table 6) and McDonald Creek for the summer irrigation season (May 16 to September 20) and subtracting from it estimated tailwaters and estimated ditch leakage. The average diversion from McDonald Creek was about 5 ft^3/s. These summer water-budget components were estimated for eight irrigated areas; areas served by Eureka and Independent Companies were combined for the analysis (table 7). Total diversions and tailwaters for each irrigation company were estimated from the compilation of over 9,000 estimated discharges at staff-gage locations spread throughout the irrigation-ditch system. Ditch leakage was estimated by Montgomery Water Group, Inc. using the discharge data for the ditches and previously estimated ditch-leakage rates for different types of surficial geologic material (Montgomery Water Group, Inc., 1993).

Total water-budget components estimated for the summer irrigation season (May 16 to September 20) were 74.4 ft^3/s for total diversions, 15.3 ft^3/s for tailwaters, 59.1 ft^3/s for net water flowing through the ditch system and supplied to irrigated fields, 30.0 ft^3/s for ditch leakage, and 29.1 ft^3/s for water applied to the fields (table 7). The 29.1 ft^3/s was spread over 513 model cells representing 5,130 acres of irrigated land. The amount of water applied to areas served by the different irrigation companies and districts ranged from 6.3 to 53.4 in. (table 8). The water applied to fields was added to precipitation in the DPM for the irrigation season of May 16 to September 20. Within the boundaries of each irrigation company, the supplied water was spread evenly over the irrigated fields. The DPM was then run using the same input data that was used for estimating precipitation recharge. The resulting difference in recharge for cells with the added irrigation water is the percolation of unconsumed irrigation water. The total percolation of unconsumed irrigation water was 5.0 ft^3/s (an average of 4.8 in. for the irrigated areas), and it ranged from less than 0.1 to 34.6 in. for the irrigated areas of the irrigation companies and districts (table 8).

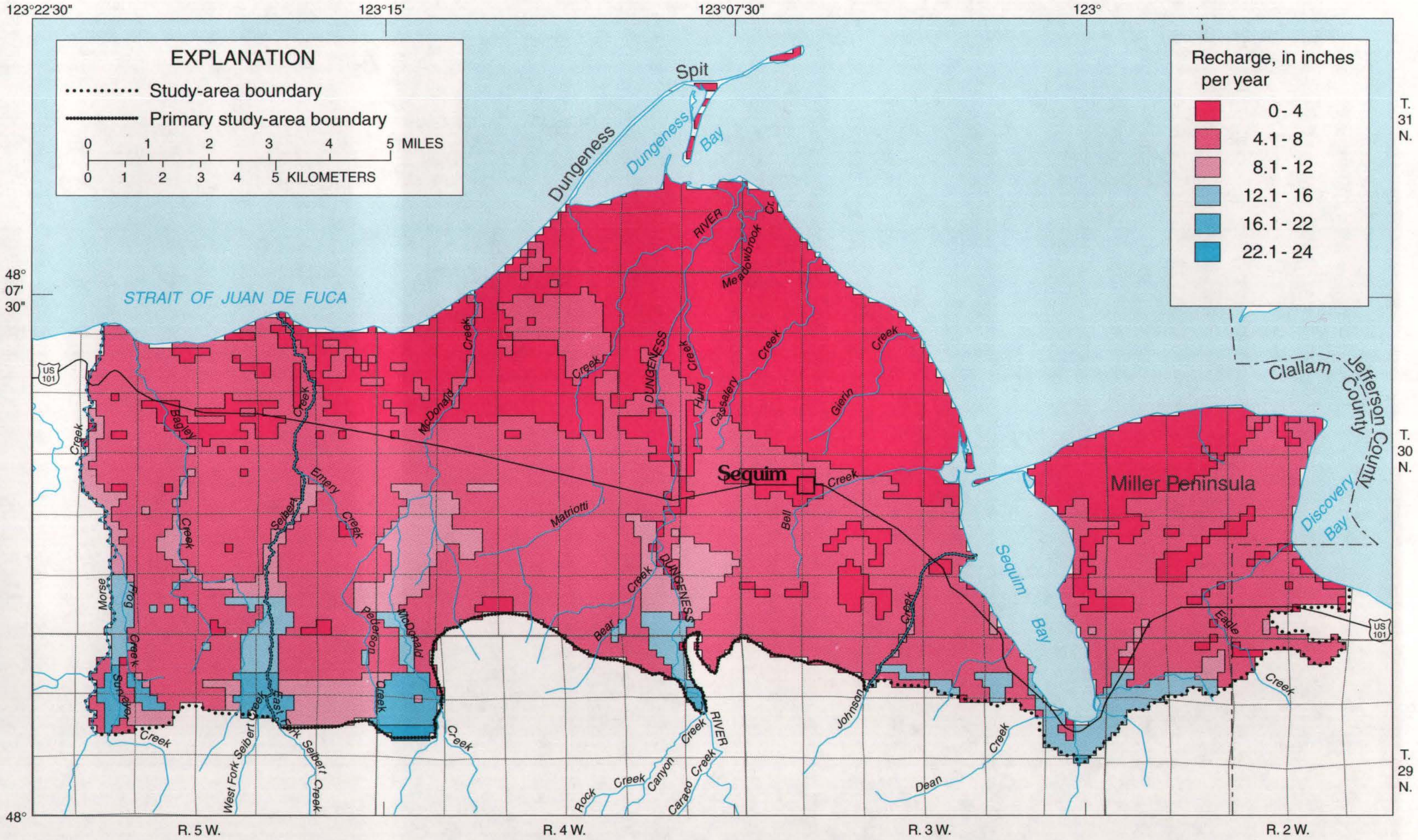


Figure 32. Long-term average annual ground-water recharge from infiltration and percolation of precipitation.

Table 6. Monthly average diversions from the Dungeness River by irrigation companies or districts, December 1995 to September 1997, Sequim-Dungeness area, Washington

[--, missing data; >, greater than]

		Average diversion, in cubic feet per second									
Month	Year	Agnew	Clallam	Cline	Dungeness Company	Dungeness District	Eureka	Highland	Independent	Sequim-Prairie	Total
December	1995	5.1	0	0	0	--	0.8	1.3	4.9	--	>12.1
January	1996	3.4	0	0	0	--	0.7	2.9	4.0	--	>11.0
February		0.5	0	0	0	--	1.1	2.2	3.6	--	>7.4
March		3.5	0	0	0	--	1.6	1.8	3.7	--	>10.6
April		11.7	1.1	0	0.1	--	2.2	4.5	3.6	--	>23.2
May		14.1	3.8	8.6	2.2	--	3.0	5.6	5.2	--	>42.5
June		16.5	4.0	9.9	5.6	8.1	4.1	8.0	7.3	7.5	71.0
July		19.7	4.9	7.9	6.2	8.9	4.6	7.8	7.6	8.0	75.6
August		17.9	4.3	6.6	6.1	8.0	7.1	7.7	6.2	8.5	72.4
September		9.4	4.3	7.4	2.6	5.6	4.2	5.6	3.7	6.0	48.8
October		5.8	3.8	4.8	0.6	5.2	1.9	4.8	4.5	3.6	35.0
November		4.4	3.2	4.0	3.2	1.6	1.5	5.0	6.1	0.8	29.8
December		0.7	2.4	5.7	1.6	1.6	0.8	4.0	6.2	0.5	23.5
June-September	1996	15.9	4.4	8.0	5.1	7.6	5.0	7.3	6.2	7.5	67.0
January	1997	0	0	0	0	0.8	0.6	0	3.1	0.8	5.3
February		0.5	0	0	0	0.9	0.8	0.4	3.7	0.6	6.9
March		2.1	0	0	0	--	0.5	0.7	3.9	--	>7.2
April		7.8	2.6	5.0	3.2	6.5	2.8	2.2	6.5	6.5	43.1
May		12.7	4.9	9.7	8.0	8.8	5.4	4.7	8.6	8.9	71.7
June		15.3	5.0	9.2	7.9	7.6	4.8	6.9	10.2	6.8	73.7
July		16.7	5.6	8.2	6.4	7.6	4.7	7.8	9.4	8.0	74.4
August		19.6	5.9	9.1	6.5	10.8	5.7	7.0	12.0	9.7	86.3
September		9.6	4.8	5.9	3.4	7.0	4.4	4.0	4.7	6.3	50.1
June-September	1997	15.3	5.3	8.1	6.0	8.2	4.9	6.4	9.1	7.7	71.0

Total recharge from irrigation includes the percolation of unconsumed irrigation water and leakage from irrigation ditches. Percolation was estimated as described above to be 5.0 ft^3/s, and ditch leakage was estimated by Montgomery Water Group, Inc. to be 30 ft^3/s during the irrigation season, 20 ft^3/s during the remainder of the year, which makes an annual rate of 23.7 ft^3/s. This total recharge from irrigation, converted to inches per year, is shown on figure 33; ditch leakage was converted from cubic feet per second to inches and was spread evenly over the cells in which the ditches were located. The areas that have large amounts of irrigation recharge are along both sides of the Dungeness River and between Siebert Creek and McDonald Creek.

The recharge computed by the DPM for infiltration and percolation of precipitation was combined with irrigation recharge to produce figure 34. Within the primary study area, any area with total recharge greater than 20 in. is heavily influenced by recharge from irrigation.

Table 7. Approximate average water budgets for irrigation companies or districts for the irrigation seasons of May 16 to September 20, 1996 and 1997, Sequim-Dungeness area, Washington

[Column (A), source is table 6 and U.S. Geological Survey data on discharges in ditches; Column (B), source is U.S. Geological Survey data on discharges in ditches and Montgomery Water Group, Inc. (Kirkland, Wash., written commun., 1998); Column (C), equal to Column (A) minus Column (B); Column (D), source is Montgomery Water Group, Inc. ; Column (E), equal to Column (C) minus Column (D); Column (F), computed from DPM (deep-percolation model) with precipitation and Column (E) as input; Column (G), equal to Column (D) plus Column (F)]

	Quantity of water, in cubic feet per second						
Irrigation company or district	Total diversions (A)	Tailwaters (B)	Net water supplied (C)	Ditch leakage (D)	Water applied to fields (E)	Percolation of unconsumed irrigation water (F)	Total irrigation season recharge (G)
Agnew	20.1	5.1	15.0	5.5	9.5	2.2	7.7
Clallam	4.8	0.5	4.3	3.4	0.9	<0.1	3.4
Cline	8.2	1.0	7.2	3.7	3.5	0.9	4.6
Dungeness Company	5.7	0.4	5.3	3.7	1.6	<0.1	3.7
Dungeness District	8.2	0.9	7.3	3.4	3.9	1.4	4.8
Eureka plus Independent	12.7	4.4	8.3	3.0	5.3	0.4	3.4
Highland	6.8	1.1	5.7	4.4	1.3	<.1	4.4
Sequim-Prairie	7.9	1.9	6.0	2.9	3.1	0.1	3.0
Total	74.4	15.3	59.1	30.0	29.1	5.0	35.0

Table 8. Applied irrigation water used in the deep-percolation model for the irrigation seasons of May 16 to September 20, 1996 and 1997, Sequim-Dungeness area, Washington

[DPM, deep-percolation model; <, less than; --, not applicable]

Irrigation company or district	Irrigated area		Water applied to irrigated fields during irrigation season		DPM simulated percolation of unconsumed irrigation water (inches per season per cell)
	Number of DPM cells	Area (acres)	(Cubic feet per second)	(Inches per cell)	
Agnew	119	1,190	9.5	24.1	5.6
Clallam	41	410	0.9	6.6	0.1
Cline	46	460	3.5	23.0	5.8
Dungeness Company	71	710	1.6	6.8	0.1
Dungeness District	41	410	3.9	28.8	10.7
Eureka plus Independent	30	300	5.3	53.4	34.6
Highland	62	620	1.3	6.3	<0.1
Sequim-Prairie	103	1,030	3.1	9.1	0.3
Total	513	5,130	29.1	--	--

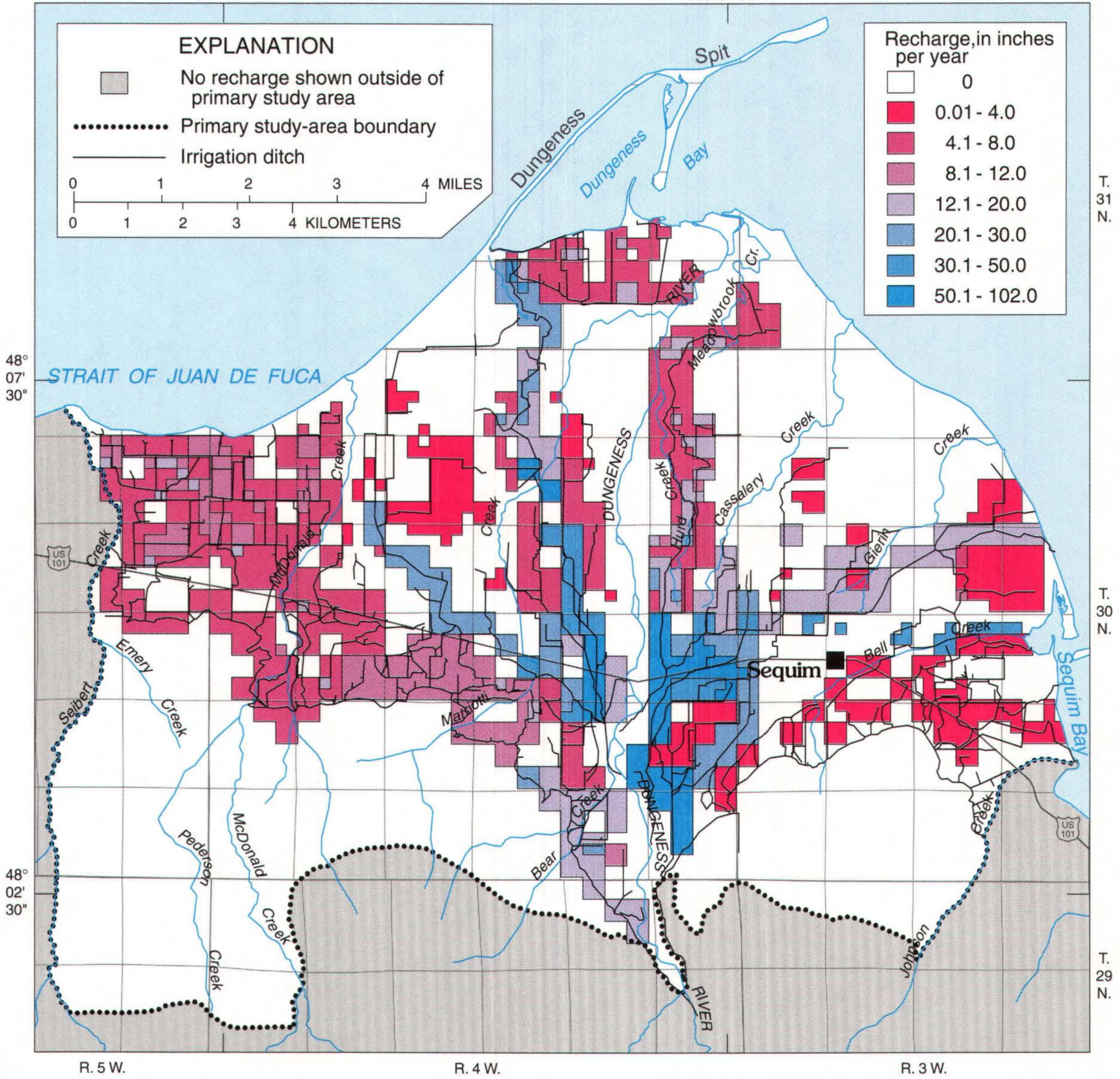


Figure 33. Increase in average annual ground-water recharge caused by percolation of unconsumed irrigation water and leakage from irrigation ditches during December 1995 to September 1997. Volume of estimated ditch leakage is converted to inches and is spread evenly over each 10-acre cell in which the ditch is located.

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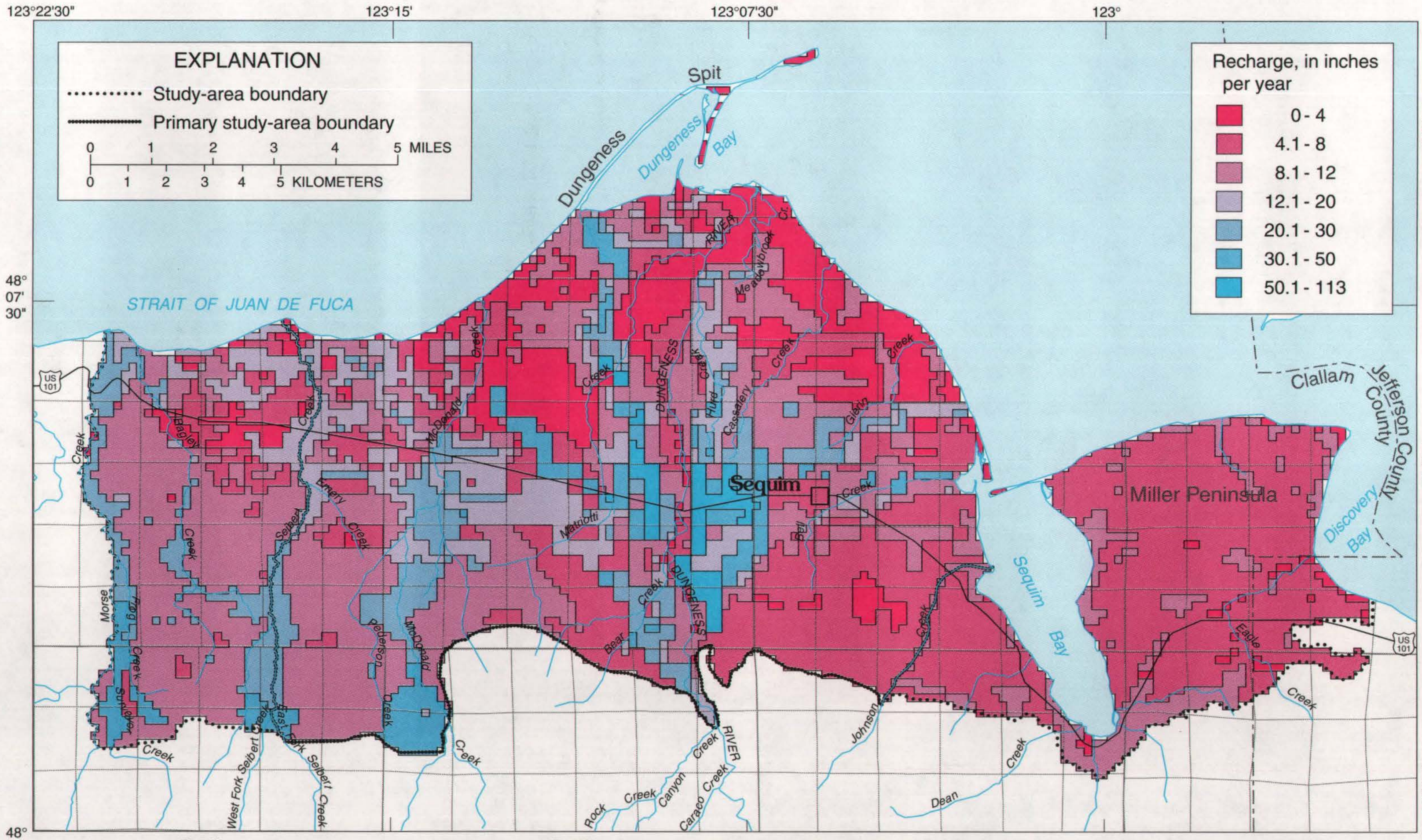

Figure 34. Average annual ground-water recharge from precipitation, unconsumed irrigation water, and irrigation-ditch leakage during December 1995 to September 1997.

Subsurface Inflow

Water moves into the ground-water system in unconsolidated deposits as subsurface inflow from outside the study area. Most of this inflow probably comes from lateral flow through the southern boundary of the study area, either as near-surface flow through soils and the veneer of unconsolidated deposits overlying bedrock or as flow from fractures in bedrock into the shallow aquifer. Only the shallow aquifer extends to the southern boundary (fig. 18); all other hydrogeologic units are north of the southern boundary (figs. 17i, 17j, 17k, 19,and 21). The other possible subsurface inflow is ground water that moves vertically from bedrock underlying the study area into the hydrogeologic units directly overlying the bedrock.

The lateral subsurface inflow to the shallow aquifer was estimated in this study. Vertical subsurface inflow, however, could not be estimated because no data were available. Estimated average annual lateral subsurface inflow to the study area was 23.0 ft^3/s.

Lateral subsurface inflow was estimated for a west-east cross section of the shallow aquifer located about 1,000 to 2,000 ft north of the southern study-area boundary. Darcy's equation (4) was used, and the average values for data at the east-west section are 0.05 foot per foot (ft/ft) for hydraulic gradient, 7 ft/d for hydraulic conductivity, and 50 ft for aquifer thickness. Ground-water flow was estimated for several segments of the boundary. Widths are 21.4 mi for the entire study area, 13.5 mi for the primary study area, 4.6 mi for Miller Peninsula, and 3.3 mi for the western area between Siebert Creek and Morse Creek. Estimates of subsurface inflow for these boundary segments are 23.0 ft^3/s for the entire study area, 14.5 ft^3/s for the primary study area, 5.0 ft^3/s for Miller Peninsula, and 3.5 ft^3/s for the western area between Seibert Creek and Morse Creek. The estimate of 14.5 ft^3/s for the primary study area agrees well with the 15.2 ft^3/s estimated by Drost (1983).

The estimates of subsurface inflow were assumed to represent average annual values. They were computed using water-level data collected in 1996. However, it was assumed that the gradients do not change appreciably over the years. The water-level gradients were similar to those in 1979 (Drost, 1983).

Leakage From Streams

Leakage from streams contributes some recharge to ground water. This leakage generally is in the southern part of the study area where water levels in the streams are higher than the water table. Estimated average annual leakage from the Dungeness River is 28 ft^3/s and leakage from other streams is considered negligible.

Streamflow measurements were made at selected points along the Dungeness River (table 9) and 15 other streams (table 10), and the gains or losses in discharge between those points were computed. If no other sources or diversions of water are within the measured reach, then the gains are assumed to be ground-water discharge and the losses are assumed to be ground-water recharge.

The upper part of Bear Creek (fig. 13) had a small loss of 0.12 ft^3/s (table 10). No other streams had measured losses; Morse Creek had a loss of 1.20 ft^3/s, but the total flows were about 68 ft^3/s and that loss is less than the expected measurement errors.

The Dungeness River had two reaches with measured losses—between the USGS gaging station and the railroad bridge and between Woodcock Road and Schoolhouse Road (figs. 13, 35, and table 9). The average of two sets of measurements indicate that annual recharge is about 16 ft^3/s between the USGS gage and the railroad bridge and about 12 ft^3/s between Woodcock Road and Schoolhouse Road. The losses for May 3, 1996, were less than the measurement errors of the discharges. However, the losses for September 10, 1996, were greater than the measurement errors. So, the assumption of ground-water recharge for these reaches is considered reasonable.

Discharge

Ground water discharges as subsurface flow to saltwater bodies, flow to streams, and flow to springs. Subsurface flow to saltwater bodies and flow to springs were not estimated in this study. Drost (1983) estimated 68.4 ft^3/s of subsurface flow from his study area, which is analogous to the primary study area. Drost (1983) did not estimate flow to springs, but it is probably small compared with the sum of subsurface flow to saltwater bodies and flow to streams. Certain small parts of the study area may have considerable amounts of flow to springs.

Table 9. Measurements of discharge and computed gains or losses in discharge for reaches of the Dungeness River, Sequim-Dungeness area, Washington

[See figure 12 for locations of measurement sites; +, gain; -, loss]

Measurement sites and reaches of Dungeness River		Discharge (cubic feet per second)	Gain or loss in discharge between sites (cubic feet per second)	Distance between sites (miles)	Unit gain or loss in discharge (cubic feet per second per mile)
Sites	05-03-96				
1) Dungeness River at U.S. Geological Survey gage		354			
Canyon Creek		12.4			
Bear Creek		1.2			
Irrigation diversions		-52.2			
2) Dungeness River at railroad bridge		308			
3) Dungeness River at Woodcock Road		351			
Hurd Creek		4.1			
Well discharge into Hurd Creek		2.5			
Estimated diversions into Hurd Creek		0.8			
Matriotti Creek		12.4			
4) Dungeness River at Schoolhouse Road		355			
Reaches					
Gaged site to railroad bridge			-7	6.1	-1.1
Railroad bridge to Woodcock Road			+43	2.3	+19
Woodcock Road to Schoolhouse Road			-16	2.3	-7.0
Sites	09-10-96				
1) Dungeness River at U.S. Geological Survey gage		147			
Canyon Creek		2.1			
Bear Creek		0.1			
Irrigation diversions		-51.6			
2) Dungeness River at railroad bridge		73			
3) Dungeness River at Woodcock Road		84			
Hurd Creek		6.8			
Matriotti Creek		15.0			
4) Dungeness River at Schoolhouse Road		98			
Reaches					
Gaged site to railroad bridge			-25	6.1	-4.1
Railroad bridge to Woodcock Road			+11	2.3	+4.8
Woodcock Road to Schoolhouse Road			-8	2.3	-3.5

Table 10. Measurements of discharge and computed gains or losses in discharge for reaches of selected streams, Sequim-Dungeness area, Washington

[See figure 12 for locations of measurement sites; +, gain; -, loss; --, not applicable]

Stream	Site	Date	Discharge (cubic feet per second)	Gain or loss in discharge between sites (cubic feet per second)	Distance between sites (miles)	Unit gain or loss in discharge (cubic feet per second per mile)
Irrigated area						
Bear Creek	1	10-07-97	0.09	--	--	--
	2		0.05	--	--	--
	3		0.02	-0.12	2.45	-0.05
Bell Creek	1	10-06-97	0.04	--	--	--
	2		2.39	+2.35	3.58	+0.66
Cassalery Creek	1	10-06-97	0.02	--	--	--
	2		3.57	+3.55	2.36	+1.50
Gierin Creek	1	10-07-97	0.32	--	--	--
	2		1.16	+0.84	1.21	+0.69
Hurd Creek	1	10-07-97	0.23	--	--	--
	2		1.27	+1.04	0.37	+2.81
	3		5.91	[1]+2.44	0.40	+6.10
Matriotti Creek	1	10-06-97	0.05	--	--	--
	2		0.12	+0.07	1.62	+0.04
	3		8.10	+7.98	4.80	+1.66
McDonald Creek	1	10-07-97	0.06	--	--	--
	2		0.01	--	--	--
	3		9.70	--	--	--
	4		11.6	+1.83	2.90	+0.63
	5		13.9	+2.3	2.81	+0.82
Meadowbrook Creek	1	10-07-97	2.89	--	--	--
	2		4.26	+1.37	0.65	+2.11
Siebert Creek	1	10-07-97	9.03	--	--	--
	2		11.3	+2.27	1.81	+1.25
Unnamed Creek	1	10-07-97	0.0	0.0	--	--

Table 10. Measurements of discharge and computed gains or losses in discharge for reaches of selected streams, Sequim-Dungeness area, Washington—Continued

Stream	Site	Date	Discharge (cubic feet per second)	Gain or loss in discharge between sites (cubic feet per second)	Distance between sites (miles)	Unit gain or loss in discharge (cubic feet per second per mile)
Nonirrigated area						
Bagley Creek	1	9-29-97	0.01	--	--	--
	2		0.05	--	--	--
	3	9-30-97	1.35	+1.29	5.05	+0.26
	4		2.72	+1.37	1.29	+1.06
Eagle Creek	1	9-29-97	<0.01	--	--	--
	2		0.01	+0.01	2.69	<0.01
Emery Creek	1	9-29-97	<0.01	--	--	--
Morse Creek	1	9-29-97	69.1	--	--	--
	2		67.9	-1.2	2.70	-0.4
Pederson Creek	1	9-30-97	<0.01	--	--	--
	2		0.06	+0.06	2.57	+0.02

[1] The fish hatchery near Hurd Creek discharges about 2.2 cubic feet per second of water into Hurd Creek between sites 2 and 3.

Ground-water discharge to streams was estimated using streamflow data as described in the previous section on recharge. Most streams in the study area receive ground-water discharge. The Dungeness River had one reach with measured gains—between the railroad bridge and Woodcock Road (fig. 13 and table 9). The average of two sets of measurements indicate the annual discharge to the Dungeness River is about 27 ft^3/s. Estimated average annual ground-water discharge to all other streams in the study area is 39 ft^3/s.

Total estimated average annual ground-water discharge to the small streams in the primary study area is 33 ft^3/s (table 10). Of that total, 29.6 ft^3/s were measured and 3.2 ft^3/s were estimated. Stream discharges were measured at a sufficient number of sites to compute ground-water discharge to Bell Creek, Cassalery Creek, Gierin Creek, Hurd Creek, Matriotti Creek, Meadowbrook Creek, and the lower parts of Siebert Creek and McDonald Creek. The upper parts of Siebert and McDonald Creeks were assumed to have a ground-water discharge of 2.6 ft^3/s. The upper parts were assumed to have the same ground-water discharge as the upper part of Bagley Creek (1.3 ft^3/s), which has a similar length and similar degree of dissection of land surface. Johnson Creek had no measured discharges, and it was assumed to have a ground-water discharge of 0.6 ft3/s, which is half the discharge of upper Bagley Creek.

Total estimated average annual ground-water discharge to streams outside the primary study area is 6 ft^3/s (table 10). Bagley Creek had a measured gain of 2.7 ft^3/s and Pederson Creek had a measured gain of 0.1 ft^3/s. Eagle Creek and Emery Creek had no measured gains. Morse Creek was assumed to have a gain of about 3.2 ft^3/s. The lower part of Morse Creek actually showed a loss of 1.2 ft^3/s, but that was only

2 percent of the total streamflow, and was less than measurement errors. Because all the other streams in a similar landscape position showed gains in streamflow, it was assumed that Morse Creek would also have some ground-water discharge. The 3.2 ft^3/s estimated for Morse Creek is about the same ground-water discharge that was estimated for Siebert Creek.

The estimates of ground-water discharge were assumed to represent average annual values. They were computed using streamflow data measured in 1996–97. However, it was assumed that the transient conditions controlling discharge (ground-water levels and streamflow) do not change appreciably over the years.

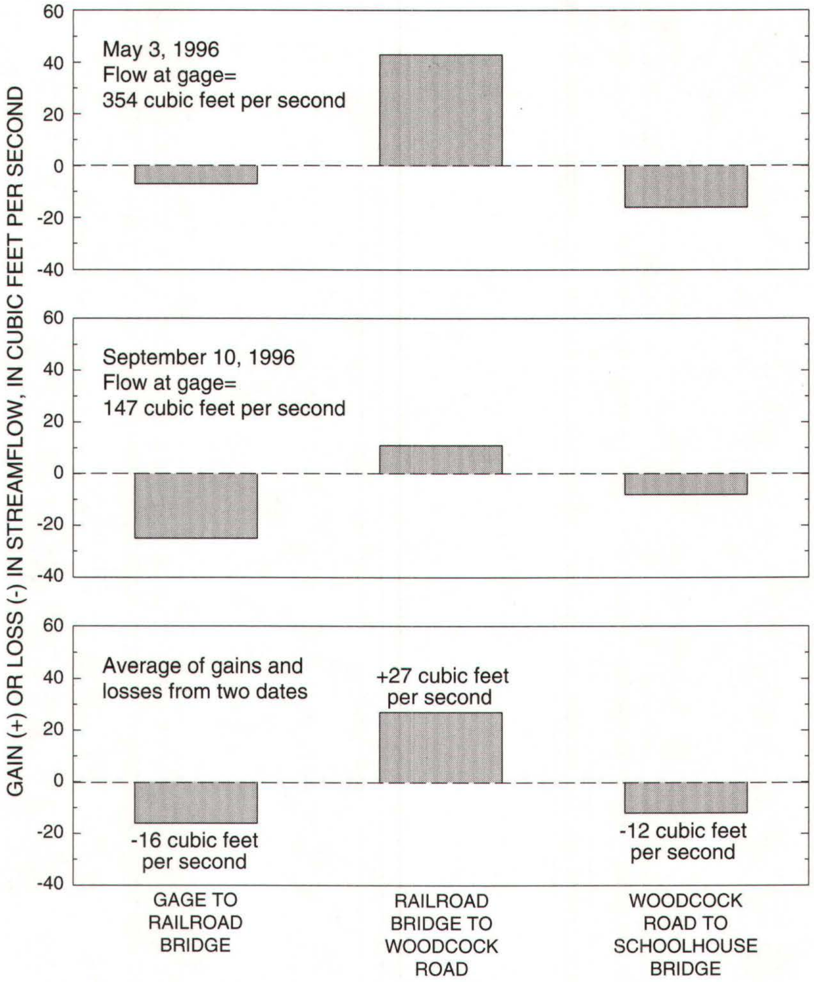

Figure 35. Gains and losses in streamflow in reaches of the Dungeness River, Sequim-Dungeness area, Washington.

In addition to natural ground-water discharge, ground water is withdrawn from wells. Ground-water withdrawals during 1996 for the study area were estimated for the following water-use categories: domestic self-supplied, public supply, irrigated agriculture, golf courses, dairy operations, fish hatcheries, and commercial or industrial (fig. 36 and table 11) (Peter Schwartzman, Pacific Groundwater Group, Seattle, Wash., written commun., 1998; Ann C. Soule, Clallam County, written commun., 1998).

Total ground-water withdrawals for 1996 were estimated to be 6,055 acre-feet (acre-ft) from the entire study area and 5,212 acre-ft from the primary study area (table 11). This quantity represents gross withdrawals. Septic systems return water to the ground-water system by percolation of the water that leaves the drainfields of the systems. When this return flow is subtracted from the gross withdrawals, the total net withdrawals for 1996 were 3,738 acre-ft from the entire study area and 3,344 acre-ft from the primary study area.

Three water-use categories account for most of the gross water withdrawals. Domestic self-supplied users withdraw about 26 percent, public supply withdraws about 41 percent, and a fish hatchery on Hurd Creek withdraws about 27 percent.

Most of the well withdrawals are from the shallow aquifer. The distribution of gross withdrawals is about 67 percent from the shallow aquifer, 13 percent from the middle aquifer, and 7 percent from the lower aquifer.

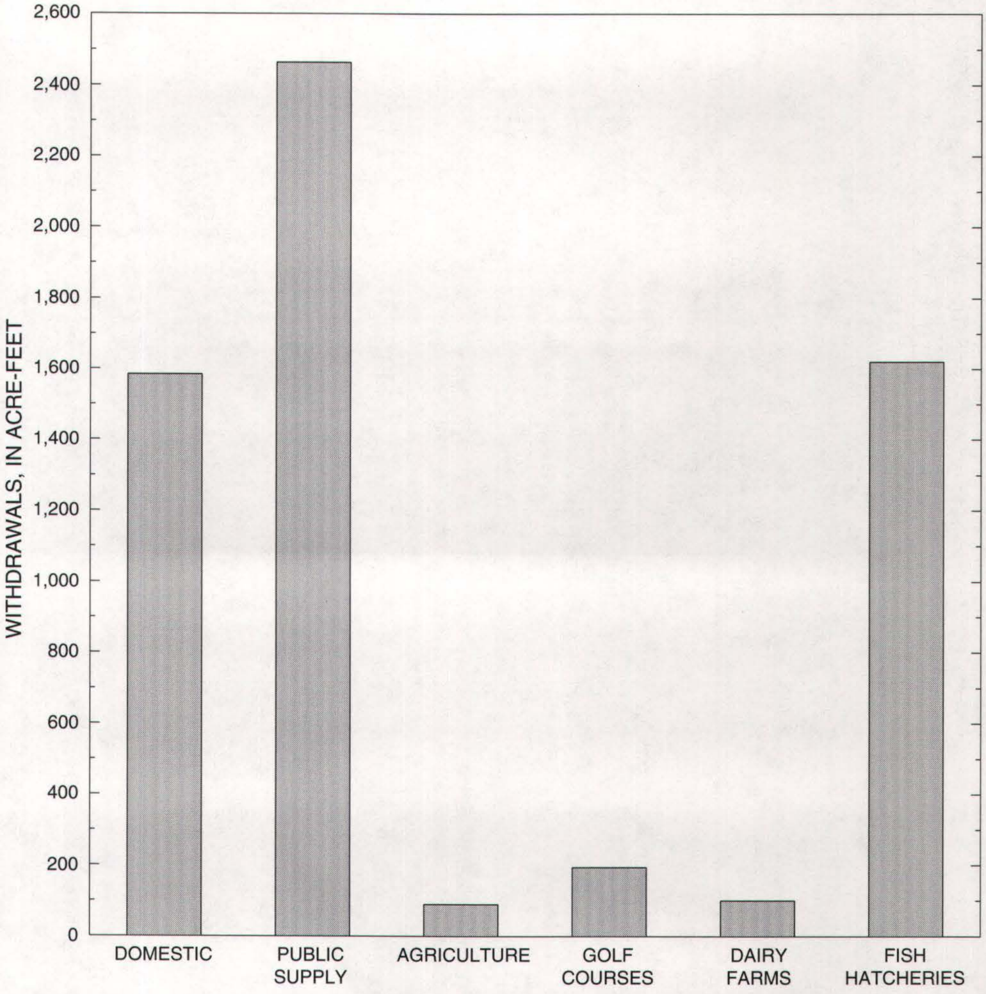

Figure 36. Ground-water withdrawals during 1996, Sequim-Dungeness area, Washington.

Table 11. Summary of ground-water withdrawals from wells by hydrogeologic unit in 1996, Sequim-Dungeness area, Washington

[Net total withdrawals are the gross total withdrawals minus the estimated amount of water returned to the ground-water system by percolation from septic systems. See text for explanation of net withdrawals]

Use category	Withdrawals, in acre feet							
	Shallow aquifer	Upper confining bed	Middle aquifer	Lower confining bed	Lower aquifer	Undifferentiated deposits	Bedrock	Total
			Entire study area					
Domestic self-supplied	1,236	55	112	25	21	4	131	1,584
Public supply	929	291	642	47	308	101	146	2,464
Irrigated agriculture	89	0	0	0	0	0	0	89
Golf courses	141	0	0	0	43	10	0	194
Dairies	58	0	14	0	28	0	0	100
Fish hatcheries	1,620	0	0	0	0	0	0	1,620
Commercial/industrial	4	0	0	0	0	0	0	4
Gross total	4,077	346	768	72	400	115	277	6,055
Net total								3,738
			Primary study area					
Domestic self-supplied	1,165	45	80	18	8	2	100	1,418
Public supply	881	22	508	15	230	100	31	1,787
Irrigated agriculture	89	0	0	0	0	0	0	89
Golf courses	141	0	0	0	43	10	0	194
Dairies	58	0	14	0	28	0	0	100
Fish hatcheries	1,620	0	0	0	0	0	0	1,620
Commercial/industrial	4	0	0	0	0	0	0	4
Gross total	3,958	67	602	33	309	112	131	5,212
Net total								3,344

Water-Level Fluctuations

Ground-water levels fluctuate over time in response to temporal changes in recharge to and discharge from the ground-water system. These water-level fluctuations reflect changes in the amount of storage in the system. As water levels rise, more water is added to storage in the system, and as water levels drop, water is removed from storage in the system.

Ground-water levels fluctuate seasonally because of the variation in recharge and discharge during a year. When recharge exceeds discharge, water levels rise, and when discharge exceeds recharge, water levels decline. The magnitude of seasonal water-level fluctuations and the timing of the response to recharge are related to the source and amount of recharge, depth to the water table, and depth within the ground-water system. Shallow wells and shallow water tables are close to the sources of recharge, so the sources and quantities can often be discerned in seasonal water-level fluctuations. Ground water in deep aquifers generally has several sources of recharge, so individual sources are difficult to distinguish.

Ground water in the study area is recharged from several sources, and the dominance of one source over the others can be seen in seasonal water-level hydrographs for selected wells in the study area (fig. 37). Recharge from precipitation is reflected in the water-level fluctuations of well 30N/04W-21G03. Water levels rise during the fall and winter responding to the increased recharge from precipitation. The magnitude of recharge can also be seen in the water levels; during 1996-97, precipitation and recharge were larger than in 1994-95, and the seasonal change in water levels was larger during 1996-97.

Most recharge from irrigation is in the summer when ditch leakage increases and all the crops are irrigated. This summer recharge is reflected in the water-level fluctuations of well 30N/03W-19D01 (fig. 37). The water table near this well also receives recharge from precipitation, but the irrigation recharge is much larger and causes the water levels to rise in the summer and drop in the fall and winter.

The middle aquifer is recharged from downward flow from the shallow aquifer and upward flow from the lower aquifer. These sources are difficult to discern in water-level fluctuations because the amount and timing do not necessarily follow precipitation or irrigation. The muted water-level fluctuations in the middle aquifer are shown for well 30N/03W-31R01 (fig. 37).

Ground-water levels may fluctuate or change over a long period of time (over many years) because of variations in the ground-water recharge and discharge over that time period. Natural recharge and discharge fluctuate with changes in precipitation; however, precipitation and recharge-discharge relations tend to even out over many years, and long-term water levels tend to remain relatively constant. If water levels decline consistently over many years, it generally indicates that either discharge has been artificially increased by withdrawals of water through wells or recharge has been decreased by changes to the conditions controlling recharge.

Water levels in the shallow aquifer in areas with recharge predominately from precipitation appear to have changed little from 1978 to 1997. The average change in water levels from 1978–79 to 1994–97 for 12 wells is -2 ft (table 12). Hydrographs for three wells show a small decline at well 30N/03W-06M01, a small rise at well 30N/04W-21G03, and a small decline at well 30N/03W-17D02 (fig. 38).

Water levels in the shallow aquifer in areas with recharge predominately from irrigation have generally declined from 1978 to 1997. The average change in water levels from 1978–79 to 1994–97 for four wells is -6 ft (table 12). Hydrographs for three wells show a small decline at well 30N/04W-12K01 and declines of about 8 ft at wells 30N/03W-19D01 and 30N/04W-24G02 (fig. 39). In addition to the general decline in water levels in irrigated areas, the magnitude of seasonal change in water levels decreased from 1978–80 to 1994–97 in wells 30N/03W-19D01 and 30N/04W-24G02 (fig. 39). This decrease is probably a result of decreased recharge from irrigation; average summer diversions from the Dungeness River were about 115 ft^3/s in 1979–80 and about 80 ft^3/s in 1992–97.

Water levels in the middle aquifer have only changed slightly from 1978 to 1997. The average change in water levels from 1978–79 to 1994–97 for three wells is -2 ft (table 12). Hydrographs for three wells show small rises at wells 30N/03W-31R01 and 30N/04W-07N01 and a decline of about 9 ft at well 30N/04W-24R01 (fig. 40).

There is a geographic pattern in water-level changes from 1978 to 1997. Water levels generally declined from about 3 to 10 ft in about a 7-mi^2 area east of the Dungeness River (fig. 41). Water-level changes were small and had no apparent patterns in the remainder of the primary study area where data are available.

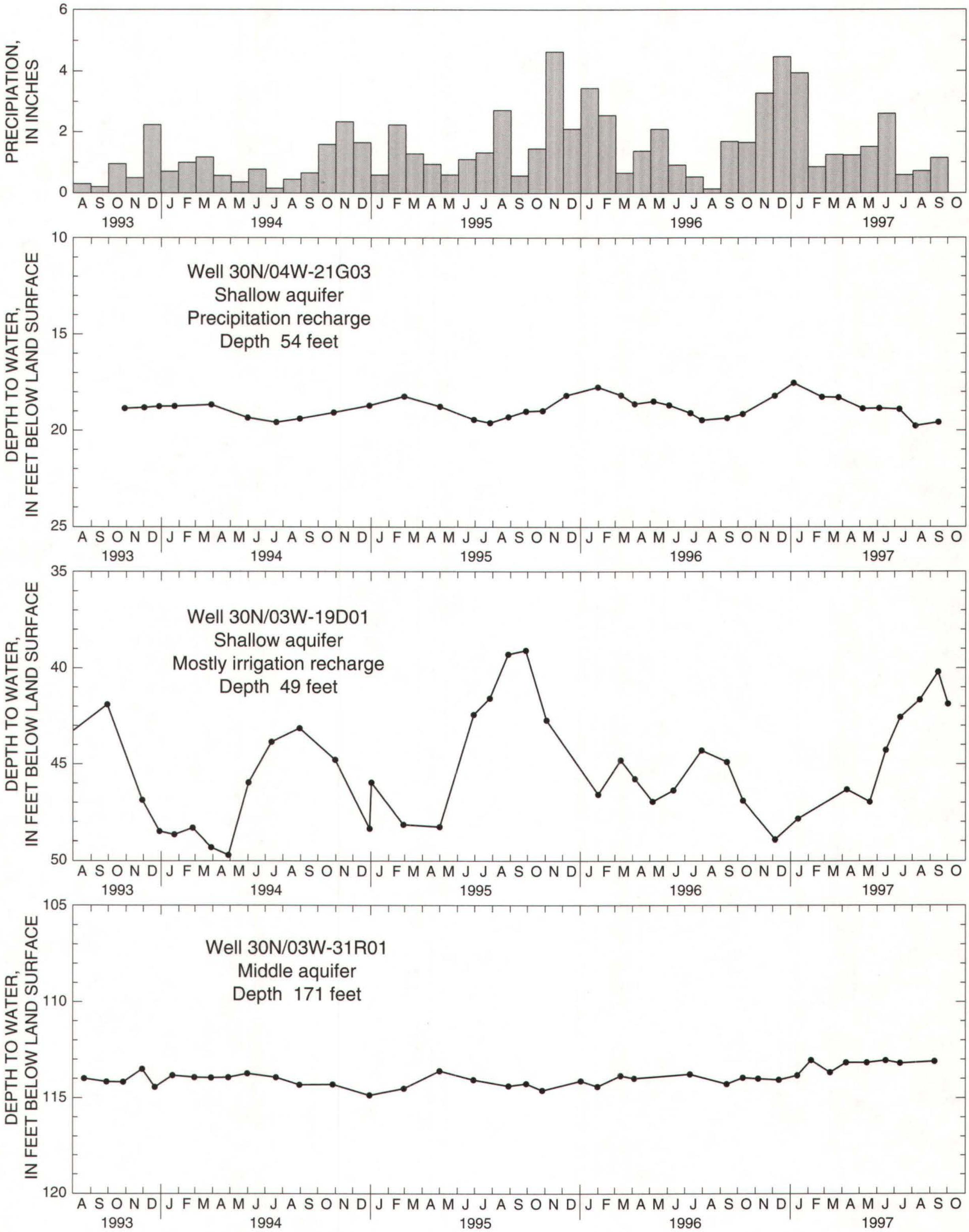

Figure 37. Relation between monthly precipitation and water levels in selected wells, Sequim-Dungeness area, Washington.

Table 12. Changes in average water levels in selected wells from earlier (October 1978–September 1980) to later (October 1993–September 1997) periods, Sequim-Dungeness area, Washington

[Hydrogeologic unit: 1, shallow aquifer; 3, middle aquifer; Mix, mixed source of recharge; Precip., precipitation recharge; Irrig., irrigation recharge]

Local well number	Hydrogeologic unit	Principal recharge	Number of water levels in October 1978–September 1980	Number of water levels in October 1993–September 1997	Change in average water level from October 1978–September 1980 to October 1993–September 1997 (feet)
29N/04W-01M01	1	Mix	24	35	1
30N/03W-05R01	1	Precip.	15	14	-1
30N/03W-06M01	1	Precip.	24	34	-1
30N/03W-07P03	1	Precip.	22	33	-10
30N/03W-17D02	1	Precip.	19	14	-3
30N/03W-18A03	1	Precip.	23	25	-3
30N/03W-19D01	1	Irrig.	23	25	-8
30N/03W-31J02	1	Precip.	23	36	-1
30N/03W-31R01	3	Mix	20	36	1
30N/04W-01M03	1	Mix	22	25	-2
30N/04W-02R01	1	Precip.	22	15	-2
30N/04W-03H03	1	Precip.	24	15	0
30N/04W-04N01	1	Mix	24	32	-4
30N/04W-07L01	1	Mix	24	17	1
30N/04W-07N01	3	Mix	24	14	2
30N/04W-11J01	1	Mix	20	12	0
30N/04W-12K01	1	Irrig.	21	33	-3
30N/04W-14P01	1	Mix	21	34	-1
30N/03W-15A01	1	Irrig.	24	36	-3
30N/04W-16G01	1	Mix	22	21	-1
30N/04W-17B01	1	Mix	21	36	2
30N/04W-21G03	1	Precip.	16	34	1
30N/04W-22R02	1	Precip.	22	38	1
30N/04W-23Q04	1	Precip.	20	20	-3
30N/04W-24G02	1	Irrig.	21	34	-8
30N/04W-24R01	3	Mix	13	33	-9
30N/04W-25D03	1	Irrig.	24	32	-7
30N/04W-26E03	1	Precip.	20	12	-6
30N/04W-26H02	1	Mix	16	34	-9
31N/04W-35D01	1	Mix	24	27	0

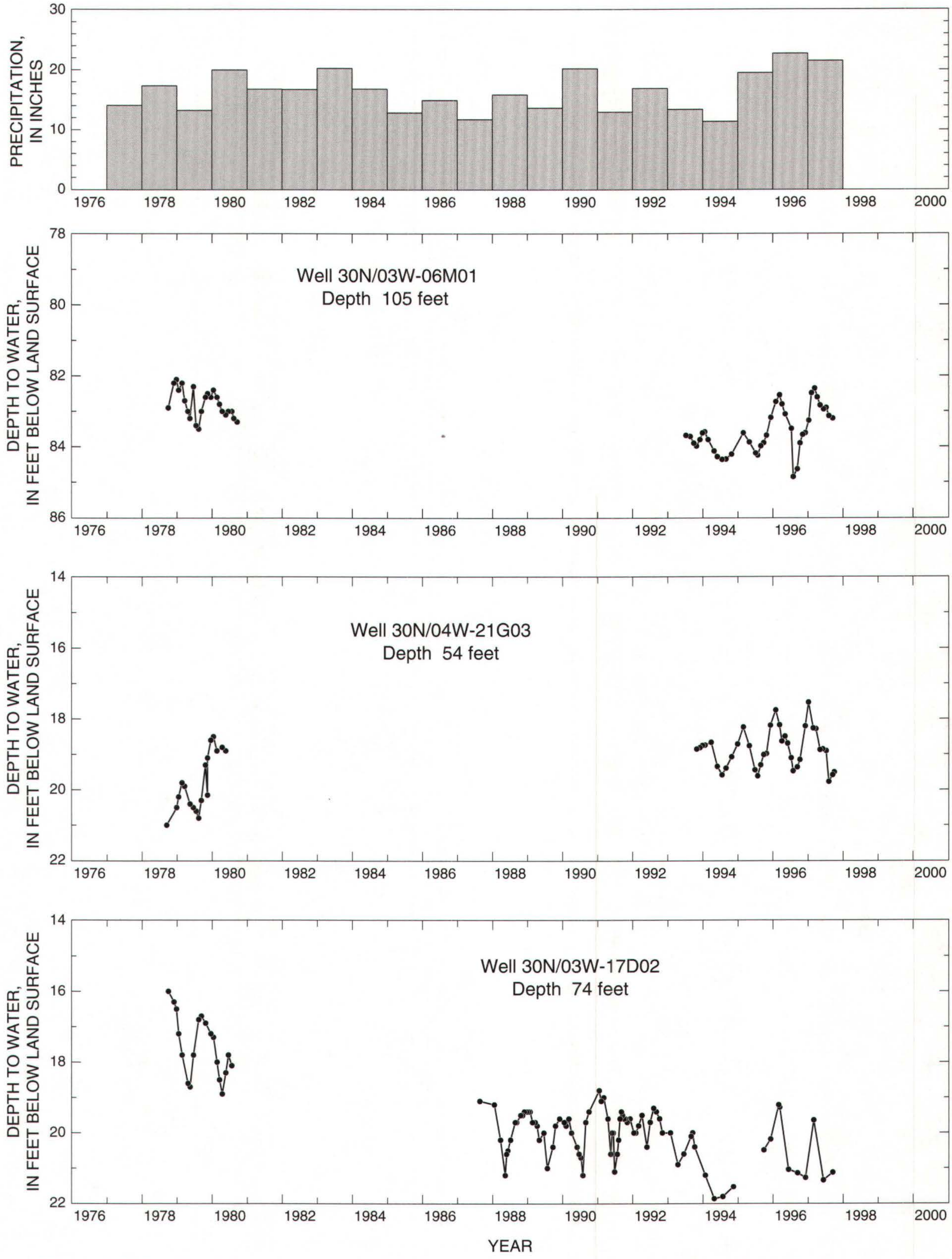

Figure 38. Relation between annual precipitation and long-term water levels in selected wells in areas of the shallow aquifer recharged by precipitation, Sequim-Dungeness area, Washington.

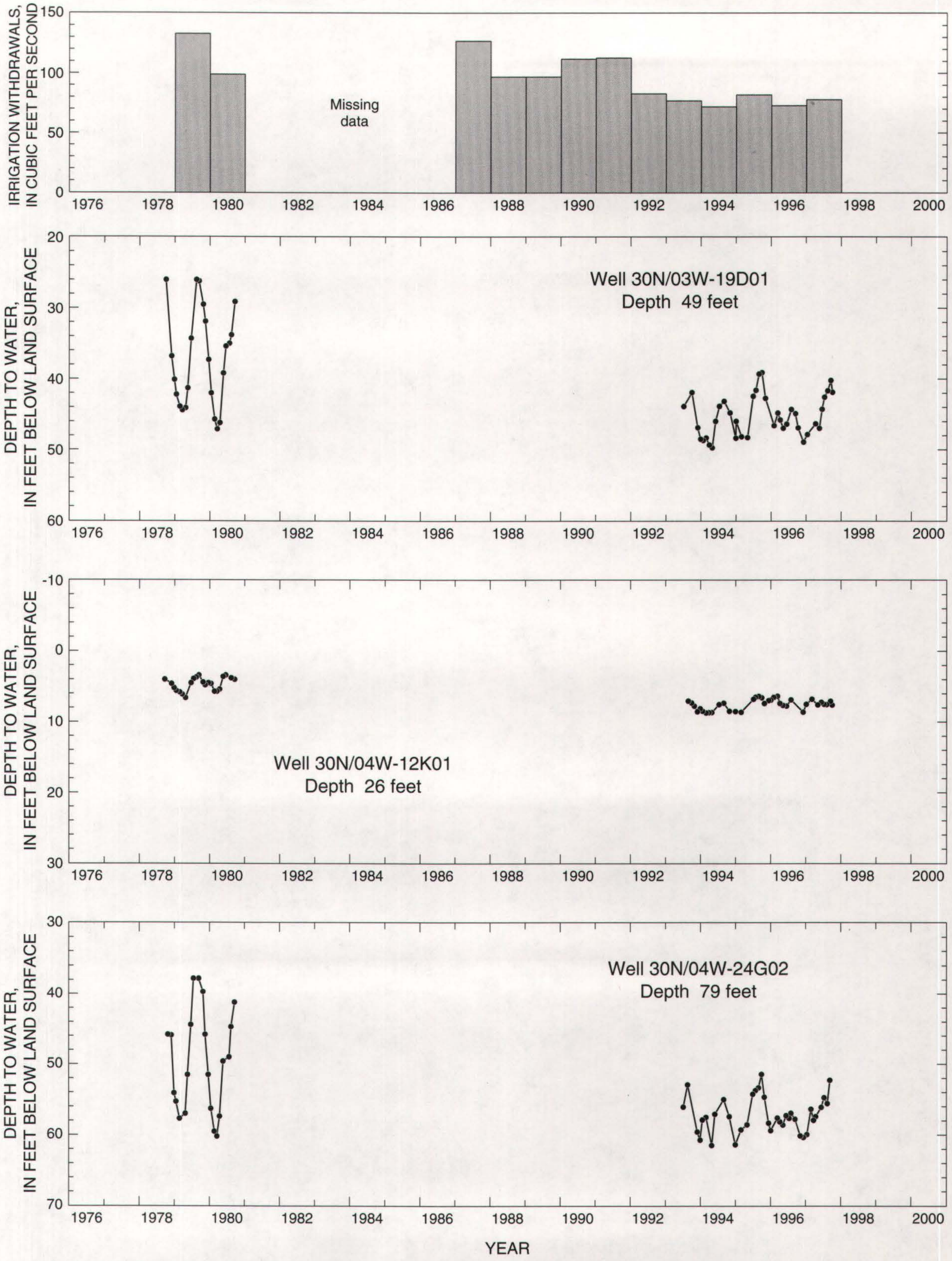

Figure 39. Relation between summer irrigation withdrawals and long-term water levels in selected wells in areas of the shallow aquifer recharged mostly by irrigation, Sequim-Dungeness area, Washington.

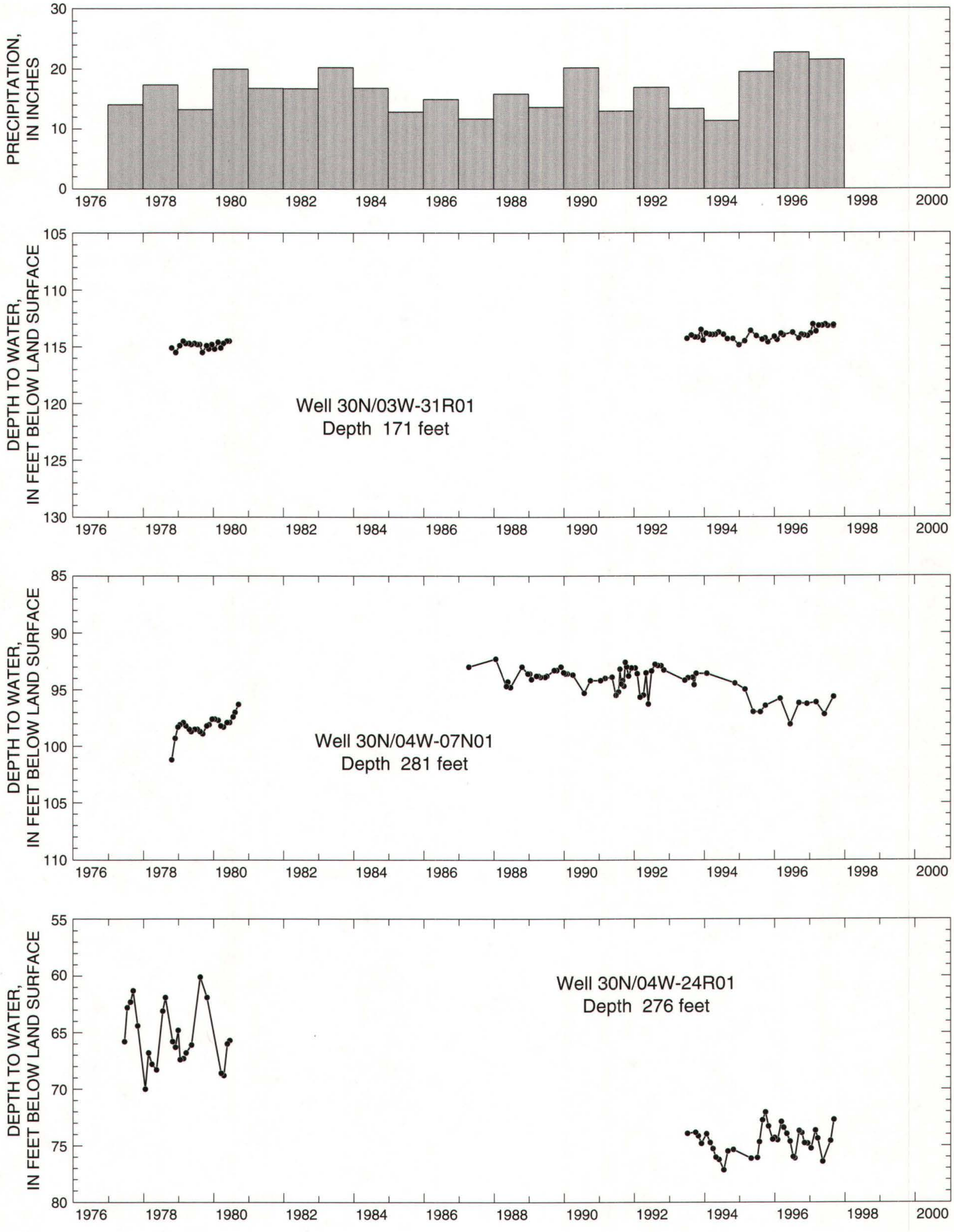

Figure 40. Relation between annual precipitation and long-term water levels in selected wells in the middle aquifer, Sequim-Dungeness area, Washington.

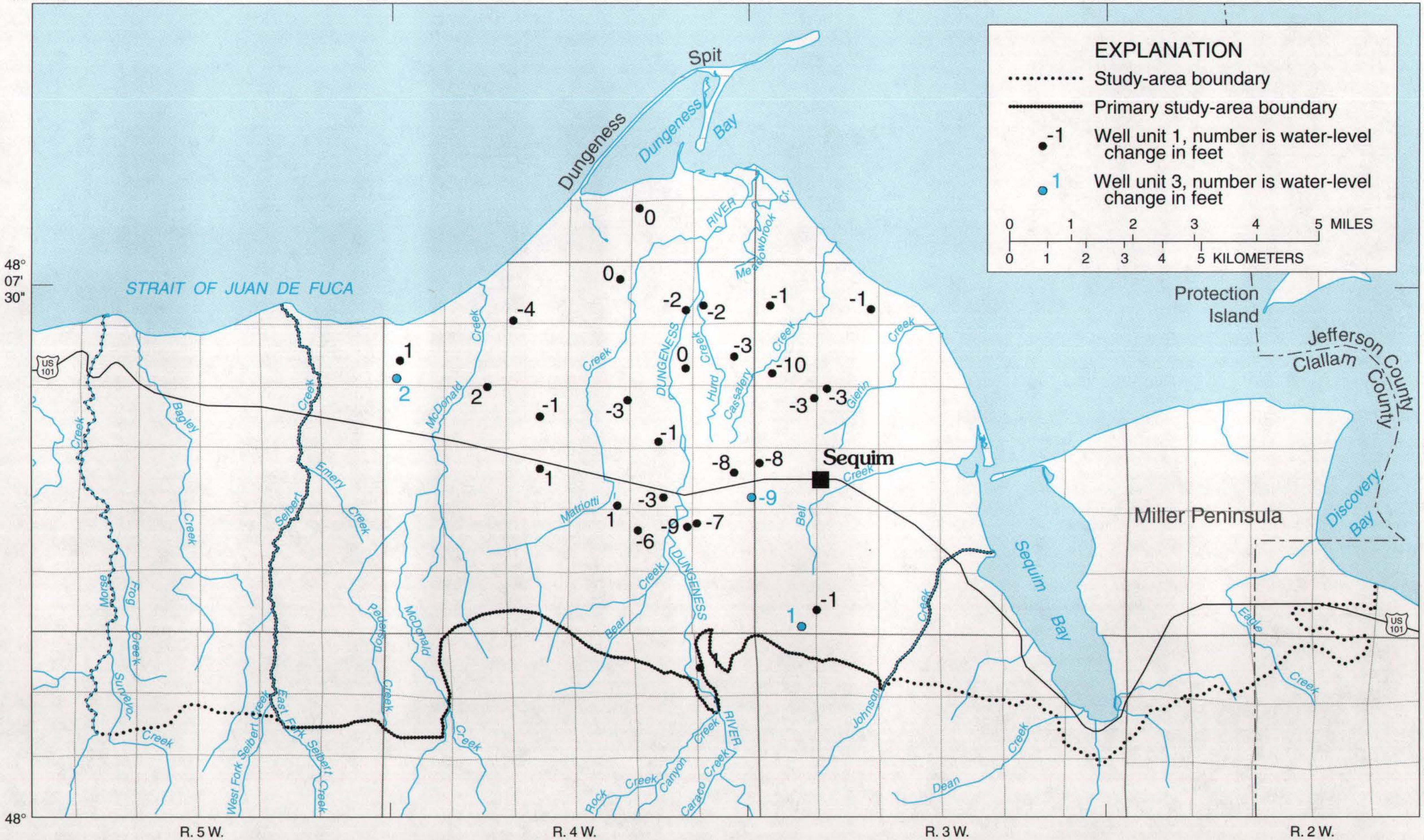

Figure 41. Changes in average water levels in selected wells from earlier (October 1978-September 1980) to later (October 1993-September 1997) periods. A negative number is a decline in water level.

WATER BUDGET

A water budget for the study area shows total inflow of water from precipitation and how that inflow is distributed in the hydrologic system. Two water budgets were estimated for the study area on the basis of measured data and simulations of several components of the budget. One mostly complete budget shows average annual values for the period of data collection of this study—December 1995 to September 1997 (table 13). The other less complete budget shows long-term average annual values (table 14). Detailed explanations of the methods used to estimate the components of the water budget are given in previous sections of this report.

The average annual water budget for December 1995 to September 1997 was estimated for the entire study area (116 mi^2) and the primary study area (74 mi^2) (table 13). Components for the entire study area were 27.9 in. of precipitation, 8.6 in. of ground-water recharge, 3.7 in. of surface runoff, and 15.4 in. of evapotranspiration. The fate of precipitation was similar for both study areas; about 31 percent becomes ground-water recharge, about 13 percent becomes surface runoff, and about 55 percent returns to the atmosphere by evapotranspiration.

The average annual ground-water budget during December 1995 to September 1997 for the primary study area includes four sources of recharge and four areas of discharge (fig. 42).

Table 13. Estimated average annual water budget for December 1995 to September 1997, Sequim-Dungeness area, Washington

[Hydrologic budget components do not balance exactly because the deep-percolation model computed a change in storage of about 1 percent for the study period (December 1995–September 1997); --, no data]

Hydrologic component	Entire study area			Primary study area		
	Inches per year	Acre-feet per year	Cubic feet per second	Inches per year	Acre-feet per year	Cubic feet per second
Precipitation	27.9	173,000	238.4	26.6	105,000	145.0
Surface runoff	3.7	22,900	31.6	2.9	11,400	15.8
Evapotranspiration	15.4	95,300	131.6	15.9	62,800	86.7
Ground-water recharge						
Precipitation	8.6	53,200	73.5	8.0	31,600	43.6
Subsurface inflow	2.7	16,700	23.0	2.7	10,500	14.5
Irrigation	3.1	19,200	26.5	4.9	19,200	26.5
Dungeness River leakage	3.3	20,300	28.0	5.1	20,300	28.0
Total	17.7	109,400	151.0	20.7	81,700	112.7
Ground-water discharge						
Subsurface outflow	--	--	--	--	--	--
Flow to Dungeness River	3.2	19,500	27.0	5.0	19,500	27.0
Flow to other streams	4.6	28,200	39.0	6.1	23,900	33.0
Flow to springs	--	--	--	--	--	--
Net withdrawals by wells	0.6	3,740	5.2	0.8	3,340	4.6
Total	17.7	109,400	151.0	20.7	81,700	112.7

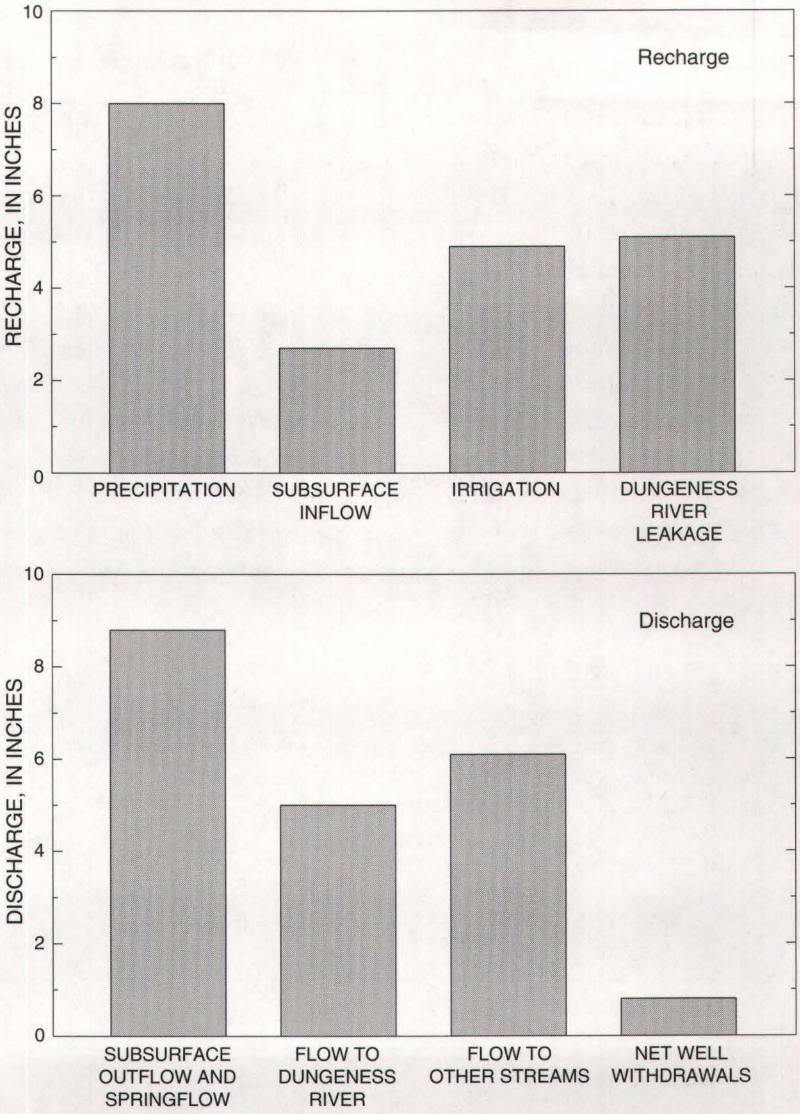

Figure 42. Average annual ground-water buget for primary study area during December 1, 1995 to September 30, 1997, Sequim-Dungeness area, Washington.

Recharge from infiltration and percolation of precipitation accounts for about 40 percent of the recharge, and the remaining 60 percent is from sources of water outside the study area (subsurface inflow, irrigation water from the Dungeness River, and direct leakage from the Dungeness River). About half the recharge is estimated to come from the Dungeness River by irrigation diversions or direct leakage.

About 43 percent of the ground-water discharge is estimated to be subsurface outflow to saltwater bodies and springflow, 24 percent is flow to the Dungeness River, 29 percent is flow to other streams, and 4 percent is net withdrawals by wells. An implication of this distribution of discharge is that potential decreases in discharge could have appreciable effects on streamflow in the study area.

The long-term average annual water budget was also estimated (table 14). Long-term average annual precipitation is about 21 in., which is about 75 percent of the precipitation that fell during the study period. The estimated long-term average annual recharge from precipitation for the entire study area was 5.4 in., which is about 63 percent of the precipitation recharge that was estimated for the study period. Irrigation leakage was not estimated for long-term average annual conditions, because irrigation diversions have been decreasing the last several years, and the amount of future irrigation diversions is unknown.

A simple comparison between ground-water recharge and withdrawals is not a good indicator of the quantity of water that is potentially available for ground-water development. Any additional withdrawal superimposed on a previously stable ground-water system must be balanced by a decrease in discharge, a loss in storage in the system (reflected by lower water levels), an increase in recharge, or a combination of these factors (Bredehoeft and others, 1982). Considering the ground-water system of the Sequim-Dungeness area in particular, the possibility of increased recharge on a long-term basis appears remote. In fact, the trend of increased residential development and decreased irrigation will most likely result in decreased recharge. Additional withdrawals, therefore, would probably result in a decrease in natural discharge and a loss in storage (with an attendant decline in water levels). The magnitude of sustainable ground-water development, therefore, depends on the acceptable amount of water-level declines and decreases in natural discharge.

Table 14. Estimated long-term average annual water budget, Sequim-Dungeness area, Washington

[Ground-water recharge from precipitation computed by deep-percolation model with long-term average annual precipitation; recharge from subsurface inflow and the Dungeness River is assumed to equal amount estimated for December 1995 to September 1997; ground-water discharge to Dungeness River and other streams is assumed to equal amount estimated for December 1995 to September 1997; --, no data]

	Entire study area			Primary study area		
Hydrologic component	Inches per year	Acre-feet per year	Cubic feet per second	Inches per year	Acre-feet per year	Cubic feet per second
Precipitation	20.6	127,000	176.0	19.8	78,200	107.9
Surface runoff	--	--	--	--	--	--
Evapotranspiration	--	--	--	--	--	--
Ground-water recharge						
Precipitation	5.4	33,300	46.0	4.8	19,100	26.4
Subsurface inflow	2.7	16,700	23.0	2.7	10,500	14.5
Irrigation	--	--	--	--	--	--
Dungeness River leakage	3.3	20,300	28.0	5.1	20,300	28.0
Total	--	--	--	--	--	--
Ground-water discharge						
Subsurface outflow	--	--	--	--	--	--
Flow to Dungeness River	3.2	19,500	27.0	5.0	19,500	27.0
Flow to other streams	4.6	28,200	39.0	6.1	23,900	33.0
Flow to springs	--	--		--	--	--
Net withdrawals by wells	--	--	--	--	--	--
Total	--	--		--	--	

NITROGEN AND OTHER SELECTED CONSTITUENTS IN GROUND WATER

Two objectives of this study were to describe the magnitude and distribution of nitrate in ground water and to estimate the probable major sources of nitrate. To describe magnitude and distribution, water samples were analyzed for concentrations of dissolved nitrogen species, including ammonia, ammonia plus organic nitrogen, nitrite, and nitrate. A loading analysis estimated the amount of nitrogen that enters the ground-water system from all the major sources. Land uses and corresponding sources of nitrogen were also compared to nitrate concentrations in ground water to determine if different sources result in different nitrate concentrations. To facilitate the analysis of sources of nitrate, water samples were also analyzed for dissolved chloride and iron, and field measurements were made for specific conductance, temperature, pH, and dissolved oxygen (DO) concentration.

Concentrations in this Study (1996)

Seventy-four water samples were collected and analyzed in July–August 1996, and 65 of those samples were from the primary study area. The basic water-quality data collected in this study are shown in table 15.

pH, Dissolved Oxygen, and Specific Conductance

The pH values of the samples collected in this study ranged from 5.6 to 8.4, and the median was 7.4 (table 16). The median pH values were 7.4 for the shallow aquifer and 7.7 for the middle aquifer (table 17). Concentrations of DO ranged from <0.1 to 10.2 mg/L, and the median was 2.4 mg/L (table 16). Concentrations of DO were higher in the shallow aquifer (median of 3.0 mg/L) compared with the middle aquifer (median of 1.0 mg/L) because the shallow aquifer is closer to recharge water that contains DO (table 17). The median specific conductance for the 74 samples was 312 microsiemens per centimeter (μS/cm), and the range was 167 to 712 μS/cm. Median specific conductance was 294 μS/cm in the shallow aquifer and 404 μS/cm in the middle aquifer.

Nitrogen Species

Median values for the nitrogen species were <0.01 mg/L for nitrite, 0.32 mg/L for nitrate, <0.04 mg/L for ammonia, and <0.2 mg/L for ammonia plus organic nitrogen (table 16). The values ranged from less than detection limits for the minimums to maximums of 0.04 mg/L for nitrite, 4.3 mg/L for nitrate, 2.7 mg/L for ammonia, and 3.1 mg/L for ammonia plus organic nitrogen. Nitrate concentrations were higher in the shallow aquifer (median of 0.53 mg/L), compared with the middle aquifer (median of 0.24 mg/L) because the shallow ground water is closer to sources of nitrogen (table 17).

Consistently elevated concentrations of nitrate were found in a large area east of the Dungeness River and north of Bell Creek, and scattered elevated concentrations were found in the area west of the Dungeness River and east of McDonald Creek (fig. 43). For this study area, natural concentrations of nitrate (concentrations unaffected by human activity) were estimated to be lower than 1.0 mg/L. Ninety-five percent of the water samples collected in areas of natural grasslands or forests had concentrations lower than 1.0 mg/L and 68 percent of all samples had concentrations lower than 1.0 mg/L.

Chloride and Iron

Chloride concentrations ranged from 1.5 to 120 mg/L, and the median was 6.2 mg/L (table 16). Five water samples (7 percent of the samples) had concentrations higher than 20 mg/L (table 15). These samples were scattered throughout the study area and had no geographic pattern. The elevated concentrations are probably not a result of a regional source, but are related to individual sources at each well, such as septic systems or animal wastes. Chloride concentrations were slightly higher in the middle aquifer than in the shallow aquifer, but not so much higher as to indicate a source such as seawater intrusion (table 17).

Iron concentrations ranged from <3.0 to 1,700 μg/L, and the median was <30 μg/l (table 16). Six water samples (8 percent of the samples) had elevated concentrations of higher than 300 μg/L (table 15). No geographic pattern is apparent in the distribution of these six samples. The six samples had low concentrations of DO (lower than 1.0 mg/L), and the high iron concentrations are probably a result of natural causes. Iron concentrations were about the same in the shallow and middle aquifers (table 17).

Table 15. Field measurements and concentrations of selected constituents in ground-water samples, July–August 1996, Sequim-Dungeness area, Washington

[Hydrogeologic unit: 1, shallow aquifer; 2, upper confining bed; 3, middle aquifer; 5, lower aquifer; --, no data; <, less than]

Local well number	Hydro-geo-logic unit	Date	Time	Land-surface altitude (feet above sea level)	Depth of well (feet)	Specific conduct-ance, field (micro-siemens per centi-meter)	Specific conduct-ance, laboratory (micro-siemens per centi-meter)	pH, field (stan-dard units)	pH, labora-tory (stan-dard units)
29N/02W-07C03	1	08-23-96	1220	180	95	287	287	6.8	7.1
29N/03W-12G01	1	08-22-96	1430	10	62	209	210	8.0	7.9
30N/02W-28N03	1	08-07-96	1440	140	138	267	262	7.3	7.4
30N/02W-31J02	1	08-07-96	1540	185	118	426	415	5.6	6.1
30N/03W-05H02	1	07-23-96	1700	11.8	31	358	360	6.9	7.2
30N/03W-06B01	1	08-01-96	1500	15	85	266	268	7.6	7.5
30N/03W-06R02	1	07-31-96	1310	45	45	245	248	6.9	6.9
30N/03W-07Q03	1	08-07-96	1240	120	116	221	218	7.4	7.4
30N/03W-08B01	1	08-08-96	1430	34.4	51.5	307	298	7.1	7.3
30N/03W-08M01	3	08-08-96	1520	120	250	342	330	8.0	7.8
30N/03W-09R01	5	08-23-96	0950	105	579	315	312	8.4	8.1
30N/03W-15G01	5	08-07-96	1120	20	574	341	331	8.3	8.0
30N/03W-17D02	1	07-24-96	1025	97.4	74	271	269	7.4	7.5
30N/03W-17M01	1	07-30-96	1150	120	37	350	348	7.8	7.6
30N/03W-17P01	1	08-05-96	1830	140	55	378	373	7.8	7.8
30N/03W-18E06	1	07-25-96	1210	150	41	224	227	8.2	7.8
30N/03W-18M03	1	08-07-96	1120	165	50	297	294	7.9	7.7
30N/03W-20K01D1	1	07-31-96	1220	145	121	424	423	7.1	7.2
30N/03W-21A01	1	08-07-96	0940	100	46	462	443	7.9	7.7
30N/03W-21K03	3	07-31-96	1010	147	280	518	519	7.7	7.6
30N/03W-23H03	3	08-06-96	1540	60	149	712	679	7.7	7.7
30N/03W-27B04	1	07-31-96	1730	100	65	597	595	7.6	7.6
30N/03W-28C03	1	07-31-96	1350	180	114	613	608	7.8	7.7
30N/03W-30K03	1	08-08-96	1050	390	64	487	476	7.1	7.4
30N/03W-31H01	1	08-06-96	1230	530	82	377	368	7.6	7.6
30N/03W-33P01	3	08-06-96	1030	640	150	517	498	7.3	7.5
30N/03W-36L01	2	08-07-96	1430	60	118	371	358	8.3	7.9
30N/04W-01R01	1	08-08-96	1620	120	94	276	266	7.8	7.6
30N/04W-02M05	3	07-30-96	1710	75	239	378	375	7.6	7.5
30N/04W-03H03	1	07-30-96	1450	86.1	61	280	278	7.2	7.2
30N/04W-03Q01	3	07-30-96	1310	108	249	355	360	8.2	7.9
30N/04W-04L02	1	07-30-96	1500	121	56	280	280	6.8	6.8
30N/04W-05J01	1	07-23-96	1525	118	117	409	410	7.2	7.3
30N/04W-05P01	2	07-31-96	1750	120	161	512	508	7.7	7.6
30N/04W-07L01	1	08-01-96	1050	156	92	294	291	7.1	7.1
30N/04W-08M04	1	07-30-96	1140	170	84	273	280	6.7	6.9
30N/04W-09N02	1	07-31-96	1440	150	75	291	294	7.4	7.4

Table 15. Field measurements and concentrations of selected constituents in ground-water samples, July–August 1996, Sequim-Dungeness area, Washington–Continued

Local well number	Temperature, water (degrees Celsius)	Oxygen, dissolved (milligrams per liter)	Chloride, dissolved (milligrams per liter as Cl)	Nitrogen, nitrite, dissolved (milligrams per liter as N)	Nitrogen, nitrite plus nitrate, dissolved (milligrams per liter as N)	Nitrogen, ammonia, dissolved (milligrams per liter as N)	Nitrogen, ammonia, plus organic dissolved (milligrams per liter as N)	Iron, dissolved (micrograms per liter as Fe)
29N/02W-07C03	11.0	5.4	7.8	<0.01	1.3	<0.04	<0.2	32
29N/03W-12G01	16.5	9.0	5.6	<.01	0.12	<0.04	<.2	14
30N/02W-28N03	12.0	1.7	7.6	<.01	.38	<0.04	<.2	14
30N/02W-31J02	12.5	6.7	120	<.01	<0.10	<0.04	<.2	4.0
30N/03W-05H02	12.0	3.7	11	<.01	2.4	<0.04	<.2	<3.0
30N/03W-06B01	10.5	2.9	3.1	<.01	.46	.05	<.2	38
30N/03W-06R02	11.5	4.9	3.1	<.01	.44	.05	<.2	5.0
30N/03W-07Q03	12.5	4.7	2.5	<.01	1.4	<0.04	<.2	18
30N/03W-08B01	11.5	5.2	5.3	<.01	1.7	<0.04	<.2	<3.0
30N/03W-08M01	--	--	3.8	<.01	1.7	<0.04	<.2	<3.0
30N/03W-09R01	12.5	<0.1	5.0	<.01	<0.10	.18	<.2	12
30N/03W-15G01	13.0	.3	4.5	<.01	<0.10	.08	<.2	25
30N/03W-17D02	13.5	3.4	2.7	.01	1.5	<0.04	<.2	<3.0
30N/03W-17M01	12.5	9.6	5.1	<.01	4.3	<0.04	<.2	<3.0
30N/03W-17P01	12.0	7.3	5.0	<.01	3.8	<0.04	<.2	<3.0
30N/03W-18E06	13.0	8.9	1.5	.01	.68	<0.04	<.2	<3.0
30N/03W-18M03	13.5	8.0	4.0	<.01	3.2	<0.04	<.2	<3.0
30N/03W-20K01D1	12.0	2.8	7.4	<.01	1.1	.05	<.2	<3.0
30N/03W-21A01	12.0	.1	10	<.01	<0.10	.20	.3	170
30N/03W-21K03	12.0	1.0	11	<.01	.24	<0.04	<.2	<3.0
30N/03W-23H03	14.5	5.2	14	.01	.29	<0.04	<.2	7.0
30N/03W-27B04	14.0	2.0	15	.01	.19	.06	<.2	<3.0
30N/03W-28C03	12.5	--	14	<.01	.14	.05	<.2	??
30N/03W-30K03	10.5	2.1	16	<.01	1.4	<0.04	<.2	<3.0
30N/03W-31H01	11.0	.2	8.5	<.01	.16	<0.04	<.2	48
30N/03W-33P01	11.5	5.0	11	<.01	.24	<0.04	<.2	50
30N/03W-36L01	--	--	8.6	.01	.11	<0.04	<.2	4.0
30N/04W-01R01	10.0	3.0	3.3	<.01	.53	<0.04	<.2	<3.0
30N/04W-02M05	11.5	<.1	6.0	<.01	<0.10	.42	.4	370
30N/04W-03H03	12.5	<.1	5.9	<.01	<0.10	.09	<.2	1700
30N/04W-03Q01	9.5	.1	5.0	<.01	<0.10	.05	<.2	6.0
30N/04W-04L02	12.5	10.2	7.0	<.01	1.2	<0.04	<.2	20
30N/04W-05J01	11.5	.3	15	.01	1.5	<0.04	<.2	10
30N/04W-05P01	11.0	--	14	.01	.13	.79	.9	37
30N/04W-07L01	11.5	.1	8.2	.01	.64	<0.04	<.2	120
30N/04W-08M04	14.0	5.4	4.8	<.01	1.0	<0.04	<.2	4.0
30N/04W-09N02	13.5	.4	4.3	.02	.16	.07	<.2	60

Table 15. Field measurements and concentrations of selected constituents in ground-water samples, July–August 1996, Sequim-Dungeness area, Washington–Continued

Local well number	Hydro- geo- logic unit	Date	Time	Land- surface altitude (feet above sea level)	Depth of well (feet)	Specific conduc- tance, field (micro- siemens per centi- meter)	Specific conduc- tance, laboratory (micro- siemens per centi- meter)	pH, field (stan- dard units)	pH, labora- tory (stan- dard units)
30N/04W-10C01	1	07-24-96	1245	117	60	331	331	7.4	7.6
30N/04W-10H01	1	07-23-96	1345	99.4	38	286	288	7.4	7.6
30N/04W-10Q02	1	07-30-96	1320	138	81	340	342	7.6	7.6
30N/04W-11J01	1	07-24-96	1445	122	76	167	168	7.9	7.7
30N/04W-12C07	1	07-24-96	1350	89.2	65	219	219	7.1	7.4
30N/04W-12K01	1	07-29-96	1550	110	26	198	199	6.9	6.8
30N/04W-13K14	1	08-07-96	1740	156	59	265	257	8.0	7.8
30N/04W-14L03	1	08-07-96	1540	170	76	224	218	8.3	7.9
30N/04W-15K03	1	08-20-96	1640	180	98	310	308	7.4	7.5
30N/04W-16P02	3	07-29-96	1800	230	144	421	398	7.8	7.6
30N/04W-17B01	1	08-06-96	1540	179	91	280	275	7.4	7.4
30N/04W-17P01	1	08-22-96	1520	340	66	225	226	6.7	7.3
30N/04W-17R02	3	07-24-96	1555	320	211	388	390	7.7	7.8
30N/04W-18H06	1	08-06-96	1430	230	121	258	254	7.1	7.2
30N/04W-20E01	1	07-25-96	1040	380	38	212	213	6.4	6.4
30N/04W-22C02	1	08-06-96	1310	210	58	391	389	7.3	7.3
30N/04W-23C03	1	08-22-96	1740	200	118	294	293	7.6	7.7
30N/04W-24E02	1	08-08-96	1150	210	140	275	268	8.2	7.8
30N/04W-25A01D1	1	08-08-96	1030	315	130	301	294	7.7	7.6
30N/04W-25L10	1	08-23-96	1110	340	125	256	255	7.8	7.6
30N/04W-26E03	1	07-30-96	1640	369	130	455	458	7.4	7.5
30N/04W-27A08	1	08-21-96	1530	410	96	526	519	7.7	7.7
30N/04W-29D02	1	07-31-96	1620	470	115	374	374	7.8	7.7
30N/04W-30G08	2	08-21-96	1020	530	166	717	712	7.7	7.9
30N/04W-35A03	1	08-06-96	1700	350	93	327	322	7.4	7.4
30N/05W-12K01	1	08-01-96	1300	172	105	334	335	6.8	6.9
30N/05W-13R01	1	08-21-96	1240	400	68	242	240	7.3	7.4
30N/05W-15D01	1	08-08-96	1320	300	34	532	519	7.4	7.4
30N/05W-20G01	1	08-08-96	1450	490	131	366	357	7.4	7.5
30N/05W-23N01	1	08-22-96	1050	625	100	233	233	7.5	7.6
30N/05W-26Q01	1	08-21-96	1350	825	130	287	287	8.2	8.0
31N/03W-31E03	1	08-09-96	1120	15	54	185	183	7.1	7.3
31N/04W-26Q09	1	08-01-96	1320	70	88	411	416	7.2	7.3
31N/04W-27P01	1	08-01-96	1530	90	130	303	304	7.7	7.7
31N/04W-34N01	1	08-01-96	1140	90	134	620	613	7.2	7.3
31N/04W-35M04	1	08-09-96	1230	145	157	500	492	7.0	7.2
31N/04W-36E03	1	08-09-96	1330	80	130.6	268	263	7.4	7.5

Table 15. Field measurements and concentrations of selected constituents in ground-water samples, July–August 1996, Sequim-Dungeness area, Washington–Continued

Local well number	Temperature, water (degrees Celsius)	Oxygen, dissolved (milligrams per liter)	Chloride, dissolved (milligrams per liter as Cl)	Nitrogen, nitrite, dissolved (milligrams per liter as N)	Nitrogen, nitrite plus nitrate, dissolved (milligrams per liter as N)	Nitrogen, ammonia, dissolved (milligrams per liter as N)	Nitrogen, ammonia, plus organic dissolved (milligrams per liter as N)	Iron, dissolved (micrograms per liter as Fe)
30N/04W-10C01	11.5	0.4	6.4	0.01	<0.10	0.29	0.3	88
30N/04W-10H01	13.0	.2	7.5	.04	1.8	<0.04	<.2	<3.0
30N/04W-10Q02	13.0	4.9	5.6	<.01	2.5	<0.04	<.2	<3.0
30N/04W-11J01	10.0	5.0	1.6	<.01	.12	<0.04	<.2	<3.0
30N/04W-12C07	13.5	4.7	2.3	<.01	.57	<0.04	<.2	6.0
30N/04W-12K01	11.5	4.9	3.0	.01	1.5	<0.04	<.2	<3.0
30N/04W-13K14	11.0	3.7	2.0	<.01	.46	<0.04	<.2	10
30N/04W-14L03	11.0	.1	1.9	<.01	<0.10	<0.04	<.2	42
30N/04W-15K03	12.0	5.5	5.3	<.01	3.1	<0.04	<.2	7.0
30N/04W-16P02	10.5	.1	11	.01	<0.10	.16	<.2	190
30N/04W-17B01	12.0	1.3	6.3	<.01	1.3	<0.04	<.2	<3.0
30N/04W-17P01	15.0	4.2	7.5	<.01	1.5	<0.04	<.2	4.0
30N/04W-17R02	10.5	3.0	9.0	<.01	.33	<0.04	<.2	3.0
30N/04W-18H06	13.5	3.5	6.2	<.01	1.2	<0.04	<.2	8.0
30N/04W-20E01	12.5	8.2	8.9	.01	3.9	<0.04	<.2	15
30N/04W-22C02	14.0	.1	8.7	.01	.85	<0.04	<.2	160
30N/04W-23C03	12.5	4.1	3.8	<.01	1.3	<0.04	<.2	3.0
30N/04W-24E02	12.0	.5	5.5	<.01	<0.10	<0.04	<.2	6.0
30N/04W-25A01D1	13.5	6.5	3.9	<.01	2.3	<0.04	<.2	<3.0
30N/04W-25L10	13.0	6.5	2.7	<.01	1.0	<0.04	<.2	7.0
30N/04W-26E03	18.5	4.7	5.1	<.01	.31	<0.04	<.2	<3.0
30N/04W-27A08	12.5	1.0	11	<.01	<0.10	.05	<.2	13
30N/04W-29D02	9.0	<.1	6.0	<.01	.11	.05	<.2	30
30N/04W-30G08	12.0	.2	67	<.01	<0.10	2.70	3.1	870
30N/04W-35A03	11.5	2.1	6.1	<.01	1.1	<0.04	<.2	<3.0
30N/05W-12K01	11.0	<.1	11	.02	.21	<0.04	<.2	250
30N/05W-13R01	11.5	5.1	8.3	<.01	.12	<0.04	<.2	7.0
30N/05W-15D01	12.0	.5	25	<.01	.28	<0.04	<.2	78
30N/05W-20G01	10.5	.2	6.4	<.01	<0.10	<0.04	<.2	490
30N/05W-23N01	10.5	5.0	6.3	<.01	.31	<0.04	<.2	10
30N/05W-26Q01	11.0	.2	3.2	<.01	<0.10	.33	.2	9.0
31N/03W-31E03	10.5	1.6	1.9	<.01	.18	<0.04	<.2	<3.0
31N/04W-26Q09	11.5	1.0	10	<.01	.77	<0.04	<.2	4.0
31N/04W-27P01	12.0	<.1	6.3	<.01	<0.10	.16	.2	410
31N/04W-34N01	11.5	.6	49	<.01	<0.10	1.10	1.2	1,500
31N/04W-35M04	13.5	1.4	25	<.01	<0.10	.05	<.2	180
31N/04W-36E03	10.5	1.1	5.2	<.01	<0.10	.05	<.2	150

Table 16. Summary of field measurements and constituent concentrations in ground-water samples, July–August 1996, Sequim-Dungeness area, Washington

[<, less than; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter]

Constituent or property	Concentration, in milligrams per liter unless otherwise noted					
	Number of wells	Minimum	25th percentile	Median	75th percentile	Maximum
pH (standard units)	74	5.6	7.2	7.4	7.8	8.4
Dissolved oxygen	70	<0.1	0.3	2.4	5.0	10.2
Specific conductance (µS/cm)	74	167	268	312	410	712
Chloride	74	1.5	4.2	6.2	10	120
Nitrite	74	<.01	<.01	<.01	<.01	0.04
Nitrate	74	<.10	<.10	.32	1.3	4.3
Ammonia	74	<.04	<.04	<.04	.05	2.7
Ammonia plus organic nitrogen	74	<.2	<.2	<.2	<.2	3.1
Iron, (µg/L)	74	<3.0	<3.0	<3.0	44	1,700

Table 17. Field measurements and constituent concentrations in the shallow and middle aquifers, July–August, 1996, Sequim-Dungeness area, Washington

[<, less than; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter]

Constituent or property	Aquifer	Number of wells	Concentration, in milligrams per liter unless otherwise noted				
			Minimum	25th percentile	Median	75th percentile	Maximum
pH (standard units)	Shallow	61	5.6	7.1	7.4	7.8	8.3
	Middle	8	7.3	7.6	7.7	8.0	8.2
Dissolved oxygen	Shallow	60	<0.1	0.4	3.0	5.1	10.2
	Middle	7	<.1	.1	1.0	5.0	5.2
Specific conductance (µS/cm)	Shallow	61	167	262	294	378	620
	Middle	8	342	361	404	518	712
Chloride	Shallow	61	1.5	3.8	6.1	8.6	120
	Middle	8	3.8	5.2	10	11	14
Nitrite	Shallow	61	<.01	<.01	<0.01	<0.01	0.04
	Middle	8	<.01	<.01	<.01	<.01	.01
Nitrate	Shallow	61	<.10	.12	.53	1.4	4.3
	Middle	8	<.10	<.10	.24	.32	1.7
Ammonia plus organic nitrogen	Shallow	61	<.2	<.2	<.2	<.2	1.2
	Middle	8	<.2	<.2	<.2	<.2	.4
Ammonia	Shallow	61	<.04	<.04	<.04	.05	1.1
	Middle	8	<.04	<.04	<.04	.13	.42
Iron, (µg/L)	Shallow	61	<3.0	<3.0	7.0	40	1,700
	Middle	8	<3.0	<3.0	6.5	155	370

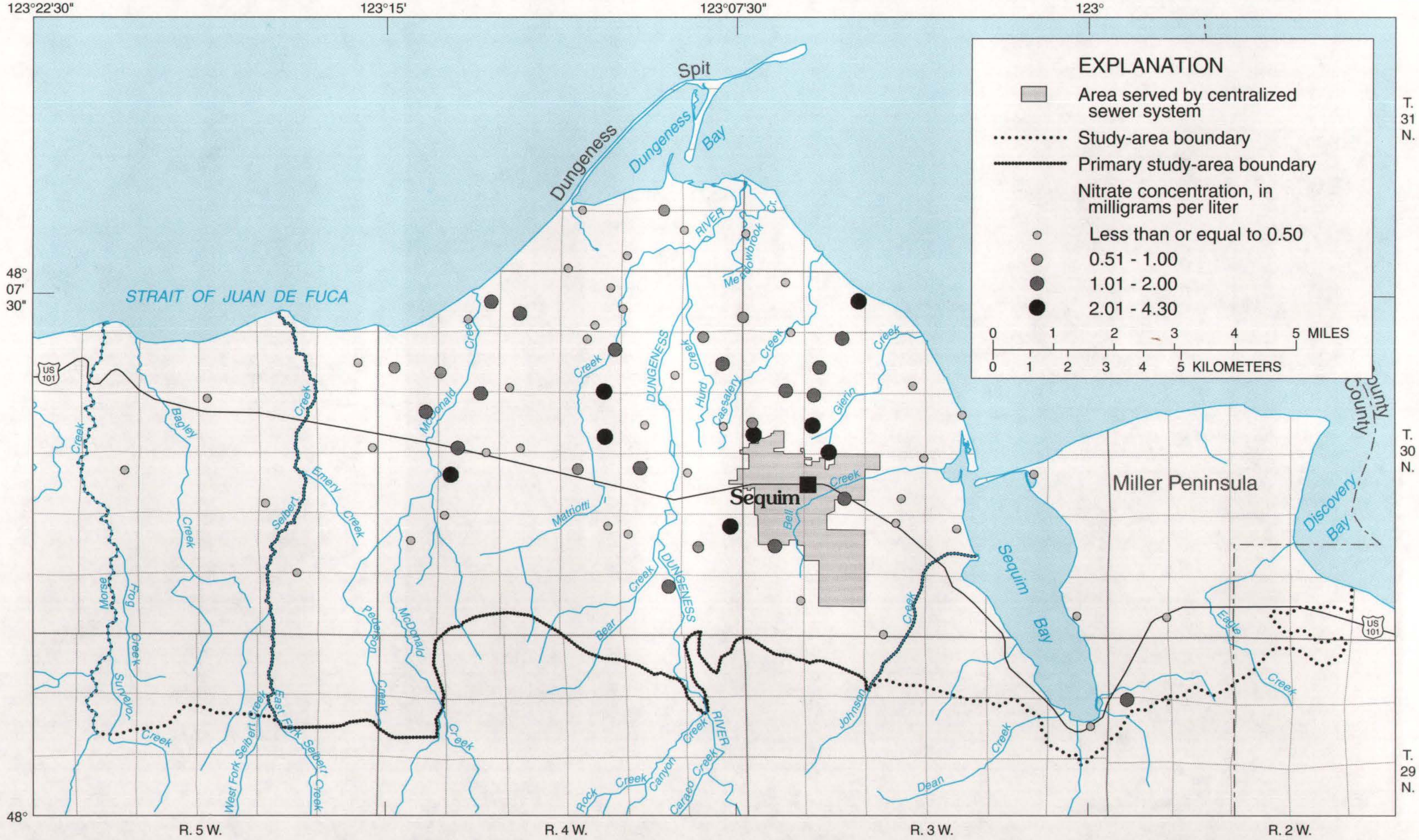

Figure 43. Concentrations of dissolved nitrate in ground water, July-August 1996.

Changes in Nitrate Concentrations From 1980 to 1996

In June 1980, 129 ground-water samples collected from the primary study area were analyzed for nitrate (Drost, 1983). Ninety-one percent of the samples were from the shallow aquifer and 9 percent were from the middle or lower aquifers. The median nitrate concentration was 0.37 mg/L. The same areas of elevated nitrate concentrations observed in 1980 (fig. 44) were also observed in 1996 (fig. 43).

In August 1992, 316 ground-water samples collected from the primary study area were analyzed for nitrate (Clallam County Department of Community Development, 1994). The hydrogeologic units from which the samples were collected are unknown, but about 80 percent of the wells were less than 120 ft deep, so 70 to 80 percent of the samples were probably from the shallow aquifer. The median concentration of those samples was 0.55 mg/L. The areal pattern of elevated nitrate concentrations was similar to that found in the 1980 and 1996 samples.

In July and August 1996, 65 ground-water samples collected from the primary study area were analyzed for nitrate. Eighty-three percent of the samples were from the shallow aquifer and 17 percent were from the upper confining bed, middle aquifer, or lower aquifer.

The changes in nitrate concentrations from 1980 to 1992 to 1996 were evaluated using statistical tests. Median nitrate concentrations were 0.37 mg/L in 1980, 0.55 mg/L in 1992, and 0.46 mg/L in 1996 (table 18). Nitrate concentrations significantly increased from 1980 to 1992 and from 1980 to 1996, but there was no significant change from 1992 to 1996. There is an areal pattern in the increase in nitrate concentrations from 1980 to 1996 (fig. 45); east of the Dungeness River, north of Bell Creek, and north of Highway 101, 42 percent of the ground-water samples had greater than a 1.0 mg/L increase in concentration. West of the Dungeness River, east of McDonald Creek, and north of Highway 101, only 8 percent of the samples had greater than a 1.0 mg/L increase in concentration.

The sources of the increase in nitrate concentrations from 1980 to 1996 are uncertain. Potential sources are septic systems, residential fertilizers, leaching of nitrogen stored in soils from historical agricultural activity, and less dilution of nitrate because of decreasing quantities of ground-water recharge from irrigation during the past 15 years. Data were not available to determine a particular source. All these sources probably have influenced the increase in nitrate concentrations.

Some evidence that less dilution has caused increased nitrate concentrations is that the area of most consistent increases in nitrate concentrations (east of the Dungeness River, north of Bell Creek and north of Highway 101) (fig. 45) is also the area with the most consistent declines in ground-water levels (fig. 41). The declines in water levels are probably a result of about a 30 percent decrease in irrigation diversions and resultant decrease in recharge in that area over the past 15 years. This decrease in recharge may have resulted in less dilution of ground water and higher concentrations of nitrate if the same amount of nitrate was added to ground water during that period.

Sources of Nitrogen

The annual amount of nitrogen that enters the ground-water system in the primary study area in 1996 was estimated. Land uses and corresponding sources of nitrogen were also compared with nitrate concentrations in ground water to determine if different sources result in different nitrate concentrations. Sources of nitrogen are recharge from precipitation, recharge from irrigation and leakage from the Dungeness River, dry deposition from the atmosphere, dry deposition from dairy farms, mineralization from soil organic matter, application of agricultural fertilizers, application of residential fertilizers, effluent from septic systems, storage and application of manure, and leakage from dairy manure lagoons.

About 543,200 pounds of nitrogen are estimated to enter the ground-water system each year (table 19). Four sources that account for about 85 percent of the nitrogen appear to be approximately equivalent in amounts of nitrogen. Residential fertilizers supply about 129,000 pounds of nitrogen (24 percent), septic systems supply about 114,000 pounds (21 percent), mineralization of soil organic matter supplies about 112,000 pounds (20 percent), and agricultural fertilizers supply about 107,000 pounds (20 percent). Most of the remaining nitrogen is from dairy farms, which produce about 41,000 pounds of nitrogen (8 percent).

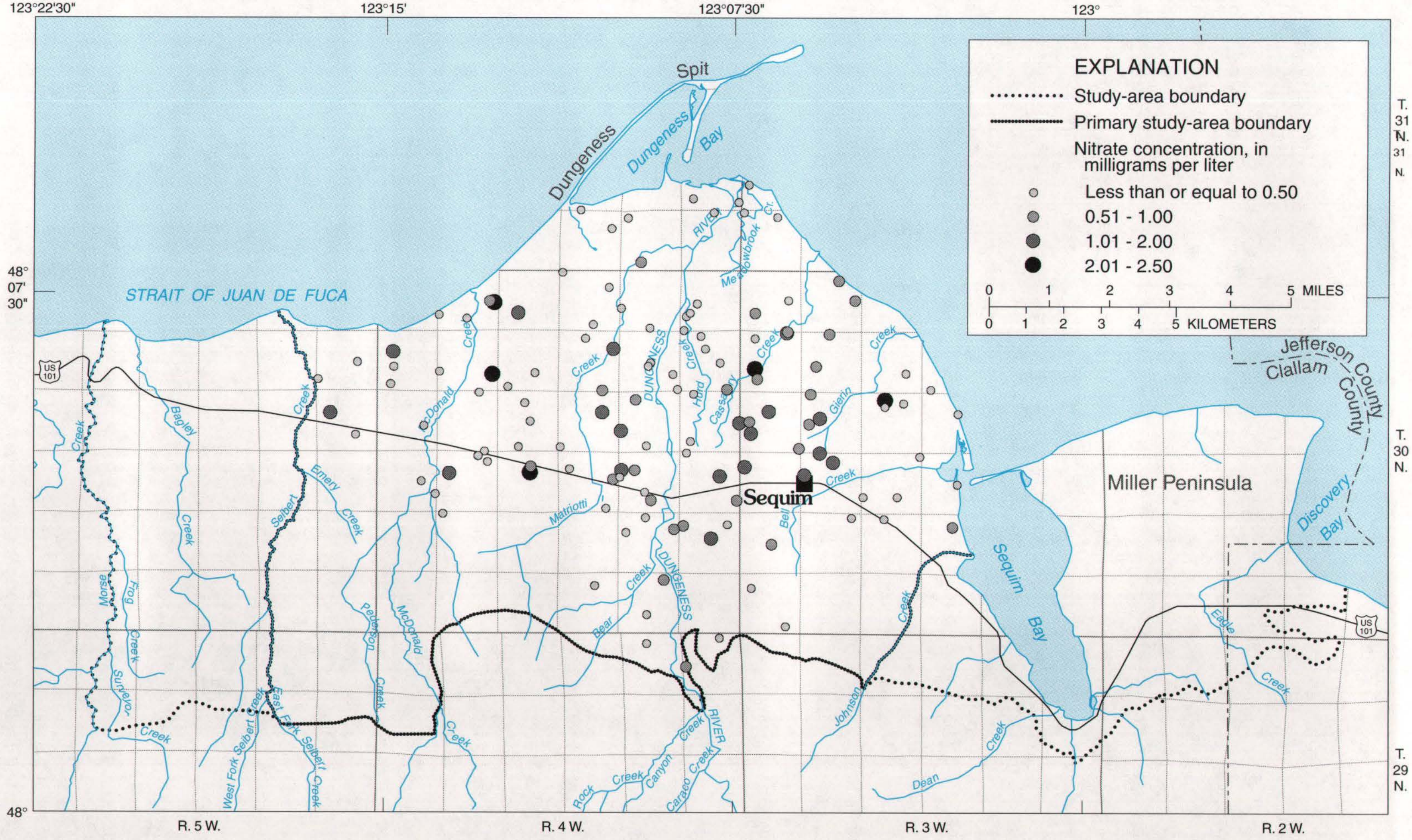

Figure 44. Concentrations of dissolved nitrate in ground water, June 1980.

Table 18. Nitrate concentrations in ground-water samples collected from the primary study area in August 1980, August 1992, and July–August 1996, Sequim-Dungeness area, Washington

[Group of samples: the paired samples are ones collected in 1980 and in 1996 from the same wells; <, less than]

			Nitrate concentrations, in milligrams per liter			
Group of samples	Year	Number of samples	25th percentile	Median	75th percentile	P-value
All available	1980	129	0.05	0.37	0.87	[1]0.026
	[2]1992	316	.03	.55	1.3	
All available	1992	316	.03	.55	1.3	[3].602
	1996	65	<.10	.46	1.4	
All available	1980	129	.05	.37	.87	[1].032
	1996	65	<.10	.46	1.4	
Paired	1980	35	.08	.41	.87	[4].001
	1996	35	.11	.44	1.5	

[1] A rank-sum nonparametric test (one-sided) was used to test the null hypothesis that the nitrate concentrations are the same in the two time periods. The alternative hypothesis is that nitrate concentrations increased over time (early to later time period). P-values less than 0.05 indicate a significant increase in nitrate concentrations over time.

[2] Samples from Clallam County Department of Community Development (1994).

[3] A rank-sum nonparametric test (two-sided) was used to test the null hypothesis that nitrate concentrations are the same in 1992 and 1996. Alternative hypotheses are that nitrate concentrations are different (lower or higher) in 1992 and 1996. P-values less than 0.05 indicate a significant change in nitrate concentrations over time.

[4] A Wilcoxon signed-ranks nonparametric test (one-sided) was used to test the null hypothesis that the nitrate concentrations are the same in 1980 and 1996. The alternative hypothesis is that nitrate concentrations increased from 1980 to 1996. P-values less than 0.05 indicate a significant increase in nitrate concentrations over time.

Much of the information used in the loading analysis, including how much of the nitrogen applied at land surface moves downward and eventually reaches ground water, is from Cox and Kahle (in press) who performed an extensive nitrogen loading analysis for Whatcom County in northwestern Washington. Most of the data and assumptions used in the loading analysis for this study are shown in table 19. The estimates of nitrogen loading are rough because many assumptions were used and much of the data had to be estimated from ranges of values used in other areas of western Washington. The following explanation of the data and methods used to estimate each source of nitrogen also contains a relative indication of the reliability of the estimates. The estimated total amount of nitrogen was given a fair rating. Several of the larger sources were rated poor, but some of the bias in the estimates probably evens out when they are all combined, and several of the sources with moderate amounts of applied nitrogen were rated fair or good.

The estimate of nitrogen in precipitation recharge was given a good rating because the recharge was estimated in this study. The 0.26 mg/L of nitrate in precipitation is an average of data from three locations in western Washington (Cox and Kahle, in press).

The estimates of nitrogen in dry atmospheric deposition for the study area and for dairy farms were given poor ratings because there are many assumptions in the methods, and the values for nitrogen are from Whatcom County. Dry atmospheric deposition includes nitrogen in particulate fallout, submicron particle deposition, and gaseous adsorption and absorption (Cox and Kahle, in press).

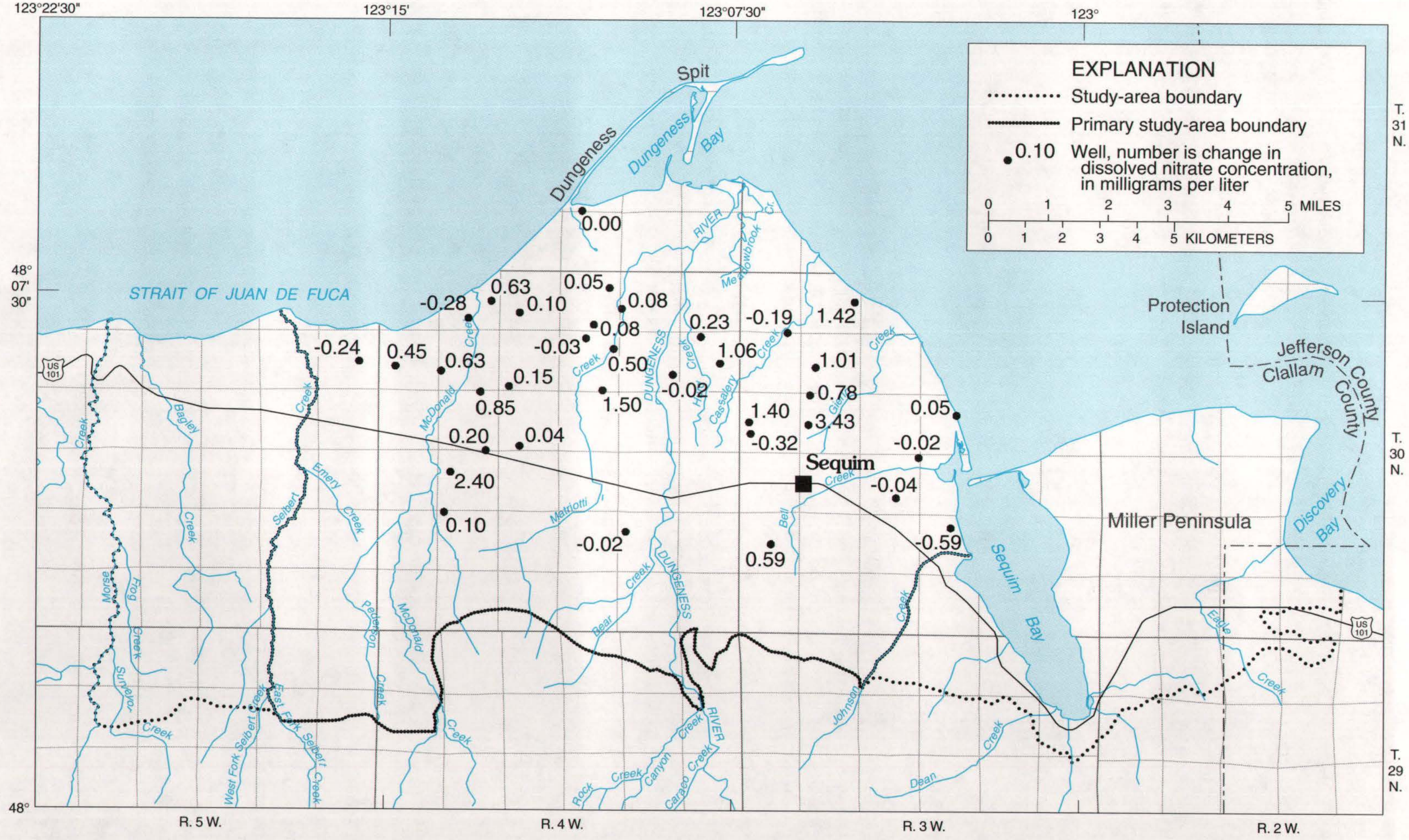

Figure 45. Changes in concentrations of dissolved nitrate from June 1980 to July-August 1996. A positive number is an increase in nitrate concentration.

Table 19. Estimates of annual nitrogen loading for primary study area in 1996, Sequim-Dungeness area, Washington

[Acre-ft, acre-feet; mg/L, milligrams per liter; lbs/acre, pounds per acre; lbs, pounds; lbs/d, pounds per day; mm/d, millimeter per day; m^2, square meter; L/m^3, liters per cubic meter; N/A, not applicable]

Source	Area (acres)	Data and equation	Relative reliability	Annual load (pounds)
Precipitation recharge	[1]47,300	0.26 mg/L of nitrate in precipitation[2] 31,600 acre-ft of recharge[1] Load = (0.26) (31,200) (2.718) (2.718 converts mg/L and acre-ft to pounds)	Good	22,300
Dry atmospheric deposition	47,300	[2]1.0 lbs of nitrogen per acre 30 percent of dry deposition reaches ground water (percent of precipitation that becomes recharge)[1] Load = (1.0) (47,300) (0.3)	Poor	14,200
Dry atmospheric deposition from dairy farms	[3]873	Redeposition of volatilized nitrogen yields 15 pounds of nitrogen per acre for land used in dairy farming[2] 30 percent of dry deposition reaches ground water[1] Load = (15)(873)(0.3)	Poor	3,900
Recharge from irrigation and Dungeness River leakage	N/A	0.05 mg/L of nitrogen in Dungeness River[4] 0.02 mg/L of nitrogen in irrigation water[4] 20,300 acre-ft of Dungeness River leakage[1] 19,200 acre-ft of irrigation recharge[1] Load from Dungeness River = (0.05) (20,300) (2.718) Load from irrigation = (0.02) (19,200) (2.718)	Good	3,800
Mineralization from soil organic matter	[5]15,000	150 lbs/acre mineralized per year[2] 5 percent of mineralized nitrogen reaches ground water[2] Load = (150)(15,000)(0.05)	Poor	112,000
Agricultural fertilizers	[5]15,000	[6]Average annual agricultural nitrogen loading in study area for 1985 to 1991 was 162 tons 33 percent of applied nitrogen reaches ground water[2] Load = (162) (2,000) (0.33)	Poor	107,000
Residential fertilizers	[5]2,600	150 lbs/acre of nitrogen fertilizer use[7] 33 percent of applied nitrogen reaches ground water[2] Load = (150)(2,600)(0.33)	Poor	129,000
Septic systems	N/A	6,993 septic systems in primary study area[8] 2.4 people per household[9]		

Table 19. Estimates of annual nitrogen loading for primary study area in 1996, Sequim-Dungeness area, Washington—Continued

<table>
<tr><th>Source</th><th>Area (acres)</th><th>Data and equation</th><th>Relative reliability</th><th>Annual load (pounds)</th></tr>
<tr><td>Storage and application of manure at dairies</td><td>[3]873</td><td>Average weight of a cow is 1,200 lbs[10]
Average amount of nitrogen in manure:[11]
Lactating cows 0.45 lbs/d/1,000 lbs cow
Dry cows 0.36 lbs/d/1,000 lbs cow
Heifers 0.31 lbs/d/1,000 lbs cow
Beef 0.31 lbs/d/1,000 lbs cow
<table>
<tr><th></th><th>Number of cows[4]</th><th>Total weight (pounds)</th><th>Nitrogen deposited (pounds)</th></tr>
<tr><td>Lactating</td><td>693</td><td>832,000</td><td>137,000</td></tr>
<tr><td>Dry</td><td>226</td><td>271,200</td><td>35,600</td></tr>
<tr><td>Heifers</td><td>535</td><td>642,000</td><td>72,600</td></tr>
<tr><td>Beef</td><td>100</td><td>120,000</td><td>13,600</td></tr>
</table>
Because of volatilization and denitrification, only
30 percent of nitrogen in manure is available on the field[2]
30 percent of available nitrogen reaches ground water[2]
Total nitrogen deposited is 259,000 lbs
Load = (259,000) (0.3) (0.3)</td><td>Fair</td><td>23,300</td></tr>
<tr><td>Dairy manure lagoons</td><td>5</td><td>[4]5 lagoons and each lagoon is 1 acre
[2]Seepage rate of 1 mm/d
[2]Ammonia concentration of 840 mg/L
Load = 840 mg/L (4,050 m^2 /acre)(0.365 m/yr) (1,000 L/m^3) (0.0000022 lbs/mg)(5 lagoons)
Load = 2,740 lbs/acre</td><td>Fair</td><td>13,700</td></tr>
<tr><td>Total</td><td>47,300</td><td></td><td>Fair</td><td>543,200</td></tr>
</table>

[1] This study.

[2] Cox and Kahle (in press).

[3] Kerry Perkins (U.S. Department of Agriculture, Natural Resources Conservation Service, oral commun., 1998).

[4] Ann Soule (Clallam County Department of Community Development, Wash., written commun., 1998).

[5] Penny Eckert (University of Washington, Seattle, Wash., written commun., 1998).

[6] S.S. Embrey (U.S. Geological Survey, written commun., 1998).

[7] Embrey and Inkpen (1998).

[8] Peter Schwartzman (Pacific Groundwater Group, Seattle, Wash., written commun., 1998).

[9] U.S. Bureau of the Census (1997).

[10] Ned Zaugg (Washington State Cooperative Extension Service, Lake Stevens, Wash, oral commun., 1998).

[11] U.S. Department of Agriculture (1992)

The estimate of nitrogen in recharge from irrigation and Dungeness River leakage was given a good rating because recharge from those sources was estimated in this study, and the concentrations of nitrate in the Dungeness River and irrigation water are based on measured data collected in the early 1990's.

The estimate of nitrogen from mineralization of soil organic matter was given a poor rating. Nitrogen typically makes up about 5 percent of soil organic matter. Mineralization of this nitrogen forms nitrate, which is mobile and susceptible to leaching to ground water (Cox and Kahle, in press). The area of land used to compute nitrogen from this source includes historical and current agricultural areas, and the area is fairly reliable. It was assumed that nitrogen in soil organic matter in all other areas (residential, forest, and natural grassland) is in equilibrium—that is, the amount of mineralization of nitrogen equals the amount of uptake by plants. The estimate of 150 pounds per acre (lbs/acre) of mineralized nitrogen is uncertain, because it is from a range of 150 to 240 lbs/acre (Cox and Kahle, in press). The lower end of the range was used because the range was developed for an area with a much larger density of dairies and other agricultural activity (Whatcom County in northwestern Washington) than this study area.

The estimate of nitrogen from agricultural fertilizers was given a poor rating. The amount of applied fertilizers was estimated specifically for the Dungeness River Basin by S.S. Embrey (U.S. Geological Survey, written commun., 1998). However, fertilizer use in the study area is very difficult to estimate because many farmers do not buy their fertilizers locally, and the amount of use and types of fertilizers vary widely.

The estimate of nitrogen from residential fertilizers was given a poor rating for the same reasons as described for agricultural fertilizers. Also, the value used in this analysis is from a range of residential fertilizer use for the entire Puget Sound Basin. This study used an average value of 150 lbs/acre from the range of 130 to 170 lbs/acre (Embrey and Inkpen, 1998). The value for area of residential use, 2,600 acres, is fairly reliable because it is from a recent detailed land-use study (Penny Eckert, University of Washington, Seattle, Wash., written commun., 1998).

The estimate of nitrogen from septic systems was given a fair rating. The number of septic systems and the average of 2.4 people per household are fairly accurate. The most uncertain factor is the estimate of 6.8 pounds of nitrogen per person that reaches the ground-water system (Cox and Kahle, in press).

The estimate of nitrogen from storage and application of manure at dairies was given a fair rating. The values for the number and types of cows are accurate. But the average amount of nitrogen in manure can vary widely and the volatilization percentage and percentage reaching ground water are uncertain.

The estimate of nitrogen from dairy-manure lagoons was given a fair rating. The number and size of lagoons is fairly accurate. The seepage rate and ammonia concentration, however, are uncertain and could be quite variable.

The nitrogen loading analysis achieved the study objective of estimating the probable major sources of nitrate in ground water. Residential fertilizers, septic systems, mineralization of soil organic matter, and agricultural fertilizers account for about 85 percent of the total nitrogen loading. The loading analysis did not determine if the areal distribution and intensity of loading from each source resulted in different concentrations of nitrate in ground water under each source. To investigate this question, nitrate concentrations in the shallow aquifer were statistically compared with land uses or sources of nitrogen. Land uses were combined into three groups: residential, agricultural, and natural grasslands or forests (table 20 and fig. 46). Residential land use represents residential fertilizers and septic systems; agricultural land use represents agricultural fertilizers, mineralization of soil organic matter, and dairy manure; and natural grasslands or forests represent background or natural levels of nitrogen loading. The mineralization of soil organic matter is assumed to take place only in agricultural areas. To perform the statistical tests, ground-water samples from wells in the shallow aquifer were placed into the three land-use groups, and their nitrate concentrations were statistically compared using a nonparametric rank-sum test (two-sided) (Helsel and Hirsch, 1992, p. 118-124).

Land use and the corresponding sources and loading of nitrogen appear to result in different concentrations of nitrate in shallow ground water under the land use. Median nitrate concentrations in the shallow aquifer were 1.3 mg/L under residential areas, 0.55 mg/L under agricultural areas, and 0.12 mg/L under natural grasslands or forests (table 20, figs. 46 and 47). Statistical tests provide some evidence to support this relation between nitrate concentration and land use. Nitrate concentrations were significantly higher under residential areas than under natural grasslands or forests (p-value is <0.001). Statistical tests comparing nitrate concentrations under the other two land uses resulted in low but not significant p-values. Agricultural areas compared with residential areas had a p-value of 0.031, and agricultural areas compared with natural grasslands or forests had a p-value of 0.019. The overall threshold significance p-value for the land-use comparison is 0.05, which results in a threshold significance p-value for three dependent comparisons of 0.017.

The intensity of nitrogen loading also supports the relation between land use and nitrate concentration in shallow ground water. Estimated nitrogen loading was about 40 lbs/acre for residential areas, about 20 lbs/acre for agricultural areas, and about 1 lb/acre for natural grasslands and forests.

Table 20. Land use and nitrate concentrations in water samples from the shallow aquifer, July–August 1996, Sequim-Dungeness area, Washington

[<, less than]

Land use	Number of samples	Nitrate concentration (milligrams per liter) 25th percentile	Median	75th percentile	P-value[1]
Residential	20	0.52	1.3	2.4	<0.001
Natural grasslands or forests	15	<.10	.12	0.31	
Agricultural	26	.12	.55	1.3	.019
Natural grasslands or forests	15	<.10	.12	.31	
Residential	20	.52	1.3	2.4	.031
Agricultural	26	.12	.55	1.3	

[1] A rank-sum nonparametric test (two-sided) was used to test the null hypothesis that the nitrate concentrations are the same in ground water under two types of land use. Alternative hypotheses are that nitrate concentrations are different in ground water under the two types of land use (lower or higher). The overall threshold significance level for the comparison betwen nitrate concentrations and land use is 0.05. The threshold significance level for each of the three dependent comparisons is 0.017; therefore; p-values less than 0.017 indicate a significant difference in nitrate concentrations.

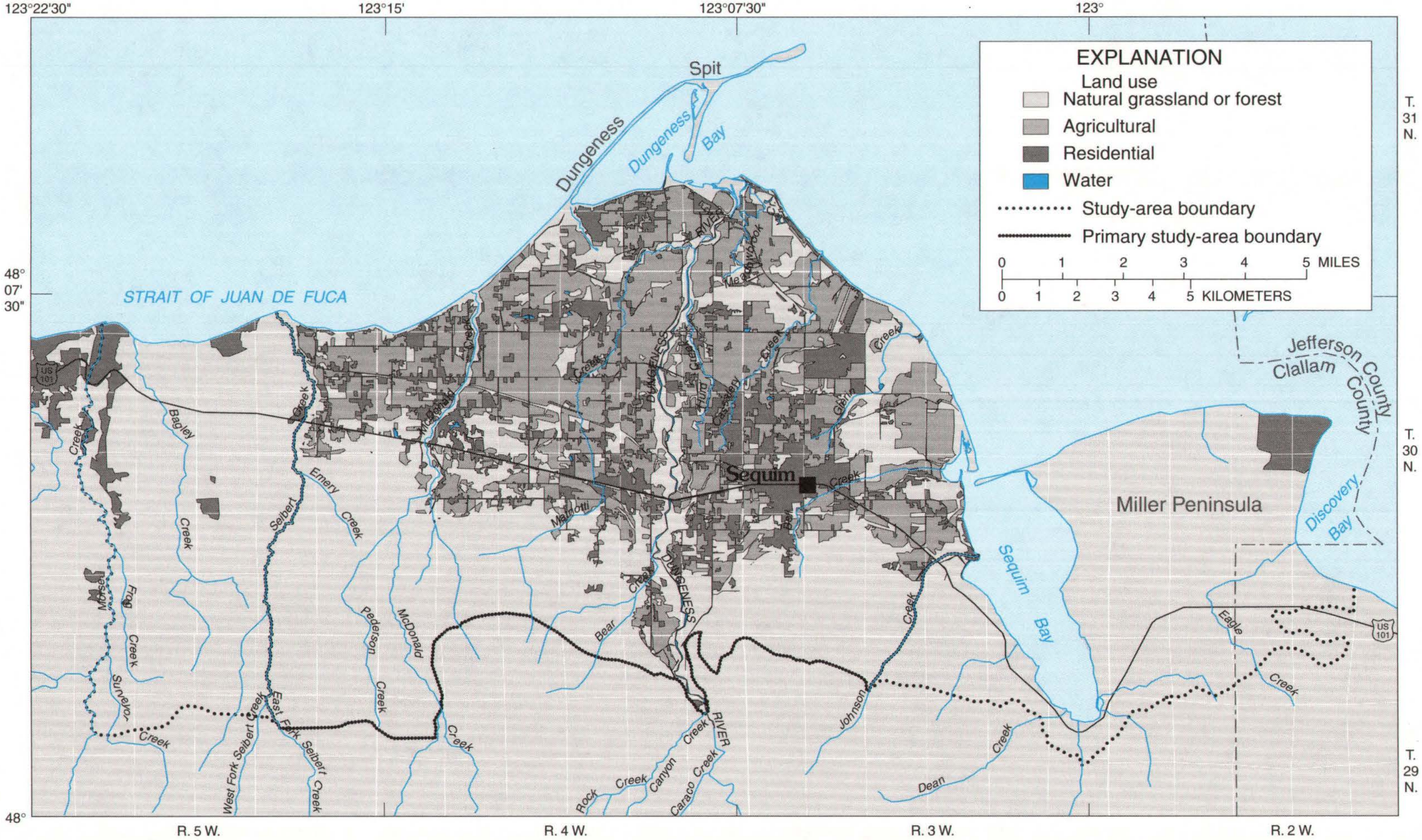

Figure 46. Generalized land use in 1994. (Penelope Eckert, University of Washington, written communication, 1998; Steve Gray, Clallam County, written communication, 1998; Montgomery Water Group, Inc., Kirkland, Washington, written communication, 1998).

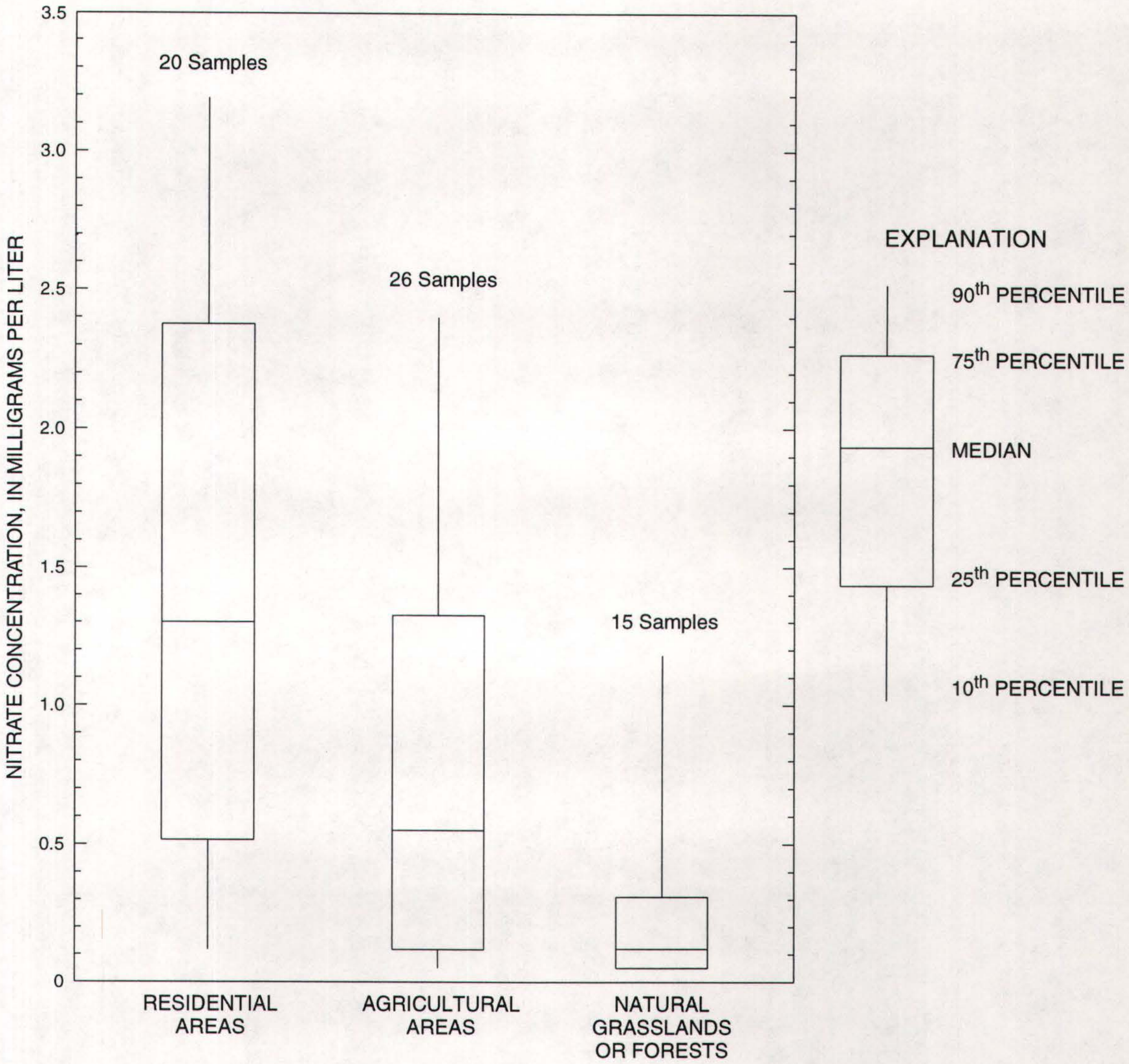

Figure 47. Nitrate concentrations in the shallow aquifer in 1996 and land use, Sequim-Dungeness area, Washington.

In addition to the comparison between land use and nitrate concentrations, another statistical test was made to determine the relation between septic-system density and nitrate concentrations (table 21). Ground-water samples from the shallow aquifer were placed into three groups of septic-system density: less than or equal to 100 septic systems per square mile, 101 to 200 systems per square mile, and more than 200 systems per square mile. A nonparametric rank-sum test was used to determine if nitrate concentrations significantly changed from (1) the low to moderate group, (2) the moderate to high group, and (3) the low to high group. Median nitrate concentrations were 0.16 mg/L in low density, 0.57 mg/L in moderate density, and 0.92 mg/L in high density. These increases in nitrate concentrations, however, were not statistically significant.

Table 21. Septic-system density and nitrate concentrations in water samples from the shallow aquifer, July–August 1996, Sequim-Dungeness area, Washington

[Septic-system density: low is less than or equal to 100 systems per square mile, moderate is 101 to 200 systems per square mile, high is more than 200 systems per square mile; <, less than]

Septic-system density	Number of samples	Median nitrate concentration (milligrams per liter)			P-value[1]	
		25th percentile	Median	75th percentile		
Low	27	<0.10	0.16	1.2		
					0.06	
Moderate	19	.18	.57	1.5		0.07
					.28	
High	12	.35	.92	1.4		

[1] A rank-sum nonparametric test (one-sided) was used to test the null hypothesis that the nitrate concentrations are the same in ground water under two densities of septic systems. The alternative hypothesis is that nitrate concentrations in ground water increased from lower to higher density of septic systems. The overall threshold significance level for the comparison between nitrate concentrations and septic-system density is 0.05. The threshold significance level for each of the three dependent comparisons is 0.017; therefore, p-values less than 0.017 indicate a significant increase in nitrate concentrations.

POSSIBLE ADDITIONAL DATA AND STUDIES

The current state of knowledge about the hydrogeology of the Sequim-Dungeness area was assessed and improved during this investigation. The data collected and analyzed for this study provide a solid baseline of information that presents a picture of the ground-water system in 1995–97. However, as part of the analyses, areas where additional data or studies would be helpful were identified.

The hydrogeologic framework was defined for the shallow aquifer, upper confining bed, and middle aquifer. More data are needed to define the areal extents and top and bottom surfaces of the lower confining bed and the lower aquifer. The undifferentiated unconsolidated deposits below the lower aquifer are a mixture of many different lithologies, and with more data, this unit probably could be separated into additional aquifers and confining beds. Wells drilled into the lower hydrogeologic units or geophysical studies could provide the needed information to define hydrogeologic boundaries.

Ground-water flow in the shallow aquifer was defined for the primary study area, but in Miller Peninsula and west of Siebert Creek, flow directions and water-level gradients are uncertain. Ground-water flow directions in the middle aquifer were defined, but the density of data was not sufficient to accurately define water-level gradients. Directions of ground-water flow and gradients in the lower aquifer are unknown. Water-level data collected from existing wells and from newly constructed wells in the areas of uncertainty could provide the data needed to better define ground-water flow in those areas.

A general water budget of the ground-water system was estimated. Recharge from infiltration and percolation of precipitation was estimated with the deep-percolation model. To obtain a measure of the accuracy of a deep-percolation model, runoff in several basins could be measured for about two years to provide calibration data. Soil water could also be measured in a sufficient number of sites to define the magnitude, seasonal changes, and areal variability of water contents near the measured runoff basins. In addition to the water-budget approach of the deep-percolation model, other methods such as environmental tracers could be employed to estimate recharge from precipitation.

The estimates of recharge from percolation of irrigation water and leakage from irrigation ditches only apply to the study period from December 1995 to September 1997. Irrigation recharge will vary depending on the amounts of water diverted from the Dungeness River and the efficiency of the application of irrigation water to fields. Also, several projects are underway, or planned, to replace the open ditches with pipes. Ditch leakage will decrease as more and more pipes are installed. Continued monitoring of irrigation outtakes and tailwaters, and more detailed measurements of ditch-leakage rates would help improve and monitor estimates of recharge from irrigation.

Recharge from lateral subsurface inflow at the southern boundary of the study area was roughly estimated because data are meager there. Wells drilled near the boundary could provide needed data on water levels and transmissivity. A digital model could be used to integrate recharge and ground-water flow near the boundary. Chemical analyses of water collected near the boundary between bedrock and unconsolidated material could provide information on amounts of subsurface inflow. Types of analyses that could be valuable are age-dating the water with tritium and carbon-14 analyses, general chemistry, temperatures, and various isotope ratios. The amount of vertical subsurface inflow from bedrock is unknown, and similar methods as described above could be used to estimate this recharge.

Ground-water discharges by subsurface outflow to saltwater bodies, flow to streams, and flow to springs. Outflow to saltwater bodies could be defined by drilling wells near the outflow boundaries and collecting data on water levels, transmissivity, and vertical hydraulic conductivity of confining beds. Flow to streams was estimated on the basis of discharge measurements made in September and October 1997. Additional discharge measurements made at different times of the year would help define seasonal variation in this ground-water discharge.

Ground-water recharge from and discharge to the Dungeness River were estimated on the basis of two sets of discharge measurements at four sites (three reaches). Refinements could be made to the relation between the river and ground water by measuring discharge at more sites along the river (shorter reaches) and by measuring discharge more times during a year.

The potential effects of ground-water development (pumping) or changes in the irrigation system could be evaluated by constructing a digital ground-water model of the study area. Digital models are useful tools that integrate all parts of a ground-water system—the water-budget components, hydrogeologic boundaries, and hydraulic properties. In addition to evaluating effects of stresses imposed on a ground-water system, digital models also can improve the understanding of a ground-water system by showing the interrelationships among all parts of the system. Most of the data needed to construct a digital model were collected or estimated in this study.

This study found four major sources of nitrogen in ground water: residential fertilizers, septic systems, mineralization of soil organic matter, and agricultural fertilizers. They were fairly equivalent in amounts, so further refinement of the amount from each source might be gained using isotopes.

Future concerns in the study area are overpumping of the ground-water system that could cause declines in ground-water levels, overpumping that could cause declines in ground-water discharge to the Dungeness River and the consequent lowering of base flows in late summer and early fall, a decrease in irrigation recharge causing the same problems as overpumping, and degradation of water quality. Ground-water monitoring programs would help provide early warnings if any of these problems became serious. A network designed to measure water levels every three months in a sufficient areal distribution could provide the needed information on the effects of increased pumping or decreased irrigation recharge.

Nitrate data collected in this study confirmed a conclusion of a previous study that nitrate concentrations have increased during the past 10 to 15 years (Clallam County Department of Community Development, 1994). Continued monitoring of nitrate would help track this trend. A minimum water-quality monitoring program would be the periodic collection of samples for the analysis of nitrate and chloride. Monitoring of these constituents would detect the most common potential water-quality problems in the study area—contamination from septic systems, animal wastes, fertilizers, and seawater intrusion. If other sources of contamination became a concern, such as industrial, commercial, or agricultural activity, an expanded program could be established. This expanded program could include analyses for common ions, trace elements, and synthetic organic compounds (including pesticides).

SUMMARY AND CONCLUSIONS

This study was undertaken to improve the understanding of the ground-water system in the Sequim-Dungeness area, which covers 116 square miles on the northern part of the Olympic Peninsula in northwestern Washington. Much of the work was focused on a 74-square-mile primary study area that includes most of the area's population. Domestic water is withdrawn from ground water and irrigation water is withdrawn from the Dungeness River. During the past two decades, the population has rapidly increased, land use has changed from mostly agricultural to residential, and salmon populations in the Dungeness River have appreciably declined. There is a close relation between ground water, the Dungeness River, and an extensive irrigation system in the study area. This close relation and the conflict between increasing needs of domestic water supply, irrigated agriculture, and salmon populations has created a need for a better understanding of ground water and the relation between ground water and surface water in the study area.

The hydrogeologic framework and ground-water system in the study area were described using data collected from a field inventory of 369 wells during 1995-96, along with data from 402 other previously inventoried wells in the U.S. Geological Survey computer data base. Ground-water recharge was estimated using a water-budget model with data collected for 22 months (December 1995 to September 1997); daily precipitation was measured at five sites, and periodic measurements of staff-gage heights and streamflow were made at 74 sites in the irrigation-ditch system. The relation between ground water and streams was investigated by measuring discharges at several sites in the Dungeness River and 15 other streams in the study area. The magnitude and distribution of nitrate were described using chemical analyses of water samples collected from 74 wells during July–August 1996. Analyses were made for ammonia, ammonia plus organic nitrogen, nitrite, nitrate, chloride, iron, specific conductance, temperature, pH, and dissolved oxygen.

The Sequim-Dungeness area is underlain by as much as 2,000 feet (ft) of unconsolidated Quaternary deposits that are mostly of glacial origin. Beneath these unconsolidated deposits is bedrock, which is composed of consolidated rocks mostly of Tertiary age. Interpretation of 10 hydrogeologic cross sections and lithologic logs of about 600 wells resulted in the delineation of six hydrogeologic units in the unconsolidated deposits. There are three aquifers, two confining beds, and a lower unit of undifferentiated deposits. A bedrock unit at the bottom is considered the base of the ground-water system.

The shallow aquifer at the top of the sequence of hydrogeologic units covers almost the entire study area, has a typical thickness of about 100 ft, and provides water to about 75 percent of the study wells. The middle aquifer covers about 60 percent of the study area, has a typical thickness of about 40 ft, and provides water to about 15 percent of the study wells. The lower aquifer probably covers about half the study area, has a typical thickness of about 90 ft, and supplies only about 5 percent of the study wells.

Ground-water flow directions are similar in all three aquifers; water generally flows from south to north, where it discharges into the Strait of Juan de Fuca. In the southern part of the study area, vertical flow between aquifers is mostly downward, and in the northern part, flow is mostly upward.

Ground water in the study area is recharged from infiltration and percolation of precipitation, percolation of unconsumed irrigation water, leakage from irrigation ditches, subsurface inflow through the southern study-area boundary, and leakage from streams. Depending on the location within the study area, one of these sources may dominate over the others. Recharge to the shallow aquifer was estimated in this study; the amount of vertical flow between aquifers was not estimated.

Average annual recharge for the study period (December 1995 to September 1997) was estimated to be 17.7 inches (in.). (151 cubic feet per second (ft^3/s)). About half the recharge is from precipitation inside the study area (8.6 in. or 74 ft^3/s) and about half is from sources outside the study area. Contributions from outside the study area were 2.7 in. (23 ft^3/s) from subsurface inflow, 3.1 in. (26 ft^3/s) from irrigation, and 3.3 in. (28 ft^3/s) from leakage from the Dungeness River. The 8.6 in. of recharge from precipitation is much higher than would be expected in an average year because average annual precipitation during the study period was about 28 in., which is 1.35 times higher than long-term average precipitation. The long-term average annual recharge from precipitation was estimated to be 5.4 in. (48 ft^3/s).

Ground water discharges as subsurface flow to saltwater bodies, flow to streams, flow to springs, and as withdrawals from wells. Subsurface flow to saltwater bodies and flow to springs were not estimated in this study. Estimated average annual discharge was 3.2 in. (27 ft^3/s) to the Dungeness River and 4.6 in. (39 ft^3/s) to other streams in the study area. Assuming that natural ground-water recharge and discharge are in equilibrium, the discharge to the Dungeness River and other streams accounts for about 44 percent of the total natural discharge. Gross withdrawals from wells for 1996 were estimated to be 1.0 in. (8.4 ft^3/s or 6,055 acre-ft). Estimated net withdrawals (pumpage minus return flow from septic systems) were 0.6 in. (5.2 ft^3/s or 3,740 acre-ft).

There was a small but statistically significant increase in nitrate concentrations in ground water from 1980 to 1996. Median concentrations in the primary study area were 0.37 mg/L in 1980 and 0.46 mg/L in 1996. The areal pattern of elevated nitrate concentrations has not changed during the past 15 years. Elevated concentrations as high as 4.3 mg/L are present in a large area east of the Dungeness River and north of Bell Creek, and scattered elevated concentrations as high as 3.9 mg/L are present in the area west of the Dungeness River and east of McDonald Creek.

About 543,200 pounds of nitrogen are estimated to enter the ground-water system in the primary study area each year. Four sources that account for about 85 percent of the nitrogen appear to provide roughly equivalent amounts of nitrogen. Residential fertilizers produce about 129,000 pounds of nitrogen, septic systems produce about 114,000 pounds, mineralization of soil organic matter produces about 112,000 pounds, and agricultural fertilizers produce about 107,000 pounds. Most of the remaining nitrogen is from dairy farms, which produce about 42,000 pounds of nitrogen.

Concentrations of nitrate in the shallow aquifer were significantly higher under residential areas than under natural grasslands or forests. Shallow ground water under agricultural areas also had higher nitrate concentrations than shallow ground water under natural grasslands or forests, but the difference was not statistically significant. Median nitrate concentrations were 1.3 mg/L under residential areas, 0.55 mg/L under agricultural areas, and 0.12 mg/L under natural grasslands or forests.

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APPENDIX A. Physical and Hydrologic Data for the Study Wells

APPENDIX A. PHYSICAL AND HYDROLOGIC DATA FOR THE STUDY WELLS

EXPLANATION

Project number:	1, this study; 2, previous study.
Hydrogeologic unit:	1, shallow aquifer; 2, upper confining bed; 3, middle aquifer; 4 lower confining bed; 5, lower aquifer; 6, undifferentiated unconsolidated deosits; 7, bedrock; 8, miltiple units; --, not determined.
Land-surface altitude:	Feet above sea level.
Well depth:	Depth of casing and screen, in feet below land surface; --, not known.
Casing diameter:	Diameter of casing at land surface; --, not known.
Water use:	C, commercial; H, domestic; I, irrigation; P, public supply; Q, aquaculture; S, stock; U, unused; Z, other; --, not known.
Water level:	Feet, feet below land surface; Date, month-day-year; 00, month or day not known; Source: GS, U.S. Geological Survey; OG, other government agency; DR, driller; GL, geologist; --, not determined.
Yield:	--, not determined.
Drawdown:	--, not determined.
Horizontal hydraulic conductivity:	--, not determined.
Remarks:	C, used in hydrogeologic cross section; L, driller's (lithologic) log available; Q, sample collected for water quality; 1, collected in 1996; 2, collected in 1980, collected both in 1980 and n 1996; R, inventoried both in late 1970's and 1995–96; W, water-level observation well with measurements; 1, monthly during study and in late 1970's; 2, monthly during study; 3, once every three months during study and in late 1979; 4, early 1990's and late 1970's; --, no remarks.

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
29N/02W-04C01	2	2	490	250	6	H	140	04-15-78	DR	0.7	--	--	L
29N/02W-04C02	1	1	480	129	6	H	84.3	11-01-95	GS		4		351.7L
29N/02W-04D01	1	1	460	127	6	H	69.6	03-12-96	OG	45	6	52	L,W2
29N/02W-05D01	1	5	280	312	6	H	246.4	11-02-95	GS	13	52	13	C,L1
29N/02W-05E01	1	5	280	381	6	H	249.5	03-14-96	GS	--	--	--	C,L1
29N/02W-05L01	2	1	400	89	6	H	35	08-13-77	DR	1.5	0	--	L
29N/02W-05L02	2	2	360	136	6	H	114	07-09-77	DR	8	7.3	15	L
29N/02W-05L03	2	8	350	266	6	H	150	02-27-74	DR	2	--	--	L
29N/02W-05M02	1	5	300	263	6	H	237.1	03-14-96	GS	12	11	12	C,L1
29N/02W-06B01	2	1	140	47	6	H	33	08-08-77	DR	10	10	--	L
29N/02W-06C01	1	3	160	205	6	H	180	12-05-77	DR	12	7	100	L,R
29N/02W-06F01	2	1	110	30	6	H	9	04-14-77	DR	4	18	--	L
29N/02W-06F02	1	2	100	101	6	H	78	07-25-95	DR	--	--	--	L
29N/02W-06G01	1	3	200	158	6	H	141	04-29-95	DR	8	0	--	L
29N/02W-06K01	1	1	140	76	6	H	55.6	03-14-96	GS	--	--	--	L
29N/02W-06L01	2	1	110	101	6	H	48	03-31-77	DR	10	--	--	L
29N/02W-07C02	1	1	225	119	6	H	63	03-13-96	GS	--	--	--	C,L1
29N/02W-07C03	1	1	180	95	6	H	67.3	03-13-96	GS	16	8	--	L,Q1
29N/02W-07D01	2	5	160	257	6	H	172	10-13-75	DR	4	--	--	C,L
29N/03W-01H02	2	1	45	42	6	H	--	--	--	--	--	--	--
29N/03W-01J01	1	1	20	94	6	H	26	11-15-73	DR	20	--	--	L,R
29N/03W-01J02	2	3	120	181	6	H	118	02-03-77	DR	10	50	11	L
29N/03W-02J01	2	1	50	22	6	H	14.3	07-22-68	GS	--	--	--	--
29N/03W-03E01	2	1	575	120	6	H	70	07-06-78	DR	5	29	3	L
29N/03W-03F01	2	1	575	115	6	H	60	07-28-78	DR	10	40	2.3	L
29N/03W-03Q01	2	1	590	185	--	U	--	--	--	--	--	--	L
29N/03W-03Q02	2	1	590	175	6	H	147	10-19-74	DR	2.5	28	--	L
29N/03W-03Q05	1	1	620	116	6	H	102.3	10-12-95	GS	6	3	27	L
29N/03W-03Q06	1	3	580	313	6	H	276.3	03-15-96	GS	--	--	--	L
29N/03W-04D01	2	1	675	121	6	H	112	08-09-60	DR	8	3.5	140	L
29N/03W-04K01	1	1	710	79	6	H	45	03-02-95	DR	7	29	--	L
29N/03W-04L03	1	1	860	106	6	H	73	08-26-87	DR	6	20	18	L
29N/03W-05B01	2	1	710	169	6	H	132	09-09-75	DR	15	7.1	--	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
29N/03W-05B02	2	1	700	189	6	H	90	06-28-74	DR	18	78	6	L
29N/03W-05B03	2	1	705	161	6	H	126	05-05-78	DR	10	--	--	L
29N/03W-05C01	2	1	720	77.5	6	H	58	08-15-77	DR	6	5	74	L
29N/03W-05C02	2	1	740	76	6	H	--	--	--	10	16	38	L
29N/03W-05D01	2	1	720	188	6	H	108	09-15-81	DR	0.3	--	--	C,L
29N/03W-05E01	2	1	850	112	6	H	Flowing	--	DR	3	100	--	C,L
29N/03W-05F02	2	1	800	59	6	H	40	10-02-77	DR	2	11	3.6	L
29N/03W-12A02	2	1	30	97	6	H	16	10-31-78	DR	30	45	41	L
29N/03W-12D01	2	1	15	25	1.5	H	--	--	--	--	--	--	--
29N/03W-12F02	2	1	20	27.5	6	H	13.1	07-06-78	GS	3	12	15	L
29N/03W-12G01	1	1	10	62	6	H	Flowing	11-29-90	GS	--	--	--	C,L,Q1
29N/03W-12H01	2	1	8	45	6	H	-9	10-10-77	DR	20	14	--	L
29N/03W-12L01	2	1	12	25	6	H	7	01-08-75	DR	15	--	--	L
29N/03W-12M01	2	1	40	52	6	H	38	07-22-77	DR	10	5.9	100	L
29N/03W-12M02	1	1	60	66	6	U	14.1	03-14-96	GS	50	15	44	L
29N/03W-12P01	1	1	40	62	6	H	9.6	03-14-96	GS	36	30	14	C,L
29N/04W-01B01	2	7	790	203	6	H	10	03-12-75	DR	2	200	0.013	L,Q2
29N/04W-01M01	1	1	465	21	6	H	9.6	03-11-96	OG	8	1	490	L,Q2,R,W1
29N/04W-02C01	2	1	501	25	6	H	5.2	03-20-79	GS	3	--	--	L,Q2,W4
29N/04W-03C02	2	7	880	322	6	P	--	--	--	--	--	--	L
29N/04W-03C03	2	7	890	446	--	P	--	--	--	--	--	--	C,L
29N/05W-03C01	2	1	1,100	75	6	H	31	09-25-76	DR	7	--	--	L
29N/05W-04B01	1	7	1,150	444	6	P	89.8	03-13-96	GS	--	--	--	C,L
29N/05W-04B02	1	1	1,125	108	5	P	89.9	03-13-96	GS	--	--	--	C,L
29N/05W-04N02	2	8	1,050	300	6	U	93	06-30-78	DR	7	--	--	L
30N/02W-15L01	2	1	75	90	6	P	85	08-07-75	DR	--	--	--	--
30N/02W-15L02	1	1	40	113	4	U	55	11-17-68	DR	5	30	15	L,R
30N/02W-15L03	2	1	40	92	--	U	--	--	--	20	--	--	--
30N/02W-15P02	2	1	12	10	24	H	--	--	--	12	2.5	--	L
30N/02W-17G01	1	--	240	1,000	6	U	86	07-12-77	OG	--	--	--	C,L,R
30N/02W-17R01	1	3	325	321	6	U	301	05-31-91	DR	--	--	--	C,L
30N/02W-20A01	1	3	280	280	6	U	144	05-28-90	DR	--	--	--	C,L
30N/02W-20G01	1	5	395	561	6	U	384	06-13-91	DR	--	--	--	C.L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/02W-20K01	1	5	405	420	6	N	368.1	08-27-75	GS	10	1.5	430	C,L,R
30N/02W-21Q01	1	5	290	393	8	P	271.5	03-15-96	GS	310	27	190	L,R
30N/02W-21Q02	1	5	290	392	8	P	270.5	03-15-96	GS	--	--	--	C,L,R
30N/02W-22M01	1	3	250	262	6	U	246	09-19-74	DR	30	4	460	C,L,R
30N/02W-28B01	1	3	220	188	6	H	174	02-20-82	DR	12	0	--	L
30N/02W-28G01	1	1	95	67	6	H	57	11-17-95	DR	15	2	460	L
30N/02W-28M04	1	1	120	122	6	P	67	08-07-75	GS	--	--	--	L
30N/02W-28M06	1	3	120	178	6	P	87	03-14-96	OG	--	--	--	C,L,W2
30N/02W-28M07	1	5	120	340	8	P	106.8	03-14-96	OG	--	--	--	C,L,W2
30N/02W-28N03	1	1	140	138	6	H	79	12-03-89	DR	--	--	--	C,L,Q1
30N/02W-29G01	1	5	200	322	8	I	193	05-07-84	DR	50	44	15	C,L
30N/02W-30D01	1	3	320	270	6	U	250.8	03-13-96	GS	7.5	0	--	C,L
30N/02W-30D02	1	5	320	340	6	H	312	11-11-91	DR	10	3	96	C,L
30N/02W-31C02	1	5	315	335	6	H	312	03-14-96	GS	20	5	--	C,L
30N/02W-31H04	1	5	195	290	6	H	168.7	03-12-96	OG	10	--	--	C,L,W2
30N/02W-31J02	1	1	185	118	6	H	104	03-12-96	GS	8	0	--	C,L,Q1
30N/02W-31J03	1	3	190	181	6	H	158	03-12-96	GS	5	72	4.3	C,L
30N/02W-32A01	2	2	175	176	6	H	153	10-12-78	DR	10	3	200	L
30N/02W-32C01	1	3	190	172	6	H	146.9	03-11-96	GS	10	10	--	L,R
30N/02W-32F01	1	8	190	289	8	U	149	03-04-90	DR	--	--	--	C,L
30N/02W-32L01	2	1	200	28	6	U	13	08-12-74	DR	15	2.9	120	L
30N/02W-32L02	2	3	205	183	6	H	157	08-21-74	DR	15	5	320	L
30N/02W-32L03	2	4	200	210	6	H	175	07-08-78	DR	12	8	92	L
30N/02W-32P02	1	5	220	282	6	H	205	06-26-93	DR	10	--	--	C,L
30N/02W-32Q01	2	3	325	147	6	H	130	04-20-76	DR	10	7.1	--	L
30N/02W-32Q03	2	5	320	271	6	H	260	07-21-78	DR	10	3	200	L
30N/02W-32Q04	1	5	280	256	6	H	222.4	03-11-96	GS	12	6	97	C,L
30N/02W-33D01	1	1	145	61	6	H	39	11-07-96	GS	15	--	--	C,L,R
30N/02W-33H01	1	1	200	98	6	U	4.2	11-06-96	GS	20	66	3.4	C,L
30N/02W-33M01	1	3	325	163	6	H	143	04-19-74	OG	10	--	--	C,L,R
30N/02W-33M02	1	3	300	150	6	H	126.5	03-14-96	GS	20	0	--	C,L
30N/02W-34C01	1	1	20	72	6	U	19	10-01-68	GS	--	--	--	C,L
30N/02W-34E01	1	7	235	242	6	U	8	10-20-93	DR	--	--	--	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
30N/02W-34E02	1	--	240	105	6	U	--	--	--	--	--	--	L
30N/02W-34E03	1	7	240	143	4	H	26	04-29-96	DR	--	--	--	C,L
30N/02W-34H02	1	7	160	340	6	U	--	--	--	10	--	--	C,L
30N/03W-05B02	2	1	5	10	16	H	5.1	07-07-78	GS	--	--	--	Q2
30N/03W-05B05	2	3	10	154	6	H	-35	08-18-80	DR	30	41	310	L
30N/03W-05B07	1	3	5	214	6	H	-21	05-03-92	DR	--	--	--	L
30N/03W-05G01	1	5	15	402	6	H	-21	10-01-91	DR	60	42	88	L
30N/03W-05G01D1	1	5	15	424	6	H	-20	03-06-92	DR	35	20	54	L
30N/03W-05H01	2	1	8	30	6	H	7.3	07-07-78	GS	--	--	--	--
30N/03W-05H02	1	1	11.8	31	6	H	4.4	03-11-96	GS	40	--	--	L,Q3,R
30N/03W-05H04	1	3	5	215	6	H	-12	05-02-86	DR	--	--	--	L
30N/03W-05M01	2	1	75	75	6	H	55	05-21-74	DR	20	--	--	L
30N/03W-05N01	2	1	40	22	3	U	13	11-13-74	DR	--	--	--	L
30N/03W-05N02	2	1	50	20	3	U	15	11-13-74	DR	--	--	--	L
30N/03W-05Q01	2	1	30	58	8	P	3	07-13-79	DR	180	9.5	330	L
30N/03W-05Q02	2	1	30	58	8	U	4	05-26-80	DR	182	1.1	3,500	L
30N/03W-05R01	1	1	20.6	38	10	I	5.3	03-11-96	GS	600	9	740	L,R,W3
30N/03W-05R02	2	3	23	238	6	P	--	--	--	40	--	--	L
30N/03W-06B01	1	1	15	85	6	U	-20.5	03-11-96	GS	50	12	57	L,Q1
30N/03W-06C01	2	1	30	7.3	36	U	3	07-21-60	DR	--	--	--	L
30N/03W-06H04	2	1	40	92	6	P	21	12-05-74	DR	225	27	290	L,Q2
30N/03W-06K04	1	1	90	105	6	H	83.4	03-13-96	GS	20	6	96	L
30N/03W-06M01	1	1	118	105	6	H	82.5	03-11-96	OG	30	0	--	L,Q2,R,W1
30N/03W-06M03	2	1	130	120	6	H	99	02-09-78	DR	15	--	--	L
30N/03W-06M04	2	1	125	109	6	H	78	06-27-77	DR	20	--	--	L
30N/03W-06M12	1	1	150	151	6	H	116.7	03-13-96	GS	30	1	--	C,L
30N/03W-06N01	2	1	105	138	9	H	65	05-02-72	DR	9	15	--	C,L
30N/03W-06N02	1	1	110	96.6	6	H	73.8	03-12-96	GS	22	0	--	L,R
30N/03W-06R01	2	1	55	22	6	H	18	00-00-50	DR	--	--	--	L
30N/03W-06R02	1	1	45	45	6	H	23.8	03-12-96	GS	20	5	250	L,Q3,R
30N/03W-07A01	2	1	60	32	--	H	19	08-08-60	GS	--	--	--	L,Q2
30N/03W-07A02	2	1	55	20	--	U	--	--	--	--	--	--	L
30N/03W-07C01	2	1	80	80	--	U	--	--	--	--	--	--	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
30N/03W-07C02	1	3	100	207	6	H	34	11-16-88	DR	50	45	64	C,L
30N/03W-07D01	2	1	102	130	6	H	75	10-00-58	DR	20	10	120	C,L,Q2
30N/03W-07D02	2	1	105	80	--	U	--	--	--	--	--	--	L
30N/03W-07L01	2	1	100	46	8	H	27	08-08-60	DR	200	2	4,600	L
30N/03W-07M01	2	1	82	42.5	6	H	4	08-16-77	GS	35	15	65	L,Q2
30N/03W-07M02	1	3	90	194	6	H	8.3	03-11-96	GS	25	10	150	C,L
30N/03W-07N01	2	1	103	41	6	H	8	06-06-77	DR	50	5	--	L
30N/03W-07N02	2	1	100	38	6	H	--	--	--	30	4	460	L
30N/03W-07N03	2	1	115	48	6	H	12	05-08-78	DR	20	5	200	L
30N/03W-07N07	1	1	110	98	6	H	15	01-22-92	DR	15	70	3	C,L
30N/03W-07P02	2	1	115	52	6	H	41	05-18-78	DR	9	0	--	L
30N/03W-07P03	1	1	107	74	6	H	14.4	03-11-96	OG	20	61	20	L,Q2,R,W1
30N/03W-07Q03	1	1	120	116	6	H	53.9	03-15-96	GS	14	28	12	C,L,Q1
30N/03W-07R01	2	1	118	35	6	I	16.9	06-14-60	GS	--	--	--	
30N/03W-08B01	1	1	34.4	51.5	10	I	8.3	03-11-96	GS	250	16	280	L,Q1,R
30N/03W-08C01	2	1	35	30	--	H	--	--	--	--	--	--	L,Q2
30N/03W-08C02	2	1	45	50	--	U	--	--	--	--	--	--	L
30N/03W-08C03	1	1	35	124	10	P	8.9	03-11-96	GS	705	15.3	510	L,R
30N/03W-08F01	1	5	100	330	10	U	63.8	03-11-96	GS	75	9	--	L,R
30N/03W-08J01	2	1	115	90	--	U	--	--	--	--	--	--	L
30N/03W-08J02	2	1	115	120	--	U	--	--	--	--	--	--	L
30N/03W-08J03	1	5	121	340	8	I	84.7	07-19-95	GS	170	170	8.6	L,R,W4
30N/03W-08K01	2	1	115	120	--	U	--	--	--	--	--	--	L
30N/03W-08K02	2	1	115	100	--	U	--	--	--	--	--	--	L
30N/03W-08M01	1	3	120	250	10	P	82.5	08-04-95	GS	600	33	120	L,Q3,R
30N/03W-08P03	1	3	120	144	6	H	60	04-30-66	DR	35	1	--	L
30N/03W-08R01	2	1	116	84	--	H	--	--	--	5	--	--	--
30N/03W-08R02	1	3	115	201	6	H	78.5	03-14-96	GS	--	--	--	C,L
30N/03W-08R03	1	3	110	239	6	H	91	04-20-93	DR	--	--	--	C,L
30N/03W-09D01	1	1	20	11	10	H	Flowing	09-01-95	GS	--	--	--	--
30N/03W-09K01	2	1	100	40	6	H	--	--	--	--	--	--	L,Q2
30N/03W-09Q01	2	1	105	70	--	U	--	--	--	--	--	--	L
30N/03W-09R01	1	5	105	579	8	I	79.1	03-12-96	GS	195	83	42	C,L,Q1,W2

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/03W-10N01	2	3	50	310	6	H	--	--	--	--	--	--	Q2
30N/03W-13P01	2	1	100	67	7.6	U	22	06-16-77	DR	20	43	5.9	L
30N/03W-15D01	2	1	95	70	--	U	--	--	--	--	--	--	L
30N/03W-15G01	1	5	20	574	8	H	Flowing	03-15-96	GS	100	--	--	C,L,Q3,R
30N/03W-16B01	2	1	104	39	6	H	--	--	--	--	--	--	--
30N/03W-16B02	2	1	104	27.8	36	U	26	06-14-60	GS	--	--	--	Q2
30N/03W-16B03	1	1	105	113	6	H	73	05-05-76	DR	15	28	33	C,L,R
30N/03W-16C01	2	2	111	184	6	H	73.8	03-22-79	GS	36	28	47	L,Q2
30N/03W-16C02	2	1	113	90	--	H	25	11-26-74	DR	20	33	1.7	Q2
30N/03W-16C06	1	3	115	239	6	H	80	07-06-91	DR	20	60	17	C,L
30N/03W-17B02	2	3	130	156	6	H	76	04-06-78	DR	55	--	--	L
30N/03W-17B06	1	3	125	157	6	H	76.5	03-14-96	GS	25	--	--	C,L
30N/03W-17D01	2	1	104	79.4	6	H	22	04-17-78	DR	50	--	--	L
30N/03W-17D02	1	1	97.4	74	6	H	19.2	03-01-96	OG	30	--	--	L,Q3,R,W3
30N/03W-17E02	1	3	120	133	6	H	47.6	03-12-96	GS	--	--	--	L
30N/03W-17F01	2	1	108	32	6	H	--	--	--	--	--	--	L,Q2
30N/03W-17F02	1	5	110	320	10	U	54.9	03-11-96	GS	375	145	23	C,L
30N/03W-17F03	1	5	105	417	12	P	50	10-11-95	OG	--	--	--	C,L
30N/03W-17G01	2	--	85	7,490	--	U	--	--	--	--	--	--	L
30N/03W-17M01	1	1	120	37	6	H	13.1	03-14-96	GS	25	13	120	L,Q3,R
30N/03W-17P01	1	1	140	55	6	H	8.9	03-14-96	GS	--	--	--	L,Q1
30N/03W-18A03	1	1	115	96	6	H	24.8	03-12-96	OG	--	--	--	C,L,R,W1
30N/03W-18E06	1	1	150	41	6	H	18	03-11-96	GS	50	10	--	L,Q3,R
30N/03W-18F03	1	1	144	38	6	H	20.5	03-11-96	OG	40	6	410	L,Q2,R,W1
30N/03W-18F04	2	1	135	42	6	H	6	12-09-76	DR	50	10	310	L
30N/03W-18G03	1	5	135	330	8	P	46.4	07-14-95	GS	--	--	--	C,L
30N/03W-18G04	1	1	140	76.7	8	P	23.4	07-14-95	GS	--	--	--	L
30N/03W-18M03	1	1	165	50	6	H	14	10-23-75	DR	40	17	140	L,Q3,R
30N/03W-18N02	2	1	185	50	--	U	--	--	--	--	--	--	--
30N/03W-18N03	1	2	170	133	6	H	48.6	03-11-96	GS	--	--	--	C,L
30N/03W-18R02	2	1	150	28	6	H	8	09-22-75	DR	15	12	77	L,Q2
30N/03W-19C01	2	1	180	70	--	U	--	--	--	--	--	--	L
30N/03W-19D01	1	1	208	49	6	H	44.8	03-11-96	OG	35	15	140	L.O2.R.W1

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/03W-19M02	2	2	240	165	6	H	84	02-25-71	DR	30	4	147	C,L
30N/03W-19M03	1	2	240	158	6	H	90	08-31-93	DR	--	--	--	L
30N/03W-19P01	2	3	250	207	6	H	112	03-10-86	DR	20	70	18	C,L
30N/03W-20A01	2	1	110	34	6	H	12	08-08-60	DR	10	--	--	L
30N/03W-20B01	2	1	140	23.2	6	S	--	--	--	--	--	--	Q2
30N/03W-20C01	2	1	145	50	42	H	--	--	--	300	10	260	L
30N/03W-20C02	2	1	135	36	6	H	10	05-08-71	DR	60	3	1,200	L,Q2
30N/03W-20D01	1	2	140	150	6	U	37.8	03-13-96	GS	--	--	--	L
30N/03W-20E01	2	1	172	71.2	5	I	22.2	10-03-78	GS	60	--	--	L,Q2
30N/03W-20K01D1	1	1	145	121	6	H	19.6	03-14-96	GS	30	40	18	C,L,Q1
30N/03W-20N01	2	3	215	156	6	H	80	06-09-76	DR	20	5	250	L
30N/03W-20Q01	2	3	160	236	6	P	19.1	10-06-78	GS	30	42	18	L
30N/03W-20R02	2	1	160	60	--	U	--	--	--	--	--	--	L
30N/03W-21A01	1	1	100	46	6	H	-1.6	03-12-96	OG	20	10	120	L,Q3,R,W2
30N/03W-21H01	2	3	130	298	6	P	95	02-10-70	DR	19	40	29	L
30N/03W-21H02	2	3	125	265	6	H	113	05-21-74	DR	9	39	14	L
30N/03W-21K01	2	1	168	117	6	H	100.1	05-16-79	GS	17	0	--	L
30N/03W-21K03	1	3	147	280	6	H	106.5	03-12-96	OG	6	110	3.3	L,Q3,R,W4
30N/03W-21K04	1	2	160	178	6	U	133	08-02-93	DR	10	80	6.3	L
30N/03W-21K04D1	1	3	160	290	6	H	131.8	10-12-95	GS	12	61	12	C,L
30N/03W-21M01	2	1	120	117	6	H	13	10-06-75	DR	6	46	--	L,Q2
30N/03W-21Q01	1	--	160	180	6	U	--	--	--	--	--	--	L
30N/03W-21Q01D1	1	3	160	229	6	H	123.5	03-11-96	GS	10	90	6.8	C,L
30N/03W-22K01	2	--	10	355	5	H	-4	01-01-66	GS	20	43	57	Q2
30N/03W-22M04	1	3	170	332	6	H	140	07-18-93	DR	12	60	26	L
30N/03W-22N01	2	2	205	179	6	H	150	00-00-59	DR	5	15	20	L
30N/03W-22N02	1	1	240	134	6	H	125	03-11-96	GS	6	2	56	L
30N/03W-23H03	1	3	60	149	6	I	45.3	03-12-96	OG	300	160	110	L,Q1,R,W2
30N/03W-23H04	1	3	110	112	6	P	81.2	03-12-96	GS	92	1.5	2,600	C,L,W2
30N/03W-23H05	1	3	110	112	6	P	80	12-01-95	GS	--	--	--	--
30N/03W-23J01	1	3	70	150	6	U	49	11-15 62	DR	7	81	4.7	C,L
30N/03W-24C01	1	3	205	220	8	P	165	06-03-77	DR	125	6	390	C,L
30N/03W-24F01	1	3	210	200	6	H	172	04-25-90	DR	--	--	--	C,L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
30N/03W-24N01	2	1	30	25	6	H	7	12-10-74	DR	11	10	--	L
30N/03W-25G01	2	5	120	191	6	H	114	12-08-73	DR	8	12	50	L
30N/03W-25Q01	1	5	180	262	6	H	230	11-15-88	DR	4	20	9.9	L
30N/03W-25Q01D1	1	6	180	402	4	H	229.7	03-12-96	GS	2.5	113	2	C,L
30N/03W-25R01	1	5	320	320	6	H	297.3	03-12-96	GS	7	1.5	140	L
30N/03W-27B01	2	1	50	66	6	H	35	05-00-55	DR	9	12	46	L
30N/03W-27B02	2	1	40	64	8	H	25.3	08-08-60	GS	--	--	--	--
30N/03W-27B03	2	1	25	8	6	H	3	08-08-60	DR	--	--	--	L
30N/03W-27B04	1	1	100	65	6	H	47.6	02-23-79	GS	3	0	--	C,L,Q3,R
30N/03W-27C01	2	1	140	35	6	H	--	--	--	--	--	--	--
30N/03W-27C02	1	3	160	194	6	H	153.6	03-11-96	GS	--	--	--	L
30N/03W-27D03	1	3	220	240	6	H	198.9	03-11-96	GS	--	--	--	C,L
30N/03W-27F02	1	3	210	306	6	H	190.2	03-11-96	GS	--	--	--	C,L
30N/03W-27M02	2	1	220	120	--	U	--	--	--	--	--	--	L
30N/03W-27M03	2	1	210	120	--	U	--	--	--	--	--	--	L
30N/03W-27M04	2	1	200	120	--	U	--	--	--	--	--	--	L
30N/03W-27Q01	2	1	5	15	60	H	--	--	--	--	--	--	--
30N/03W-28A01	1	3	250	300	6	C	215.8	03-11-96	GS	--	--	--	C,L
30N/03W-28C01	2	1	175	104	6	H	28	03-24-79	DR	12	67	11	L,Q2
30N/03W-28C03	1	1	180	114	6	Z	95.8	03-12-96	OG	10	16	7.2	L,Q1,W2
30N/03W-28G02	1	1	250	76	6	U	57.9	03-11-96	GS	--	--	--	L
30N/03W-28P01	1	7	400	465	6	H	376	03-15-94	DR	1	84	0.027	L
30N/03W-29A01	2	1	220	113	6	H	90	06-00-74	DR	10	23	10	L,Q2
30N/03W-30C01	1	3	260	172	6	U	126.5	03-12-96	GS	--	--	--	C,L
30N/03W-30C02	1	3	280	185	6	P	124	04-13-79	DR	50	18	170	C,L
30N/03W-30D01	2	2	300	172	6	H	47	05-30-74	DR	20	65	--	C,L
30N/03W-30D02	2	1	300	20	6	H	--	--	--	--	--	--	R
30N/03W-30D03	2	1	300	100	6	H	47	04-02-76	DR	8	33	3.6	L
30N/03W-30H02	2	1	360	66	6	H	-4	02-20-75	DR	1	100	0.61	L
30N/03W-30K01	2	7	400	199	6	H	9	10-22-79	DR	4	200	0.027	C,L
30N/03W-30K03	1	1	390	64	6	H	34.4	03-20-79	GS	13	--	--	L,Q3
30N/03W-30Q05	1	1	500	90.5	6	H	35.1	08-25-95	GS	20	2	--	L
30N/03W-31D02	1	1	520	41	6	H	1.2	08-23-95	GS	40	15	160	L.O2.R

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/03W-31D04	1	1	520	44	6	H	0.4	12-15-93	DR	24	20	27	L
30N/03W-31H01	1	1	530	82	6	H	0	04-11-94	DR	--	--	--	L,Q1
30N/03W-31J01	2	1	580	12.4	--	H	9	08-09-60	DR	--	--	--	L
30N/03W-31J02	1	1	589	87	--	H	25.2	03-11-96	OG	--	--	--	R,W1
30N/03W-31K04	1	1	580	91.9	6	H	40	02-28-95	DR	26	24	27	L
30N/03W-31N01	2	7	640	200	6	H	--	--	--	--	--	--	C,L
30N/03W-31R01	1	3	662	171	6	H	113.8	03-11-96	OG	8	47	10	C,L,Q2,R,W1
30N/03W-32D04	2	7	500	270	--	U	Dry	11-17-80	DR	--	--	--	C,L
30N/03W-32E01	1	1	540	118	6	U	-22	03-14-96	GS	80	25	45	C,L
30N/03W-32E02	1	1	540	123	8	U	--	--	--	--	--	--	L
30N/03W-32M01	1	1	580	81	6	U	4	03-13-96	GS	--	--	--	L
30N/03W-32N01	2	1	710	139	6	H	--	--	--	--	--	--	C,L
30N/03W-32P01	1	1	640	120	6	H	65.4	03-13-96	GS	--	--	--	L
30N/03W-32Q01	1	3	660	201	6	H	100	11-11 67	DR	--	--	--	C,L
30N/03W-32R01	1	3	664	185	8	U	71.8	03-14-96	GS	385	5.5	550	C,L,R
30N/03W-32R02	1	--	660	173	--	H	71.7	03-14-96	GS	--	--	--	--
30N/03W-32R03	1	3	660	179	6	H	70.6	03-14-96	GS	60	0	--	L
30N/03W-32R04	1	3	660	199	6	H	68.7	03-14-96	GS	60	23	150	L
30N/03W-33A01	1	1	340	135	6	H	100.9	08-30-95	GS	2	32	3.8	L
30N/03W-33N01	1	1	640	101	6	P	64.2	08-31-95	GS	70	8.2	160	C,L,R
30N/03W-33N02	1	7	620	404	6	H	49	03-13-96	GS	--	--	--	C,L
30N/03W-33P01	1	3	640	150	6	H	114	03-13-96	GS	--	--	--	L,Q1,R
30N/03W-34A01	2	7	60	258	6	H	26	02-27-74	DR	15	170	0.13	L
30N/03W-34A03	2	7	60	285	6	H	21	03-12-74	DR	3	210	0.012	L
30N/03W-34D01	1	7	280	499	8	U	258	08-20-91	DR	13	2	6.2	L
30N/03W-34H01	2	7	70	265	6	H	125	02-20-74	DR	6	220	1.7	L
30N/03W-34M02	1	3	460	206	6	H	184	03-13-96	GS	5	10	9.9	C,L
30N/03W-34M03	1	3	460	238	6	H	--	--	--	20	--	--	L
30N/03W-34N01	1	7	540	640	6	H	249	12-15-94	DR	--	--	--	L
30N/03W-34N02	1	3	510	263	6	U	225	12-21-91	DR	--	--	--	C,L
30N/03W-35E01	2	7	60	370	6	H	22.9	07-06-78	GS	4	--	--	L
30N/03W-35M03	1	3	20	81.6	6	H	47	05-19-75	DR	1	6	2.8	C,L,R
30N/03W-36B01	1	5	240	285	6	H	238	03-11-96	GS	15	15	22	C,L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/03W-36F02	2	1	85	86.6	6	H	64	11-19-75	DR	15	3	160	L
30N/03W-36K01	2	1	80	123	6	H	80	06-21-78	DR	18	8.2	65	L
30N/03W-36L01	1	2	60	118	6	H	80.1	03-14-96	GS	3	14	13	L,Q1,R
30N/03W-36L02	2	1	60	77	6	H	51	10-28-75	DR	5	23	4.2	L
30N/03W-36L03	1	1	90	117	6	H	94	03-08-84	DR	--	--	--	L
30N/04W-01C01	2	1	80	60	--	U	--	--	--	--	--	--	L
30N/04W-01F01	2	1	60	100	--	U	--	--	--	--	--	--	L
30N/04W-01F02	2	1	110	90	--	U	--	--	--	--	--	--	L
30N/04W-01J03	2	1	120	141	6	H	110	06-08-77	DR	20	--	--	C,L
30N/04W-01J05	2	1	120	151	6	H	114	08-12-76	DR	20	--	--	L
30N/04W-01K01	2	1	140	142	6	H	--	--	--	40	10	250	L
30N/04W-01K03	2	1	125	93	6	H	71	07-11-77	DR	25	10	150	L
30N/04W-01K06	1	1	150	129	6	H	98	03-13-96	GS	--	--	--	L
30N/04W-01L01	2	1	75.3	70	6	P	24.3	03-21-79	GS	100	0	--	L,Q2
30N/04W-01L03	2	1	125	80	--	P	--	--	--	--	--	--	L
30N/04W-01L04	2	1	115	100	--	U	--	--	--	--	--	--	L
30N/04W-01M01	2	1	67.3	118	16	Q	6.9	04-25-79	GS	1,150	33	130	L,Q2,W1
30N/04W-01M02	1	1	73.2	130	16	Q	15.1	03-21-79	GS	--	--	--	L,R,W1
30N/04W-01M03	1	1	71.5	33	6	H	13.6	03-11-96	OG	30	2.5	--	L,R,W1
30N/04W-01M04	2	1	69	134	--	U	6	01-00-74	GL	--	--	--	L
30N/04W-01N01	2	1	81.4	39	6	H	10.7	03-21-79	GS	--	--	--	L,Q2
30N/04W-01N02	2	1	74.4	18	--	H	11	12-04-78	OG	--	--	--	--
30N/04W-01N03	2	1	82.1	23	6	H	10	12-04-78	OG	--	--	--	--
30N/04W-01N04	2	1	125	104	6	H	64	04-17-80	GS	30	20	92	L
30N/04W-01P03	1	1	125	101	6	H	69.1	03-13-96	GS	--	--	--	L
30N/04W-01R01	1	1	120	94	6	H	72	03-12-96	GS	--	--	--	L,Q1
30N/04W-02D01	2	1	70	40	--	U	--	--	--	--	--	--	L
30N/04W-02E03	1	3	68	228	6	H	-20	03-15-96	GS	12	--	--	L
30N/04W-02M01	2	1	70	50.7	7	H	9	08-10-60	OG	--	--	--	L
30N/04W-02M05	1	3	75	239	6	H	-12.7	03-15-96	GS	20	150	--	L,Q3,R
30N/04W-02N02	1	3	90	180	6	H	Flowing	09-27-78	DR	30	30	57	L,R
30N/04W-02P01	2	1	82	9.5	28	H	5	08-08-60	OG	50	4.2	160	L,Q2
30N/04W-02R01	1	1	77.1	62	12	I	10.2	03-12-96	OG	500	11	870	L.R.W3

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-03D01	2	1	85	56.2	6	H	24	03-29-78	DR	30	--	--	L,Q2
30N/04W-03D02	2	1	90	72.5	6	H	39	12-20-78	DR	55	45	75	L
30N/04W-03D02D1	1	3	90	208	6	H	10.4	03-13-96	GS	55	45	75	C,L
30N/04W-03H01	2	1	72	40	--	H	3	08-09-60	OG	--	--	--	L
30N/04W-03H02	2	1	89	74.5	6	H	36	10-11-76	DR	20	0	--	L
30N/04W-03H03	1	1	86.1	61	6	H	24.5	03-12-96	OG	25	4	310	L,Q3,R,W1
30N/04W-03H04	2	1	86	56	6	H	27	08-03-78	DR	10	0	--	L
30N/04W-03H05	2	1	71	65	6	H	--	--	--	60	2	1,800	L
30N/04W-03H07	2	3	80	228	6	--	--	--	--	--	--	--	C,L
30N/04W-03J01	1	3	76	178	6	U	-0.3	03-11-96	GS	6	--	--	L,R
30N/04W-03L01	1	--	120	250	6	H	46.4	03-14-96	OG	--	--	--	W2
30N/04W-03P01	2	8	120	188	6	H	16	09-05-75	DR	10	--	--	C,L
30N/04W-03Q01	1	3	108	249	8	P	7.6	03-21-79	GS	40	20	--	C,L,Q3,R
30N/04W-04E01	1	1	100	141	6	H	82.7	03-13-96	GS	--	--	--	L
30N/04W-04L02	1	1	121	56	6	H	41.9	07-20-95	GS	10	--	--	L,Q3,R
30N/04W-04N01	1	1	124	51	6	H	32.5	03-11-96	OG	--	--	--	R,W1
30N/04W-04P01	2	1	123	48	6	S	32.9	06-15-60	GS	--	--	--	--
30N/04W-04R01	1	1	125	86	8	H	41	12-23-74	DR	258	18	250	L,R
30N/04W-04R01D1	1	5	125	462	8	H	57	03-03-83	DR	225	31	88	L
30N/04W-04R02	1	8	125	607	6	H	58	11-24-82	DR	201	17	--	C,L
30N/04W-05G03	1	3	100	198	6	H	84.5	03-12-96	GS	--	--	--	C,L
30N/04W-05J01	1	1	118	117	6	H	75.2	07-21-95	GS	30	6	--	L,Q3,R
30N/04W-05J02	2	1	110	111	6	H	63	12-18-76	DR	30	--	--	L,Q2
30N/04W-05L01	2	1	116	126	6	H	116	09-01-64	DR	5	--	--	L
30N/04W-05L02	2	1	80	92	6	H	--	--	--	--	--	--	--
30N/04W-05M01	2	1	120	108	5	H	--	--	--	--	--	--	Q2
30N/04W-05N01	2	1	128	95.4	6	H	81	01-00-60	DR	--	--	--	L
30N/04W-05P01	1	2	120	161	6	P	126	04-14-73	DR	25	20	77	L,Q3,R
30N/04W-05R01	1	3	130	289	6	H	64	03-12-96	GS	20	23	46	C,L
30N/04W-07A01	1	1	140	77	6	H	65.4	12-11-96	GS	--	--	--	--
30N/04W-07F01	2	1	148	70.7	6	H	64	07-19-60	OG	--	--	--	L,Q2
30N/04W-07G01	2	1	150	221	8	P	103	06-01-71	DR	250	69	5.8	L
30N/04W-07G02	2	1	150	221	8	P	131	08-30-76	DR	104	42	3	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-07K01	2	1	170	96	6	H	--	--	--	--	--	--	L
30N/04W-07L01	1	1	156	92	6	H	62.4	03-01-96	OG	30	--	--	L,Q3,R,W3
30N/04W-07N01	1	3	167	281	6	H	95.8	03-01-96	OG	8	20	7.1	C,L,Q2,R,W3
30N/04W-07N02	2	3	170	267	6	I	105	12-07-68	DR	18	25	--	L
30N/04W-07P02	1	1	170	105	6	H	76.4	12-11-96	GS	--	--	--	L,R
30N/04W-07Q01	2	1	180	111	6	H	72	03-07-78	DR	10	13	47	C,L
30N/04W-07Q03	1	1	180	140	6	H	72.6	03-12-96	GS	--	--	--	L
30N/04W-07R02	1	5	175	458	8	P	135	03-13-96	GS	106	111	9.2	C,L
30N/04W-07R03	1	1	200	107	6	H	70.4	08-01-95	GS	--	--	--	L
30N/04W-08A02	1	1	132	136	6	H	57.3	03-12-96	GS	20	10	120	C,L,R
30N/04W-08E02	1	1	150	149	6	H	87.8	03-12-96	GS	24	20	74	C,L
30N/04W-08F02	1	5	140	555	8	P	101.3	03-18-96	OG	178	54	29	C,L,W2
30N/04W-08G01	2	1	140	98	6	H	59	05-00-60	DR	10	6	--	L
30N/04W-08J01	2	1	158	56	6	H	38	02-00-60	DR	17	13	--	L,Q2
30N/04W-08M01	2	1	155	70	--	U	--	--	--	--	--	--	L
30N/04W-08M03	2	1	172	102	--	H	49	02-17-77	OG	--	--	--	--
30N/04W-08M04	1	1	170	84	6	H	50.1	03-12-96	GS	18	49	6.2	C,L,Q3,R
30N/04W-08N01	1	1	180	106	6	H	52.8	12-18-96	GS	20	--	--	L,W2
30N/04W-08Q01	2	1	170	105	6	H	51	12-09-91	DR	--	--	--	C,L
30N/04W-08Q02	2	1	163	111	6	H	39	04-22-92	DR	--	--	--	L
30N/04W-09C02	2	1	130	100	--	U	--	--	--	--	--	--	L
30N/04W-09F01	2	1	130	105	--	U	--	--	--	--	--	--	L
30N/04W-09F02	2	1	135	100	--	U	--	--	--	--	--	--	L
30N/04W-09K01	2	1	140	21.8	6	H	10	07-22-60	OG	--	--	--	L,Q2
30N/04W-09L01	2	1	135	70	--	U	--	--	--	--	--	--	L
30N/04W-09L02	1	6	141	830	12	Z	85.8	03-12-96	GS	715	29	220	C,L,R
30N/04W-09N02	1	1	150	75	6	H	20.5	03-12-96	GS	35	18	55	C,L,Q3,R
30N/04W-09P01	2	1	145	50	--	U	--	--	--	--	--	--	L
30N/04W-09P02	2	1	145	50	--	U	--	--	--	--	--	--	L
30N/04W-09R01	2	1	130	50	--	U	--	--	--	--	--	--	L
30N/04W-10B02	1	3	125	201	6	H	22.1	03-11-96	GS	--	--	--	L
30N/04W-10B03	1	1	120	62	6	H	21	09-12-89	DR	10	15	41	L
30N/04W-10B03D1	1	3	120	199	6	H	26.5	08-31-95	GS	30	20	86	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-10C01	1	1	117	60	6	H	6	06-22-76	DR	25	33	--	C,L,Q3,R
30N/04W-10H01	1	1	99.4	38	6	H	0	03-11-96	OG	35	17	130	L,Q3,R,W1
30N/04W-10L01	2	1	120	22	6	H	--	--	--	--	--	--	--
30N/04W-10P01	2	1	125	10	3	H	5	00-00-50	DR	--	--	--	--
30N/04W-10Q01	2	1	120	50	--	U	--	--	--	--	--	--	L
30N/04W-10Q02	1	1	138	81	6	H	11	05-05-76	DR	65	12	170	C,L,Q3,R
30N/04W-11A01	2	1	81	45	H	12		04-28-74	DR	32	15	--	L
30N/04W-11J01	1	1	122	76	6	H	16.8	03-12-96	OG	20	--	--	L,Q3,R,W3
30N/04W-11L01	2	1	110	16	6	H	--	--	--	--	--	--	L,Q2
30N/04W-11L02	2	1	110	50	--	U	--	--	--	--	--	--	L
30N/04W-11L04	2	1	110	36	6	H	10	04-13-78	DR	35	10	210	L,Q2
30N/04W-11M01	1	1	116	110	6	H	1	06-10-92	DR	--	--	--	L
30N/04W-11M01D1	1	3	116	184	6	U	-0.5	03-13-96	GS	10	45	14	L
30N/04W-11M02	1	1	118	57	6	H	7.1	03-13-96	GS	--	--	--	L
30N/04W-11N01	2	1	125	50	--	U	--	--	--	--	--	--	L
30N/04W-11P01	2	1	115	50	--	U	--	--	--	--	--	--	L
30N/04W-11R06	2	1	130	22	6	H	8	02-18-78	DR	40	5	490	L,Q2
30N/04W-11R07	2	1	130	50	6	H	20	01-16-78	DR	10	15	41	L
30N/04W-12C01	2	1	125	100	--	U	--	--	--	--	--	--	L
30N/04W-12C02	2	1	125	100	--	U	--	--	--	--	--	--	L
30N/04W-12C07	1	1	89.2	65	6	H	22.2	03-12-96	GS	25	--	--	L,Q3,R
30N/04W-12E01	2	1	80	41	6	U	3	05-13-74	DR	25	--	--	L
30N/04W-12F01	2	1	135	82	6	H	47	11-11-76	DR	30	5	370	L,Q2
30N/04W-12F04	2	1	130	87	6	H	42	04-15-80	DR	30	25	74	L
30N/04W-12J01	1	2	110	177	6	U	24	04-26-91	DR	--	--	--	L
30N/04W-12J02	1	1	110	41	6	H	12	04-27-94	DR	--	--	--	L
30N/04W-12K01	1	1	110	26	6	H	6.4	03-11-96	OG	45	5	550	L,Q3,R,W1
30N/04W-12M01	2	1	115	13.5	18	I	--	--	--	120	--	--	L
30N/04W-12M02	1	1	116	60	6	H	15.9	03-13-96	GS	--	--	--	L
30N/04W-12Q01	2	1	118	21.5	10	I	6	07-02-60	DR	180	3.5	--	L
30N/04W-12R02	2	1	119	25	6	I	13	05-01-60	DR	180	--	--	L,Q2
30N/04W-12R03	2	1	120	138	6	H	8	09-28-86	DR	20	40	--	C,L
30N/04W-13A04	2	1	120	20	3	H	--	--	--	--	--	--	--

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydrogeologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-13B03	1	1	140	89	6	H	17.4	03-13-96	GS	25	3	--	L
30N/04W-13D01	2	1	132	24	4	H	--	--	--	--	--	--	Q2
30N/04W-13F03	2	1	145	42	6	H	--	--	--	20	0	--	L
30N/04W-13H01	2	1	157	30	6	H	--	--	--	--	--	--	--
30N/04W-13J01	2	1	159	50	6	H	--	--	--	25	--	--	--
30N/04W-13J04	2	1	155	45	6	H	6	07-25-74	DR	19	--	--	L,Q2
30N/04W-13K14	1	1	156	59	6	H	18.9	03-13-96	GS	--	--	--	L,Q1
30N/04W-13N01	2	1	180	49	6	H	18.1	09-21-78	GS	30	1.5	720	L,Q2
30N/04W-13Q01	2	1	190	36	6	H	--	--	--	--	--	--	--
30N/04W-13R09	1	1	189	89	6	H	32.3	03-13-96	GS	40	--	--	C,L,R
30N/04W-14B01	2	1	135	140	6	U	--	--	--	--	--	--	C,L
30N/04W-14C01	2	1	140	20.7	6	H	12	08-09-60	OG	--	--	--	L,Q2
30N/04W-14C02	2	1	135	60	6	H	17	08-29-75	DR	20	--	--	L
30N/04W-14C04	2	1	140	66	6	H	24	05-12-75	DR	25	28	55	L
30N/04W-14D01	2	1	135	50	--	U	--	--	--	--	--	--	L
30N/04W-14D02	2	1	145	50	--	U	--	--	--	--	--	--	L
30N/04W-14E01	2	1	150	46	--	U	--	--	--	--	--	--	L
30N/04W-14E02	2	1	155	50	--	U	--	--	--	--	--	--	L
30N/04W-14E03	1	1	164	65	6	H	28.3	03-13-96	GS	25	20	77	L,R
30N/04W-14F01	2	1	155	30	30	I	--	--	--	100	--	--	L
30N/04W-14F02	2	1	146	82	6	H	22	04-07-77	DR	6	--	--	L
30N/04W-14F03	2	1	150	57	6	H	19	06-10-75	DR	25	23	--	L
30N/04W-14F04	2	1	155	81	6	H	24	04-08-66	DR	30	30	10	L
30N/04W-14F04D1	1	3	162	285	8	I	23.9	09-07-95	GS	65	33	28	L
30N/04W-14F05	1	1	162	67	6	H	23.6	03-11-96	OG	18	19	21	L,W2
30N/04W-14K01	2	1	170	80	--	U	--	--	--	--	--	--	L
30N/04W-14L01	1	1	172	81	6	H	31	03-13-96	GS	--	--	--	L
30N/04W-14L02	1	1	180	97	6	H	21.6	03-13-96	GS	40	32	32	L
30N/04W-14L03	1	1	170	76	6	H	19	07-28-95	GS	--	--	--	L,Q1
30N/04W-14M01	2	1	170	50	--	U	--	--	--	--	--	--	L
30N/04W-14M04	2	1	175	43.5	6	H	17	07-19-76	DR	15	4	120	L,Q2
30N/04W-14P01	1	1	183	38	6	H	19.7	03-11-96	OG	15	6	130	L,Q2,R,W1
30N/04W-14P02	2	1	190	52	6	H	14	06-14-73	DR	20	--	--	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydrogeologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Drawdown (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-14P03	2	1	185	98	6	H	18	06-16-76	DR	40	31	79	L
30N/04W-14P04	2	1	185	41	6	H	12	05-30-73	DR	20	20	--	--
30N/04W-14Q02	1	1	185	22	--	H	17.1	03-11-96	OG	--	--	--	W2
30N/04W-15A01	1	1	154	--	--	U	23.1	03-11-96	OG	--	--	--	R,W1
30N/04W-15E03	1	1	150	63.5	6	H	2.9	07-28-95	GS	--	--	--	L
30N/04W-15G01	2	1	150	50	8	H	--	--	--	5	--	--	--
30N/04W-15G02	2	1	150	56	6	H	12	07-24-75	DR	50	15	200	L
30N/04W-15G03	2	1	150	55	6	H	24	03-26-77	DR	25	16	96	L,Q2
30N/04W-15H01	2	1	158	50	6	H	--	--	--	25	0	--	--
30N/04W-15H02	2	1	150	50	6	H	--	--	--	25	--	--	--
30N/04W-15H03	2	1	150	50	6	H	--	--	--	25	--	--	--
30N/04W-15H04	2	1	155	48	6	H	26	05-13-71	DR	35	0	--	L
30N/04W-15H05	2	1	160	49.5	6	H	25	01-20-69	DR	37	0	--	--
30N/04W-15J02	1	3	160	144	6	H	32.5	03-13-96	GS	60	30	--	C,L
30N/04W-15J03	2	1	165	101	6	N	28	08-21-92	DR	--	--	--	C,L
30N/04W-15K01	2	1	170	55	6	H	18	01-03-79	DR	20	10	52	L
30N/04W-15K03	1	1	180	98	6	H	24.8	03-13-96	GS	--	--	--	L,Q1
30N/04W-15M01	2	1	155	14.5	6	U	5.2	06-10-60	GS	--	--	--	--
30N/04W-15M02	2	1	155	42.5	6	H	12.6	06-16-60	GS	--	--	--	--
30N/04W-15N01	2	1	175	28	6	H	4	03-16-74	DR	12	--	--	L,Q2
30N/04W-15Q01	2	1	185	58	6	H	22	08-17-76	DR	35	18	120	L
30N/04W-15R01	2	1	185	56	6	U	24	00-00-79	GL	25	19.8	77	--
30N/04W-15R02	1	3	190	177	8	P	31.5	03-13-96	GS	320	14.4	460	C,L
30N/04W-16C01	2	1	145	80	--	U	--	--	--	--	--	--	C,L
30N/04W-16C02	2	1	145	45	6	H	8	03-07-79	DR	20	5	280	L,Q2
30N/04W-16D01	1	3	150	230	6	H	27.9	03-12-96	GS	40	35	32	C,L
30N/04W-16F01	2	1	140	50	--	U	--	--	--	--	--	--	L
30N/04W-16F02	2	1	150	50	--	U	--	--	--	--	--	--	L
30N/04W-16G01	1	1	168	90	6	H	25.4	03-11-96	OG	15	25	14	L,Q2,R,W1
30N/04W-16G02	2	1	145	40	6	H	9	10-17-74	DR	3	--	--	L
30N/04W-16L01	2	1	190	50	--	--	--	--	--	--	--	--	L
30N/04W-16P02	1	3	230	144	6	H	97.6	03-13-96	GS	25	4	380	L,Q3,R
30N/04W-16P05	1	5	210	310	6	H	108.8	03-12-96	GS	40	22	54	C,L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
30N/04W-16Q05	2	1	200	63.1	6	H	61	07-22-60	OG	--	--	--	L
30N/04W-16Q06	1	1	180	97	6	H	66.7	07-28-95	GS	--	--	--	L
30N/04W-16Q07	1	1	170	101	6	H	43	03-12-96	GS	18	40	28	L
30N/04W-17B01	1	1	179	91	6	H	41.1	03-11-96	OG	40	5	220	L,Q3,R,W1
30N/04W-17D01	2	1	200	146	5	H	65	00-00-47	DR	--	--	--	C,L
30N/04W-17D04	1	1	200	121	6	H	75.4	03-12-96	GS	--	--	--	L
30N/04W-17G01	2	1	200	97	6	H	65	07-22-60	OG	--	--	--	--
30N/04W-17P01	1	1	340	66	6	H	35.6	03-13-96	GS	18	1	710	L,Q1,R
30N/04W-17R02	1	3	320	211	6	H	191	03-14-96	GS	10	10	61	L,Q3,R
30N/04W-18A01	2	1	220	145	6	H	87	07-19-60	OG	--	--	--	--
30N/04W-18A02	2	1	227	119	6	H	--	--	--	20	2	--	L
30N/04W-18A04	1	1	225	134	6	H	98.2	03-13-96	GS	12	20	12	C,L
30N/04W-18B01	1	1	200	112	6	H	68	09-08-77	DR	15	--	--	L,R
30N/04W-18E01	1	2	190	169	6	H	114	09-07-95	GS	12	25	29	L
30N/04W-18H02	2	1	230	128	6	H	97	02-25-77	DR	15	--	--	L
30N/04W-18H03	2	1	235	140	6	H	110	02-21-76	DR	15	--	--	L
30N/04W-18H06	1	1	230	121	6	H	95	05-17-92	DR	--	--	--	C,L,Q1
30N/04W-18J01	2	1	252	12	36	H	3.7	03-20-79	GS	--	--	--	Q2
30N/04W-18M01	2	1	325	82	--	U	--	--	--	--	--	--	--
30N/04W-19A01	1	1	380	118	6	C	69	06- 7-91	DR	--	--	--	C,L
30N/04W-19A02	1	1	380	93	6	H	68	06-10-95	DR	--	--	--	C,L
30N/04W-19H01	1	1	440	98	6	H	60.5	08-02-95	GS	12	30	9.5	C,L,Q2,R
30N/04W-19J01	2	1	420	9.9	12	H	6	08-09-60	OG	--	--	--	L,Q2
30N/04W-20A01	2	3	325	265	6	H	225	07-02-79	DR	17	10	100	L,Q2
30N/04W-20B01	2	1	330	85	6	H	43.4	03-20-79	GS	20	12	--	L,Q2,W4
30N/04W-20B02	2	8	375	345	6	H	204	02-14-79	DR	5	71	--	L
30N/04W-20C01	2	1	375	108	8	H	76	00-00-47	DR	--	--	--	L
30N/04W-20E01	1	1	380	38	6	H	7.2	03-12-96	GS	20	5	34	L,Q3,R
30N/04W-20H01	1	5	340	350	6	H	286	03-12-96	GS	--	--	--	L
30N/04W-20J02	2	7	360	220	6	U	4	10-20-79	DR	2.5	250	0.051	C,L
30N/04W-20J04	2	1	340	118	6	H	5	09-14-81	DR	4	113	0.8	C,L
30N/04W-20M03	2	7	430	165	6	H	20	12-03-79	DR	0.5	20	--	C,L
30N/04W-20P03	1	1	440	30	6	H	-14.4	03-12-96	GS	30	20	31	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level (Feet)	Water level (Date)	Water level Source	Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
30N/04W-20P04	1	1	470	59	6	H	8.4	03-12-96	GS	--	--	L	
30N/04W-21A02	1	1	210	93	6	U	37	01-08-92	DR	20	22	22	L
30N/04W-21B01	2	1	238	38	6	H	-0.6	03-03-69	GS	--	--	--	Q2
30N/04W-21C01	2	3	260	160	6	P	120	11-08 65	DR	15	30	--	L
30N/04W-21F02	1	5	280	352	6	H	177.8	03-12-96	GS	--	--	--	C,L
30N/04W-21F03	1	3	280	185	6	H	142.1	03-12-96	GS	--	--	--	L
30N/04W-21G02	2	1	258	45	6	H	18	03-31-78	DR	12	19	14	L
30N/04W-21G03	1	1	261	54	6	H	18.2	03-11-96	OG	18	19	28	L,Q2,R,W1
30N/04W-21K01	2	3	365	267	6	H	192	10-01-74	DR	18	28	22	L
30N/04W-21K04	2	5	365	340	6	H	275	08-19-83	DR	20	6	80	C,L
30N/04W-21K05	1	5	369	326	6	H	278.4	08-03-95	GS	15	20	44	C,L
30N/04W-21L02	1	5	365	327	6	H	269.2	08-03-95	GS	5	37	7.2	C,L,R
30N/04W-21M01	2	7	360	210	6	H	10	08-11-80	DR	2	195	--	C,L
30N/04W-22A01	2	1	200	90.5	6	H	28	06-21-77	DR	30	52	6.6	L
30N/04W-22A02	2	1	200	49	6	P	16	06-21-77	DR	17	23	45	L
30N/04W-22C02	1	1	210	58	6	H	25.8	03-12-96	GS	9	8	--	L,Q1
30N/04W-22C03	1	1	190	57	6	H	24	03-11-96	GS	--	--	--	L,Q1
30N/04W-22E01	2	1	235	68.2	6	P	55	08-24-71	DR	25	2.1	730	L,Q2
30N/04W-22E02	2	1	235	117	6	P	50	06-09-70	DR	25	56	--	L
30N/04W-22H01	2	3	215	163	6	H	95.8	02-05-73	GS	50	45	65	C,L,Q2
30N/04W-22H02	2	8	230	298	6	P	102	02-24-78	DR	30	10	--	C,L
30N/04W-22H03	2	1	210	61	6	H	37	06-12-77	DR	20	--	--	--
30N/04W-22J02	1	1	243	116	6	H	95.2	03-12-96	GS	10	4	150	L,R
30N/04W-22N01	2	3	405	275	6	H	220	12-20-73	DR	15	0	--	L
30N/04W-22N02	1	5	355	409	6	I	245.9	03-12-96	GS	2.8	152	1.1	C,L,R
30N/04W-22P01	2	2	320	270	6	U	150	08-17-74	DR	2	--	--	C,L
30N/04W-22R02	1	1	300	60	6	H	18.3	03-11-96	OG	30	10	--	L,Q2,R,W1
30N/04W-23B01	2	1	210	40	--	--	--	--	--	--	--	--	L
30N/04W-23C03	1	2	200	118	6	H	88.1	03-12-96	GS	10	34	18	L
30N/04W-23D01	2	1	205	45.5	6	H	25	05-03-76	DR	12	--	--	L
30N/04W-23E01	2	1	205	16	72	I	--	--	--	175	7	130	L,Q2
30N/04W-23E02	2	1	230	37	6	H	14	01-07-76	DR	8	--	--	L,Q1
30N/04W-23E03	2	3	240	202	6	H	121.9	03-20-79	GS	20	--	--	L,Q2

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-23E04	2	1	235	55	6	H	24	11-17-76	DR	25	15	--	L
30N/04W-23E08	1	1	230	140	6	H	90.5	03-11-96	GS	--	--	--	L
30N/04W-23F01	2	2	215	141	6	H	83	08-19-77	DR	20	--	--	L
30N/04W-23F02	2	1	220	50	6	H	20	05-17-77	DR	30	--	--	L
30N/04W-23F03	1	1	220	35.5	6	H	15	12-05-78	DR	30	--	--	L,Q2
30N/04W-23F06	2	1	230	97	6	H	50	02-02-77	DR	17	--	--	L
30N/04W-23F07	1	2	220	161	6	H	115.2	03-14-96	GS	--	--	--	L
30N/04W-23G01	2	1	240	80	--	--	--	--	--	--	--	--	L
30N/04W-23J01	2	1	240	20	6	H	13	07-21-60	OG	--	--	--	--
30N/04W-23K01	2	1	245	50	--	--	--	--	--	--	--	--	L
30N/04W-23L01	2	1	245	20	24	H	7	07-00-51	DR	7	0	--	L
30N/04W-23L03	2	1	245	16.7	30	H	10	07-28-50	DR	--	--	--	Q2
30N/04W-23L05	1	1	240	103	6	P	44	06-30-81	GS	--	--	--	L,R
30N/04W-23N03	2	3	255	201	8	P	42	12-27-79	DR	102	73	15	L
30N/04W-23N04	2	1	255	99	8	P	29	01-16-80	DR	100	31	25	L
30N/04W-23P01	2	1	260	20	--	--	--	--	--	--	--	--	L
30N/04W-23Q04	1	1	265	57	6	H	33.4	03-11-96	OG	10	4	150	L,Q2,R,W1
30N/04W-23Q05	2	1	265	55	6	H	18	01-12-78	DR	18	18	61	L
30N/04W-24A04	1	1	210	82	6	H	38.5	03-13-96	GS	12	26	28	L,R
30N/04W-24B01	2	1	200	45	6	H	--	--	--	--	--	--	--
30N/04W-24B05	2	1	200	95	6	H	31	05-06-77	DR	30	35	--	C,L
30N/04W-24D01	2	1	200	31.4	6	H	19	02-05-76	DR	10	--	--	L,Q2
30N/04W-24D02	2	1	200	37.5	6	H	21	02-17-78	DR	15	7.9	120	L
30N/04W-24E02	1	1	210	140	6	H	3	03-15-96	GS	40	20	49	L
30N/04W-24G02	1	1	232	79	6	H	57.6	03-11-96	OG	25	--	--	L,Q2,R,W1
30N/04W-24H04	2	1	230	111	6	P	47	01-07-77	DR	60	--	--	C,L
30N/04W-24H05	2	1	230	100	6	H	47	01-07-77	DR	55	--	--	L
30N/04W-24Q04	2	1	300	120	6	U	51	05-24-82	DR	--	--	--	L
30N/04W-24R01	1	3	282	276	6	H	72.9	03-11-96	OG	30	60	--	C,L,Q2,R,W1
30N/04W-25A01	1	1	315	96	6	P	52	01-02-74	DR	70	25.7	88	L,Q2,R
30N/04W-25A01D1	1	1	315	130	6	P	63	03-14-96	GS	50	3	310	C,L,Q1
30N/04W-25A02	1	1	315	102	8	P	48	05-26-73	DR	100	34.4	39	L,R
30N/04W-25A02D1	1	1	315	136	8	P	63.2	03-14-96	GS	290	29	120	C.L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-25A03	2	1	300	41	6	H	21	08-24-79	DR	10	15	41	L
30N/04W-25A05	1	1	315	104	6	P	63	03-14-96	GS	--	--	--	--
30N/04W-25C01	1	1	319	220	8	P	62	03-22-95	OG	302	74	19	C,L,R
30N/04W-25C08	2	1	310	78	--	H	--	--	--	--	--	--	--
30N/04W-25C09	2	1	310	42	--	H	--	--	--	--	--	--	--
30N/04W-25C10	2	1	305	93	6	H	32	08-04-75	GL	25	20	77	L
30N/04W-25C11	1	1	300	186	10	P	58	03-22-95	OG	351	52	32	C,L
30N/04W-25C12	1	1	300	172	10	P	49.5	01-02-96	OG	476	76.2	--	C,L
30N/04W-25D03	1	1	319	79.5	6	H	45	03-11-96	OG	15	--	--	L,Q2,R,W1
30N/04W-25D06	2	1	310	42	--	H	32	08-04-75	GL	--	--	--	--
30N/04W-25D07	2	1	305	100	--	H	--	--	--	--	--	--	--
30N/04W-25D08	2	1	319	50.5	--	H	32	08-04-75	DR	--	--	--	--
30N/04W-25D09	2	1	317	87	--	H	36	08-04-75	GL	--	--	--	--
30N/04W-25E01	2	1	321	48	6	--	--	--	--	--	--	--	--
30N/04W-25E08	2	1	318	100	--	H	37	08-04-75	GL	--	--	--	--
30N/04W-25E09	2	1	318	100	--	H	--	--	--	--	--	--	--
30N/04W-25E10	2	1	319	110	6	H	27	07-19-72	DR	20	22	56	L
30N/04W-25F05	2	1	318	120	--	H	39	08-04-75	GL	--	--	--	--
30N/04W-25F06	2	1	317	50	--	H	30	08-04-75	GL	--	--	--	--
30N/04W-25F07	2	1	316	92	6	H	39	08-04-75	GL	18	22	50	L
30N/04W-25G01	2	1	320	72	6	H	--	--	--	--	--	--	Q2
30N/04W-25G02	1	1	320	120	6	H	67	03-12-96	GS	--	--	--	L
30N/04W-25L10	1	1	340	125	6	H	77.1	03-14-96	GS	24	5	100	L,Q1
30N/04W-25M01	2	1	345	118	6	H	69	01-14-74	DR	36	10	110	L
30N/04W-26C01	2	1	278	15	36	H	--	--	--	--	--	--	Q2
30N/04W-26E02	2	1	369	130	6	H	94	10-10-74	DR	20	10	54	L
30N/04W-26E03	1	1	369	130	6	H	114.2	03-11-96	OG	15	0	--	L,Q3,R,W3
30N/04W-26H02	1	1	287	50	6	H	18.2	03-11-96	OG	12	25	29	L,Q2,R,W1
30N/04W-26P01	1	1	380	40	6	H	25	01-11-74	DR	13	7	110	L,R
30N/04W-26P01D1	1	1	380	80	6	H	49.3	03-12-96	GS	13	7	110	L
30N/04W-26P03	2	1	335	121	6	H	6	08-29-77	DR	1.5	--	--	L
30N/04W-26R01	2	1	340	57	6	I	12	08-05-46	DR	37	37	23	L
30N/04W-27A01	2	1	320	74	6	H	65	08-09-60	OG	10	2	310	L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-27A03	1	2	320	201	6	U	100	03-27-78	DR	12	--	--	C,L,R
30N/04W-27A08	1	1	410	96	6	H	74.6	03-12-96	GS	27	17	36	L,Q1
30N/04W-27E02	1	1	490	160	6	H	75.3	03-12-96	GS	7	--	--	L
30N/04W-27G01	2	1	475	67.9	8	H	56	08-09-60	OG	6	5.5	50	L
30N/04W-27L02	2	1	520	150	6	H	38	11-14-80	DR	6	42	2.6	C,L
30N/04W-27N02	1	1	580	84	6	H	47.4	03-14-96	GS	3.5	--	--	L
30N/04W-28H01	2	1	470	69	6	H	34	10-13-78	DR	10	10	27	L
30N/04W-29B02	1	1	520	158	6	H	59.1	03-14-96	GS	--	--	--	L,W2
30N/04W-29D02	1	1	470	115	6	H	3.2	08-31-95	GS	20	80	5	L,Q3,R
30N/04W-30A01	2	1	470	90	6	H	25	07-17-71	DR	3.5	25	--	C,L
30N/04W-30B02	1	1	450	70	6	H	39.8	03-15-96	GS	1.8	6	3.1	L
30N/04W-30G08	1	2	530	166	6	H	129	08-02-78	DR	5	0	--	L,Q1
30N/04W-30H02	1	7	510	190	6	H	65	03-12-96	GS	8	0	--	C,L
30N/04W-30K05	1	1	590	110	6	U	60	08- 8-79	DR	0.8	--	--	C,L
30N/04W-30K06	1	1	590	85	6	I	53	03-12-96	GS	--	--	--	--
30N/04W-33K01	1	1	770	45	6	H	33	10-15-94	DR	--	--	--	L
30N/04W-34B01	2	1	545	50	6	H	7	02-15-78	DR	4.5	--	--	L,Q2
30N/04W-34C01	2	1	570	110	6	H	14	05-28-76	DR	7	--	--	C,L
30N/04W-34E01	2	7	645	303	6	U	--	--	--	--	--	--	C,L
30N/04W-34G01	2	1	570	200	8	U	10	11-23-76	DR	15	--	--	L
30N/04W-34L07D1	1	--	670	501	6	U	2.4	03-12-96	GS	--	--	--	--
30N/04W-34L08	1	7	660	289	6	H	33	03-12-96	GS	3.5	--	--	L
30N/04W-34M01	1	--	740	--	6	U	Flowing	--	GS	--	--	--	--
30N/04W-34M02	1	1	670	29	4	U	--	--	--	--	--	--	--
30N/04W-34M03	1	1	690	--	36	--	--	--	--	--	--	--	--
30N/04W-34M04	1	1	660	29	5	H	1	03-14-96	OG	1.8	15	2.6	L,W2
30N/04W-35A03	1	1	350	93	6	H	68	10-06-94	DR	--	--	--	L,Q1
30N/04W-35B01	2	1	358	34	6	H	9.7	03-20-79	GS	30	10	180	L,Q2
30N/04W-35L02	2	1	405	27	6	H	14	11-02-77	DR	11	5	130	L,Q2
30N/04W-35L04	1	1	420	187	6	H	18.1	03-12-96	GS	14	0.5	520	L
30N/04W-35P01	2	1	510	135	6	H	110	06-21-76	DR	17	6.5	160	L
30N/04W-35P04	2	1	475	181	6	U	162	05-25-76	DR	9	3	85	L
30N/04W-35Q01	2	1	420	118	6	H	98	03-20-92	DR	24	10	150	C,L

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/04W-35Q02	2	1	435	181	6	H	--	--	--	--	--	--	C,L
30N/04W-36B01	2	1	390	40	6	U	24	11-15-78	DR	12	10	29	L
30N/04W-36J02	2	7	570	395	6	U	--	--	--	--	--	--	C,L
30N/04W-36Q01	2	8	720	220	6	H	--	--	--	8	--	--	C,L
30N/05W-09J02	1	--	170	200	--	H	--	--	--	--	--	--	--
30N/05W-09N01	1	1	230	261	6	H	217.6	03-13-96	GS	10	22	28	C,L,R
30N/05W-10B01	1	3	225	234	8	U	213	10-26 62	DR	140	2	1,500	C,L
30N/05W-10D01	1	1	130	175	6	H	157.2	03-14-96	GS	--	--	--	L
30N/05W-10F01	1	3	190	205	8	P	178.1	08-11-95	GS	330	4	1,900	L,R
30N/05W-10N01	1	8	300	186	6	U	73	05-11-81	DR	2.5	44	--	C,L,R
30N/05W-11L01D1	1	3	310	251	6	H	240.8	03-13-96	GS	7	8	54	C,L
30N/05W-11L02	1	2	315	295	6	H	154	05-05-89	DR	--	--	--	C,L
30N/05W-11M01	1	3	260	262	6	H	251	04-12-82	DR	5	20	15	C,L
30N/05W-12H01	2	1	145	76	6	H	68	07-22-60	OG	--	--	--	L
30N/05W-12K01	1	1	172	105	6	H	85	03-20-79	GS	25	5	--	L,Q3,R
30N/05W-12L01	2	1	190	102	6	H	97	07-27-60	OG	--	--	--	L
30N/05W-12L02	1	1	170	121	6	H	88	09-21-90	DR	--	--	--	L
30N/05W-12N01	2	1	115	4	36	H	0.8	07-20-60	OG	--	--	--	L,Q2
30N/05W-13E01	2	1	246	20.1	8	H	2	07-20-60	OG	--	--	--	L,Q2
30N/05W-13K01	2	1	308	4.5	24	H	2	07-20-60	OG	--	--	--	L,Q2
30N/05W-13M01	2	1	285	62	--	--	--	--	--	--	--	--	--
30N/05W-13R01	1	1	400	68	6	H	41.1	03-14-96	GS	--	--	--	L,Q1
30N/05W-14C01	1	3	310	341	6	P	147	06-09-95	DR	--	--	--	C,L
30N/05W-15D01	1	1	300	34	6	H	Flowing	03-19-93	DR	5	32	9.6	L,Q1
30N/05W-16K01	1	1	340	54	6	H	9.1	03-13-96	GS	--	--	--	L
30N/05W-20B01	1	1	450	111	6	I	55.1	03-13-96	GS	7.5	40	3.5	L,R
30N/05W-20G01	1	1	490	131	6	H	89.5	03-14-96	OG	18	12	21	L,Q1,W2
30N/05W-21B01	1	1	450	90	6	I	7	03-13-96	GS	17	50	21	L,R
30N/05W-22J01	1	1	600	80	6	H	42.1	03-13-96	GS	--	--	--	L
30N/05W-23A01	1	1	425	241	6	H	137.7	03-14-96	GS	--	--	--	C,L
30N/05W-23A02	1	1	400	104	6	H	84	11-09-90	DR	8	12	16	L
30N/05W-23B01	1	1	375	105	6	H	96.1	03-14-96	GS	10	0	--	C,L
30N/05W-23C01	2	1	450	12	32	H	6	06-28-74	DR	--	--	--	--

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
30N/05W-23C02	1	1	450	162	6	H	90.4	03-14-96	OG	--	--	--	C,L,W2
30N/05W-23N01	1	1	625	100	6	H	54.7	03-12-96	GS	--	--	--	C,L,Q1
30N/05W-25A01	1	1	615	214	6	H	184.4	03-14-96	GS	10	3	96	C,L
30N/05W-25B02	2	1	600	221	6	H	--	--	--	--	--	--	C,L
30N/05W-25C06	1	1	575	118	6	H	51.5	03-14-96	GS	--	--	--	L
30N/05W-25D02	2	1	610	154	6	H	52	09-22-78	DR	5	62	1.2	C,L
30N/05W-26K01	2	2	690	261	6	U	--	--	--	--	--	--	C,L
30N/05W-26M01	1	1	780	249	6	H	217.1	03-12-96	GS	15	0	--	C,L
30N/05W-26Q01	1	1	825	130	6	H	110.9	03-14-96	OG	--	--	--	L,Q1,W2
30N/05W-27A01	1	1	670	138	6	H	83.8	03-14-96	GS	--	--	--	C,L
30N/05W-27G01	2	1	760	16	--	H	--	--	--	--	--	--	L
30N/05W-27H01	1	1	800	87	6	H	67	05-04-78	DR	6	5	49	C,L,R
30N/05W-34Q01	2	1	975	36	6	H	12	07-29-77	DR	12	16	--	L
30N/05W-36D01	1	7	860	213	6	H	196.1	03-14-96	GS	--	--	--	L
31N/03W-18G01	2	--	10	667	4	H	Flowing	--	DR	50	--	--	L
31N/03W-30M01	2	1	8	48	6	--	5	07-22-60	DR	27	--	--	Q2
31N/03W-30N02	1	3	10	235	6	H	-19.2	03-12-96	GS	36	27	73	C,L
31N/03W-30Q01	2	--	10	250	5	P	--	07-25-68	GS	--	--	--	--
31N/03W-30Q02	2	--	10	3,620	--	--	--	--	--	--	--	--	--
31N/03W-30Q03	2	--	10	3,490	--	--	--	--	--	--	--	--	--
31N/03W-31B01	2	1	10	52.3	8	P	0.7	08-22-74	DR	--	--	--	L,Q2
31N/03W-31D01	2	1	12	57.3	6	H	6.9	03-21-79	GS	30	--	--	L,Q2
31N/03W-31E03	1	1	15	54	6	H	3.4	03-13-96	GS	60	9	210	L,Q1
31N/03W-31H01	2	1	10	44	6	P	Flowing	03-00-62	DR	50	20	87	L
31N/03W-31L01	2	1	19	88	6	H	2	04-19-79	DR	75	10	460	L
31N/03W-31L01D1	1	1	15	88	6	H	2	04-19-79	DR	75	0	--	C,L
31N/03W-31N01	1	1	30	97	6	H	12	03-13-96	GS	--	--	--	L
31N/03W-32P01	1	3	5	217	6	H	-24	03-11-96	GS	--	--	--	L
31N/04W-24E01	2	--	10	5,100	--	U	--	--	--	--	--	--	L
31N/04W-25M04	2	1	75	104	6	U	70	10-28-77	DR	34	10	210	L
31N/04W-25M05	1	3	50	210	6	H	32.9	03-11-96	GS	50	40	68	L
31N/04W-25N05	1	1	80	103	6	H	76.4	07-21-95	GS	30	7	260	L,Q2,R1
31N/04W-25P01	2	1	60	74	6	H	--	--	--	--	--	--	--

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
31N/04W-25P03	2	1	52	63	6	H	46	08-02-71	DR	15	0	--	L
31N/04W-25R01	2	1	10	40	6	H	4	09-10-75	DR	50	5	--	L,Q2
31N/04W-26M01	2	1	43	48.8	6	C	43	07-21-60	OG	--	--	--	--
31N/04W-26Q02	2	1	70	90	6	H	68	08-20-74	DR	20	5	250	L
31N/04W-26Q09	1	1	70	88	6	H	66.7	03-11-96	GS	28	0	--	L,Q1
31N/04W-26R01	1	1	60	138	6	U	59	03-11-96	GS	--	--	--	L
31N/04W-26R02	1	3	60	298	8	U	17	08-25-93	DR	35	60	15	L
31N/04W-26R02D1	1	5	60	510	8	P	12	12-19-94	DR	101	4.2	260	L
31N/04W-27P01	1	1	90	130	6	H	95	04-05-77	DR	35	4	280	C,L,Q3,R
31N/04W-27P02	2	1	85	128	6	H	89	02-28 64	DR	17	9	120	L
31N/04W-27Q01	2	1	60	84.1	6	H	50	07-21-60	OG	--	--	--	--
31N/04W-27R01	2	1	35	53	6	H	33	07-25-68	GS	40	--	--	L
31N/04W-34E01	1	1	100	108	6	H	89	03-08-77	DR	15	7.1	130	C,L,R1
31N/04W-34G01	1	5	125	542	8	H	74.5	07-29-95	GS	--	--	--	C,L
31N/04W-34G02	1	1	120	162	6	H	109.6	03-11-96	GS	--	--	--	L
31N/04W-34G03	1	1	120	163	6	H	113	08-07-95	DR	20	20	22	L
31N/04W-34H02	2	1	99.5	122	6	H	84.2	03-21-79	GS	10	12	21	C,L,Q2
31N/04W-34H03	2	1	120	146	6	H	102	01-11-67	DR	18	18	61	C,L
31N/04W-34L01	2	1	120	138	6	P	111	08-29-78	DR	10	27	9.4	L
31N/04W-34M01	2	1	95	94	6	H	58	02- 5-72	DR	25	10	150	L
31N/04W-34M06	1	1	141	141	6	H	96.9	03-13-96	GS	--	--	--	C,L,R
31N/04W-34N01	1	1	90	134	6	H	55.6	03-13-96	GS	18	24	16	C,L,Q1
31N/04W-34N02	1	1	105	68	--	H	45	--	OG	--	--	--	--
31N/04W-34P01	2	1	90	90	6	H	--	--	--	--	--	--	--
31N/04W-34Q02	1	1	110	107	6	H	85.1	03-11-96	GS	10	10	20	L,R
31N/04W-35A01	2	1	85	90	6	H	--	--	--	--	--	--	--
31N/04W-35D01	1	1	74.6	94	6	H	69.9	03-11-96	OG	20	10	120	L,Q2,R,W1
31N/04W-35E03	1	3	100	278	6	H	44.4	03-12-96	OG	--	--	--	C,L,W2
31N/04W-35F01	1	1	100	132	6	H	92.5	03-13-96	GS	25	7	220	C,L
31N/04W-35H01	2	5	100	616	12	U	41	08-31-79	DR	650	69	56	C
31N/04W-35J01	2	1	28	65	--	H	--	--	--	--	--	--	--
31N/04W-35J02	1	1	30	70	6	H	5	05-04-90	DR	--	--	--	L
31N/04W-35M04	1	1	145	157	6	H	114.8	03-11-96	GS	18	5	220	L,Q1

Appendix A. Physical and hydrologic data for the study wells--Continued

Local well number	Project number	Hydro-geologic unit	Land-surface altitude (feet)	Well depth (feet)	Casing diameter (inches)	Water use	Water level			Yield (gallons per minute)	Draw-down (feet)	Horizontal hydraulic (feet per day)	Remarks
							(Feet)	(Date)	Source				
31N/04W-35M05	1	5	140	398	6	H	86	02-24-88	DR	17	160	5.1	L
31N/04W-35N02	1	5	145	415	6	H	88	03-12-96	OG	7	246	0.67	C,L,W2
31N/04W-35P01	2	1	45	31	6	H	7	06-01-48	DR	--	--	--	L,Q2
31N/04W-36B01	2	1	30	55	6	Z	26	11-27-72	DR	25	0	--	L,Q2
31N/04W-36B06	1	1	18	96	6	H	13.9	03-12-96	OG	--	--	--	C,L,R,W2
31N/04W-36E03	1	1	80	131	6	H	84	09-01-79	DR	--	--	--	C,L,Q1,R
31N/04W-36L01	2	1	25	25	2	H	--	--	--	--	--	--	--
31N/04W-36M01	2	1	30	14	--	H	4	08-09-60	OG	--	--	--	--
31N/04W-36M02	2	1	30	21.9	--	U	2.7	09-15-78	GS	--	--	--	--
31N/04W-36P01	2	1	30	50	--	--	--	--	--	--	--	--	L
31N/04W-36P02	2	1	40	50	--	--	--	--	--	--	--	--	L
31N/04W-36P03	1	1	35	50	6	S	3	03-28-90	DR	25	7	220	L

Appendix B. Irrigation-Ditch Discharge Data

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington

[Gaged site: see figure 13 for locations; A, Agnew; C, Clallam; CL, Cline; D, Dungeness Company; DD, Dungeness District; E, Eureka; H, Highland; I, Independent; S, Sequim-Prairie; EEC, Emery Creek; ft^3-s, cubic feet per second; Ecology, Washington State Department of Ecology; --, no data]

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
A1	09-22-95	5.53	0.62	Measured by Jamestown S'Klallam Tribe
A1	10-19-95	6.20	0.74	Measured by Jamestown S'Klallam Tribe
A1	11-21-95	4.60	0.70	Measured by Jamestown S'Klallam Tribe
A1	04-15-96	16.8	1.17	
A1	05-03-96	14.4	1.08	
A1	05-31-96	12.8	1.06	Measured by Jamestown S'Klallam Tribe
A1	06-28-96	18.3	1.30	Measured by Jamestown S'Klallam Tribe
A1	07-10-96	18.6	1.28	Measured by Jamestown S'Klallam Tribe
A1	07-31-96	19.3	1.32	Measured by Jamestown S'Klallam Tribe
A1	08-09-96	20.4	1.38	Measured by Jamestown S'Klallam Tribe
A1	08-16-96	19.0	1.32	Measured by Jamestown S'Klallam Tribe
A1	08-23-96	16.5	1.20	Measured by Jamestown S'Klallam Tribe
A1	08-29-96	17.7	1.24	Measured by Jamestown S'Klallam Tribe
A1	09-10-96	9.20	0.98	
A1	09-11-96	10.9	0.97	Measured by Jamestown S'Klallam Tribe
A1	09-30-96	5.21	0.67	Measured by Jamestown S'Klallam Tribe
A1	10-18-96	5.33	0.70	
A1	04-29-97	11.4	1.00	
A1	07-11-97	13.8	1.12	Measured by Jamestown S'Klallam Tribe
A1	07-21-97	15.6	1.30	Measured by Jamestown S'Klallam Tribe
A1	07-29-97	19.7	1.34	Measured by Jamestown S'Klallam Tribe
A1	08-05-97	20.0	1.35	Measured by Jamestown S'Klallam Tribe
A2	08-12-96	0.36	0.43	
A2	01-15-97	2.10	0.63	
A2	04-30-97	1.04	0.51	
A3	08-12-96	1.53	2.41	New gage height = 7.30
A3	11-07-96	0.38	2.15	Replaced gage on 11-07-96 (old = 2.15; new = 7.04)
A3	02-06-97	0.16	6.83	Old gage height = 1.94
A3	04-30-97	0.97	7.20	Old gage height = 2.31
A4	08-12-96	0.18	5.58	Old gage height = 40.72
A4	04-30-97	0.25	5.68	Replaced gage on 3-21-96 (old gage height = 40.82)
A4	07-31-97	0.19	5.66	Old gage height = 40.80
A5	08-12-96	9.83	3.96	Total flow in main ditch
A5	02-06-97	3.23	3.66	Total flow in main ditch
A5	04-29-97	6.69	3.99	Total flow in main ditch
A5	06-25-97	8.24	3.90	Total flow in main ditch
A5	07-10-97	9.35	3.94	Total flow in main ditch
A6	08-12-96	2.29	0.34	
A6	04-29-97	2.29	0.36	
A6	06-25-97	1.59	0.28	
A6	07-10-97	2.14	0.32	
A7	05-08-96	3.62	0.42	
A7	08-13-96	4.49	0.60	
A7	04-29-97	1.75	0.42	

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
A7	08-07-97	4.99	0.61	
A7	08-21-97	5.76	0.61	
A8	08-13-96	0.57	4.20	Old gage height = 48.47
A8	04-29-97	0.60	4.15	Replaced gage on 04-15-96 (old gage height = 48.42)
A8	06-18-97	0.65	4.06	Old gage height = 48.33
A8	07-15-97	0.69	4.16	Old gage height = 48.43
A8	08-08-97	1.39	4.20	Old gage height = 48.47
A8	09-04-97	0.45	3.88	Gage damaged and replaced, but not at same datum
A9	04-29-97	0.01	2.17	
A10	05-08-96	0.27	9.79	Replaced gage on 05-08-96 (old = 44.34; new = 9.79)
A10	08-13-96	0.36	9.83	Old gage height = 44.38
A10	05-01-97	0.29	9.79	Old gage height = 44.34
A10	08-07-97	0.45	9.95	Old gage height = 44.50
A11	05-08-96	1.59	11.61	Replaced gage on 05-08-96 (old = 42.51; new = 11.61)
A11	05-01-97	0.94	11.23	Moved gage location on 05-01-97
A11	06-18-97	1.48	11.28	
A11	07-11-97	1.32	11.26	
A12	05-08-96	0.61	2.51	Replaced gage on 03-21-96 (old gage height = 12.09)
A12	08-13-96	0.84	2.69	Old gage height = 12.27
A12	01-22-97	4.06	0.87	Moved gage location on 01-22-97
A12	02-05-97	1.04	0.45	
A12	04-30-97	1.01	0.38	
A13	08-13-96	0.65	1.58	
A13	04-29-97	--	1.70	
A14	08-13-96	0.23	0.66	
A14	05-01-97	0.12	0.58	
A14	06-18-97	0.01	0.50	
A15	02-06-97	0.39	6.83	
A15	04-29-97	6.94	7.42	
A15	06-18-97	10.7	7.59	
A16	04-29-97	9.16	7.60	
A16	07-11-97	13.3	7.76	
A16	08-08-97	17.5	7.88	
A17	01-15-97	3.51	10.12	
A17	02-06-97	2.67	9.95	
A17	04-30-07	2.10	9.92	
C1	08-12-96	5.97	3.86	
C1	10-16-96	2.90	3.72	
C1	04-29-97	5.93	3.91	
C1	08-12-96	5.97	3.86	
C1	10-16-96	2.90	3.72	
C1	04-29-97	5.93	3.91	
C1	07-11-97	7.04	3.96	
C1	08-27-97	4.63	3.90	
C2	08-13-96	2.41	1.44	
C2	04-30-97	2.25	1.42	Measured by Ecology

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
C2	07-11-97	3.16	1.55	
C2	07-16-97	4.82	1.67	
C3	08-13-96	1.26	0.40	
C3	04-30-97	2.14	0.53	Measured by Ecology
C3	07-11-97	2.85	0.60	
C3	07-16-97	3.03	0.60	
C4	08-13-96	0.37	4.07	Do not use data, dam in place
C4	10-17-96	0.15	3.64	
C4	04-29-97	1.03	3.95	Measured by Ecology
C4	07-16-97	0.51	3.70	
C5	08-13-96	0.98	0.71	
C5	11-07-96	0.07	0.28	
C5	04-30-97	0.11	0.28	
C6	08-13-96	0.19	0.22	
C6	11-07-96	0.44	0.34	
C6	04-29-97	0.42	0.37	Measured by Ecology
C6	07-15-97	0.43	0.31	
C6	08-07-97	0.47	0.33	
C7	08-13-96	0.34	1.83	
C7	11-07-96	0.48	1.98	
C7	04-29-97	0.96	1.70	Measured by Ecology
C7	06-17-97	0.78	1.78	
C7	07-15-97	0.79	1.86	
C7	08-07-97	0.78	1.93	
CL1	08-12-96	6.78	41.30	Alternate gage height = 75.54
CL1	10-16-96	4.98	41.25	
CL1	11-07-96	3.78	41.22	75.32
CL1	04-29-97	7.32	--	
CL1	07-11-97	4.78	41.23	75.31
CL1	08-27-97	9.76	41.38	75.51
CL2	08-13-96	4.08	0.50	
CL2	10-17-96	2.58	0.22	
CL2	11-07-96	2.13	0.25	
CL2	04-29-97	5.42	0.42	Measured by Ecology
CL2	06-17-97	7.60	0.59	
CL3	09-27-96	2.65	0.76	
CL3	11-06-96	1.33	0.59	
CL3	04-29-97	2.96	0.75	Moved gage on 04-29-97 (old = 0.75; new = 1.69)
CL3	06-19-97	4.48	1.92	
CL3	07-31-97	3.31	1.77	
CL4	10-16-96	1.92	0.67	
CL4	11-06-96	1.07	0.52	
CL4	04-30-97	2.19	0.72	Measured by Ecology
CL5	10-16-96	1.54	4.10	
CL5	11-06-96	1.04	3.92	

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
CL5	04-30-97	1.55	4.14	Measured by Ecology
CL5	06-18-97	3.80	4.34	
CL6	10-15-96	1.60	2.95	
CL6	11-06-96	0.09	2.47	
CL6	04-30-97	0.56	2.82	Measured by Ecology
CL6	06-18-97	1.95	3.12	
CL7	10-15-96	0.63	2.66	
CL7	11-06-96	0.47	2.55	
CL7	05-01-97	0.18	2.46	Measured by Ecology
D1	08-12-96	5.89	0.90	
D1	10-16-96	0.00	0.29	
D1	11-07-96	2.48	0.78	
D1	04-29-97	3.69	0.95	
D1	06-17-97	7.88	1.03	
D1	08-27-97	6.39	0.91	
D1	09-04-97	5.81	0.83	
D2	08-12-96	0.32	3.80	
D2	04-30-97	0.72	3.84	
D2	07-10-97	0.35	3.74	
D3	08-13-96	1.61	0.85	
D3	01-22-97	3.71	1.25	
D3	02-05-97	0.41	0.48	
D3	04-30-97	1.17	0.74	Measured by Ecology
D4	08-13-96	1.27	5.62	
D4	04-30-97	0.72	5.58	Measured by Ecology
D4	06-17-97	2.45	5.74	
D5	08-13-96	0.20	4.09	
D5	05-01-97	0.22	4.06	
D5	06-17-97	0.28	4.20	
D6	02-05-97	0.12	7.46	
D6	04-30-97	0.04	7.35	
D6	06-19-97	0.19	7.53	
D7	04-30-97	0.00	8.70	
D7	06-19-97	0.20	9.08	
D7	08-07-97	0.20	9.03	
DD1	08-14-96	9.01	0.66	
DD1	10-16-96	4.85	0.33	
DD1	12-10-96	1.76	0.12	
DD1	04-29-97	3.55	0.35	Measured by Ecology
DD1	05-01-97	6.20	0.54	Measured by Ecology
DD2	08-14-96	7.57	5.96	
DD2	09-27-96	4.15	5.85	
DD2	04-29-97	4.19	5.84	Measured by Ecology
DD2	08-08-97	9.97	6.00	
DD3	08-14-96	5.73	0.88	

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
DD3	09-27-96	3.68	0.79	
DD3	12-17-96	1.49	0.35	
DD3	04-29-97	4.19	0.61	Measured by Ecology
DD4	10-15-96	0.56	3.96	
DD4	04-30-97	1.21	4.09	Measured by Ecology
DD4	06-18-97	1.92	4.27	
E1	09-27-96	2.89	1.24	
E1	11-05-96	2.07	1.08	
E1	04-29-97	3.97	1.33	Measured by Ecology
E1	06-17-97	8.20	1.86	
E2	09-27-96	1.32	7.12	
E2	04-29-97	2.38	7.06	Measured by Ecology
E2	07-16-97	2.29	7.07	
E2	07-31-97	2.20	7.06	
E2	08-08-97	2.74	7.10	
E2	08-21-97	2.66	7.10	
E3	10-16-96	1.12	0.46	
E3	04-30-97	2.57	0.78	Measured by Ecology
E3	07-31-97	1.90	8.96	Moved gage on 07-31 (gage heights are upsidedown)
E3	08-07-97	3.20	8.82	
E3	08-21-97	3.09	8.80	
E5	09-26-96	0.83	2.32	With dam
E5	12-18-96	0.30	2.18	With dam
E5	02-05-97	0.19	1.73	Without dam
E5	04-30-97	1.18	2.06	Without dam -- measured by Ecology
E5	06-16-97	1.90	2.43	With dam
E5	07-10-97	1.65	2.16	Without dam
H1	09-22-95	8.85	1.12	Measured by Jamestown S'Klallam Tribe
H1	10-19-95	7.51	1.10	Measured by Jamestown S'Klallam Tribe
H1	11-21-95	4.60	0.70	Measured by Jamestown S'Klallam Tribe
H1	04-04-96	5.88	0.94	Measured by Jamestown S'Klallam Tribe
H1	04-15-96	8.34	1.14	
H1	05-03-96	5.10	0.95	
H1	05-31-96	10.3	1.22	Measured by Jamestown S'Klallam Tribe
H1	07-10-96	13.3	1.38	Measured by Jamestown S'Klallam Tribe
H1	07-31-96	15.4	1.52	Measured by Jamestown S'Klallam Tribe
H1	08-09-96	16.0	1.58	Measured by Jamestown S'Klallam Tribe
H1	08-16-96	14.6	1.54	Measured by Jamestown S'Klallam Tribe
H1	08-23-96	13.4	1.50	Measured by Jamestown S'Klallam Tribe
H1	08-29-96	13.6	1.52	Measured by Jamestown S'Klallam Tribe
H1	09-10-96	9.20	1.24	
H1	09-30-96	4.55	1.10	Measured by Jamestown S'Klallam Tribe
H1	10-18-96	3.61	0.92	
H1	02-06-97	1.74	0.68	
H1	02-28-97	2.87	0.76	Measured by Jamestown S'Klallam Tribe
H1	07-11-97	12.0	1.36	Measured by Jamestown S'Klallam Tribe

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
H1	07-29-97	14.3	1.40	Measured by Jamestown S'Klallam Tribe
H2	11-05-96	0.74	38.62	
H2	04-09-97	0.14	38.46	
H2	05-01-97	1.76	38.72	Measured by Ecology
H3	11-05-96	0.03	11.66	
H3	05-01-97	0.22	11.72	Measured by Ecology
H3	06-18-97	2.87	11.85	
H3	08-07-97	0.14	11.66	
H4	11-05-96	0.92	0.26	
H4	05-01-97	2.40	0.39	Measured by Ecology
H4	06-17-97	7.00	0.96	
H5	09-26-96	0.15	8.70	Replaced on 09-12-96 (old = 27.50; new = 9.17)
H5	04-08-97	0.09	8.68	Old gage height = 27.01
H5	07-10-97	0.03	8.64	Old gage height = 26.97
H6	09-26-96	0.48	5.19	
H6	02-05-97	0.25	5.08	
H6	04-30-97	0.30	5.14	Measured by Ecology
H7	09-26-96	0.33	10.15	Replaced gage on 03-21-96 (old gage height = 10.23)
H7	02-05-97	0.85	10.94	Old gage height = 11.02
H7	04-09-97	0.44	10.80	Old gage height = 10.88
H7	04-30-97	1.17	10.95	Measured by Ecology, old gage height = 11.03
H7	06-17-97	2.32	11.06	Old gage height = 11.14
H7	08-27-97	1.68	10.92	Old gage height = 11.00
H8	10-16-96	0.04	8.62	
H8	02-05-97	0.11	8.82	
H8	04-30-97	0.14	9.00	Measured by Ecology
H9	10-16-96	0.01	6.07	
H9	05-01-97	0.06	6.08	Measured by Ecology
H9	06-16-97	0.18	6.14	
H10	10-17-96	1.10	0.70	
H10	04-09-97	0.74	0.55	
H10	05-01-97	3.00	0.85	Measured by Ecology
H10	06-18-97	10.97	1.55	
I1	09-22-95	6.46	24.06	Measured by Jamestown S'Klallam Tribe
I1	02-12-96	2.53	23.90	Measured by Jamestown S'Klallam Tribe
I1	04-04-96	3.15	23.92	Measured by Jamestown S'Klallam Tribe
I1	04-15-96	4.40	23.96	
I1	05-03-96	3.10	23.91	
I1	05-31-96	6.09	24.04	Measured by Jamestown S'Klallam Tribe
I1	06-28-96	6.50	24.06	Measured by Jamestown S'Klallam Tribe
I1	07-10-96	7.96	24.12	Measured by Jamestown S'Klallam Tribe
I1	07-31-96	8.00	24.10	Measured by Jamestown S'Klallam Tribe
I1	08-09-96	5.53	24.02	Measured by Jamestown S'Klallam Tribe
I1	08-16-96	6.09	24.00	Measured by Jamestown S'Klallam Tribe
I1	08-23-96	3.54	23.94	Measured by Jamestown S'Klallam Tribe
I1	08-29-96	3.85	23.92	Measured by Jamestown S'Klallam Tribe

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
I1	09-10-96	3.00	23.90	
I1	09-30-96	2.14	23.84	Measured by Jamestown S'Klallam Tribe
I1	09-27-96	2.09	23.84	
I1	02-28-97	2.38	23.90	Measured by Jamestown S'Klallam Tribe
I1	04-29-97	4.60	24.06	Measured by Ecology
I1	07-11-97	10.6	24.18	Measured by Jamestown S'Klallam Tribe
I1	07-21-97	12.7	24.24	Measured by Jamestown S'Klallam Tribe
I1	07-29-97	7.42	24.10	Measured by Jamestown S'Klallam Tribe
I1	08-05-97	8.61	24.08	Measured by Jamestown S'Klallam Tribe
I2	10-16-96	0.61	0.32	
I2	04-29-97	3.25	0.46	Measured by Ecology
I2	06-17-97	5.51	0.60	
I3	10-16-96	0.04	0.09	
I3	11-05-96	0.91	0.26	
I3	04-29-97	1.46	0.30	Measured by Ecology
I4	09-26-96	0.06	4.77	
I4	04-29-97	0.54	4.97	Measured by Ecology
I4	06-17-97	2.86	5.20	
I5	09-26-96	1.21	0.24	Sum of 2 measurements in 2 ditches
I5	06-16-97	1.19	0.63	Sum of 2 measurements in 2 ditches
I5	07-10-97	0.95	0.54	Sum
I5	08-08-97	0.79	0.54	Sum
I5	08-27-97	1.59	0.62	Sum, 2 x 4 board in box outlet to north
I5	09-04-97	0.68	0.43	Sum, 2 x 4 board in box outlet to north
I5	09-04-97	0.68	0.27	Sum, 2 x 4 board not in box
I5	09-11-97	0.82	0.30	Sum, 2 x 4 board not in box
S1	08-14-96	9.47	59.95	Alternate gage height = 6.31
S1	10-16-96	2.95	59.50	5.86
S1	12-10-96	1.31	59.33	5.69
S1	05-01-97	6.54	6.09	59.73 measured by Ecology
S1	06-17-97	8.24	6.22	59.86
S2	08-14-96	1.38	0.47	
S2	09-27-96	0.49	0.29	
S2	12-17-96	0.11	0.18	
S2	04-30-97	0.18	0.23	Measured by Ecology
S3	08-14-96	8.29	0.78	
S3	09-27-96	1.76	0.48	
S3	04-30-97	7.10	0.60	Measured by Ecology
S4	09-26-96	2.79	12.10	
S4	12-17-96	1.35	11.98	
S4	05-01-97	5.00	12.22	Measured by Ecology
S5	09-26-96	0.83	8.79	
S5	05-01-97	0.50	8.64	Measured by Ecology
S5	06-16-97	2.63	8.92	
S6	10-16-96	0.32	11.10	
S6	04-30-97	0.75	11.15	Measured by Ecology

Table B1. Discharge measurements at staff-gage sites in irrigation ditches, Sequim-Dungeness area, Washington—Continued

Gaged site	Date	Discharge (ft^3/s)	Gage height (feet)	Remarks
S6	08-07-97	0.85	11.19	
S7	11-18-97	0.09	2.52	
S7	11-18-97	0.21	2.62	
S7	11-18-97	0.27	2.65	
S8	09-26-96	0.82	0.35	Old rating
S8	12-18-96	0.16	0.28	Old rating
S8	05-01-97	0.78	0.06	Measured by Ecology (scour during winter, new rating 02-15-97
S8	06-16-97	2.62	0.27	
S8	07-15-97	0.01	-0.11	Replaced gage on 07-31-97 (old = 0.18; new = 0.52)
S9	09-26-96	0.61	6.94	
S9	05-01-97	2.07	7.20	Measured by Ecology
S9	06-16-97	0.53	6.75	
S10	01-15-97	0.58	3.29	New Pt. Williams and Cactus Flats Road
S10	02-05-97	0.06	2.98	
S10	07-15-97	1.46	3.54	
EEC	02-06-97	1.04	0.42	Replaced gage on 03-21-96 (old = 8.13; new = 0.12)
EEC	04-09-97	0.09	0.11	
EEC	05-01-97	0.15	0.15	
EEC	11-18-97	0.07	0.09	
EEC	12-23-97	0.33	0.25	
EEC	01-28-98	1.08	0.42	

Table B2. Stage-discharge ratings for irrigation-ditch sites, Sequim-Dungeness area, Washington

[Gaged site: see figure 13 for locations; Mean discharge (ft^3/s), mean of discharge measurements in cubic feet per second; Equation estimates discharge in cubic feet per second, GH is gage height in feet; F-test p-value is for regression equation; Accuracy, good -- R-square greater than 0.94; standard error less than 11 percent; and p-value less than 0.06, poor -- R square less than 0.80,;standard error greater than 20 percent; or p-value greater than 0.20; fair -- between good and poor threshold criteria; --, no data]

Gaged site	Number of measurements	Mean discharge (ft^3/s)	Equation	R-square	Standard error of estimate (percent of mean discharge)	F-test p-value	Accuracy
Agnew- 1	22	13.7	$-9.61 + 21.5GH$	0.97	7.6	<0.01	Good
Agnew- 2	3	1.17	$-3.39 + 8.71GH$	>0.99	1.1	<0.01	Good
Agnew- 3a[1]	4	0.76	$0.000138GH^{10.5}$	0.99	[2]12	<0.01	Fair
Agnew- 3b	4	0.76	$0.376\,(GH - 6.0)^{5.06}$	0.98	[2]16	<0.01	Fair
Agnew- 4a[1]	3	0.21	$-21.64 + 0.536GH$	0.56	17	0.46	Poor
Agnew- 4b	3	0.21	$-2.81 + 0.536GH$	0.56	17	0.46	Poor
Agnew- 5a[1]	4	7.66	$-76.54 + 21.8GH$	>0.99	2.0	<0.01	Good
Agnew- 5b	--	--	Agnew-5a – Agnew-6	--	--	--	Fair
Agnew- 6 (weir)	--	--	$(20.91 - 0.67H)\,H^{1.5}$ $H = GH - 0.11$	--	--	--	Fair
Agnew- 7	5	4.12	$-2.77 + 13.0GH$	0.74	22	0.06	Poor
Agnew- 8a[1]	5	0.6	0.6 for GH48.27 – 48.52	--	--	--	Poor
Agnew- 8b	5	0.6	0.6 for GH4.00 – 4.25	--	--	--	Poor
Agnew- 9 (weir)	--	--	$(7.56 - 0.67H)\,H^{1.5}$ $H = GH - 2.16$	--	--	--	Fair
Agnew- 10a[1]	4	0.34	$-45.86 + 1.04GH$	0.94	7.4	0.03	Fair
Agnew- 10b	4	0.34	$-9.90 + 1.04GH$	0.94	7.4	0.03	Fair
Agnew- 11a[1]	1	--	$-465.40 + 11.0GH$		--	--	Poor
Agnew- 11b	1	--	$-125.50 + 11.0GH$		--	--	Poor
Agnew- 11c	3	1.25	$121.98 + 11.0GH$	0.99	3.6	0.07	Fair
Agnew- 12a[1]	2	0.72	$-16.31 + 1.4GH$	--	--	--	Fair
Agnew- 12b	2	0.72	$-2.9 + 1.4GH$	--	--	--	Fair
Agnew- 12c	3	2.04	$-1.68 + 6.56GH$	0.98	15	0.08	Fair
Agnew- 13a (weir)[1]	--	--	$(10.26 - 0.67H)\,H^{1.5}$ $H = GH - 1.33$	--	--	--	Good
Agnew- 13b (weir)	--	--	$(10.26 - 0.67H)\,H^{1.5}$ $H = GH - 1.33$	--	--	--	Good

Table B2. Stage-discharge ratings for irrigation-ditch sites, Sequim-Dungeness area, Washington—Continued

Gaged site	Number of measurements	Mean discharge (ft^3/s)	Equation	R-square	Standard error of estimate (percent of mean discharge)	F-test p-value	Accuracy
Agnew- 14	3	0.12	$-0.68 + 1.38GH$	>0.99	<1.0	<0.01	Good
Agnew- 15	3	6.01	$-88.02 + 12.9GH$	0.98	19	0.10	Gair
Agnew- 16	3	13.3	$2.09\,(GH7.0)^{18.0}$	>0.99	[2]<1.0	<0.01	Good
Agnew- 17	3	2.76	$-60.53 + 6.33GH$	0.93	9.8	0.17	Gair
Clallam- 1	7	5.55	$7.15\,(GH - 3.0)^{2.57}$	0.83	[2]14	<0.01	Gair
Clallam- 2	4	3.16	$-12.12 + 10.0GH$	0.97	7.9	0.02	Good
Clallam- 3	4	2.32	$-2.16 + 8.42GH$	0.97	6.8	0.01	Good
Clallam- 4	3	0.56	$-9.28 + 2.62GH$	0.95	26	0.15	Poor
Clallam- 5	3	0.39	$-0.49 + 2.07GH$	>0.99	7.2	0.02	Good
Clallam- 6	5	0.39	$2.89GH^{1.75}$	0.86	[2]16	0.02	Fair
Clallam- 7	5	0.69	$1.50 + 3.23GH\,(C\text{-}6) -0.993GH\,(C\text{-}7)$	0.75	26	0.25	Poor
Cline- 1a[1]	4	5.36	$-791.54 + 10.6GH$	0.88	11	0.06	Fair
Cline- 1b	5	6.02	$-1{,}463.71 + 35.6GH$	0.99	4.7	<0.01	Good
Cline- 2	5	4.36	$-0.58 + 12.5GH$	0.79	27	0.04	Poor
Cline- 3a[1]	3	2.31	$-3.87 + 8.83GH$	0.95	12	0.15	Fair
Cline- 3b	3	3.58	$-8.54 + 6.76GH$	0.98	4.0	0.08	Fair
Cline- 4	3	1.73	$-1.85 + 5.62GH$	>0.99	<1.0	0.01	Good
Cline- 5	4	1.98	$0.0312\,(GH/3.0)^{12.7}$	0.93	18	0.04	Fair
Cline- 6	4	1.05	$-7.40 + 2.97GH$	0.89	34	0.06	Poor
Cline- 7	3	0.43	$-5.25 + 2.22GH$	0.95	16	0.14	Fair
Dungeness Co- 1	7	5.94	$-11.18 + 19.1GH$	0.80	14	0.01	Fair
Dungeness Co- 2	3	0.46	$-12.31 + 3.37GH$	0.58	44	0.45	Poor
Dungeness Co- 3	4	1.72	$2.28GH^{2.30}$	>0.99	[2]3.7	<0.01	Good
Dungeness Co- 4	3	1.48	$-58.30 + 10.6GH$	0.99	6.2	0.05	Good
Dungeness Co- 5	3	0.23	$-1.86 + 0.509GH$	0.81	11	0.28	Poor
Dungeness Co- 6	3	0.12	$-6.02 + 0.824GH$	0.99	7.9	0.06	Fair
Dungeness Co- 7	3	0.13	$-4.83 + 0.555GH$	0.99	15	0.08	Fair
Dungeness Dist- 1	5	5.07	$-0.015 + 12.7GH$	0.93	17	0.01	Fair
Dungeness Dist- 2	4	6.47	$-200.83 + 35.1GH$	0.98	8.4	0.01	Good
Dungeness Dist- 3	4	3.77	$-0.66 + 6.74GH$	0.81	25	0.10	Poor
Dungeness Dist- 4	3	1.23	$-16.67 + 4.36GH$	>0.99	5.3	0.04	Good

Table B2. Stage-discharge ratings for irrigation-ditch sites, Sequim-Dungeness area, Washington—Continued

Gaged site	Number of measurements	Mean discharge (ft^3/s)	Equation	R-square	Standard error of estimate (percent of mean discharge)	F-test p-value	Accuracy
Eureka- 1	4	4.28	$-6.80 + 8.04GH$	0.99	5.7	<0.01	Good
Eureka- 2	5	2.45	$-73.55 + 10.7GH$	0.88	3.9	0.02	Fair
Eureka- 3a[1]	2	1.84	$-0.9 + 4.3GH$	--	--	--	Fair
Eureka- 3b	3	2.73	$74.66 - 8.12GH$	0.96	7.1	0.12	Fair
Eureka- 5a[1]	3	1.01	$0.0687\,(GH/2.0)^{17.0}$	>0.99	[2]3.3	0.02	Good
Eureka- 5b	3	1.01	$0.000834GH^{9.93}$	>0.99	[2]9.5	0.04	Good
Highland- 1	21	9.20	$-10.53 + 16.5GH$	0.94	12	<0.01	Fair
Highland- 2	3	0.88	$11.1\,(GH - 38.0)^{5.64}$	>0.99	[2]1.7	0.01	Good
Highland- 3	4	0.82	$32.1\,(GH - 11.0)^{15.0}$	0.89	[2]85	0.06	Poor
Highland- 4	3	3.44	$-1.12 + 8.50GH$	>0.99	7.8	0.04	Good
Highland- 5a[1]	3	0.09	$0.0682\,(GH - 26.0)^{26.9}$	>0.99	[2]1.2	0.01	Good
Highland- 5b	3	0.09	$92.0\,(GH - 8.0)^{18.0}$	>0.99	[2]0.78	<0.01	Good
Highland- 6	3	0.34	$0.000186\,(GH/4.0)^{29.9}$	0.91	[2]14	0.19	Fair
Highland- 7a[1]	1	--	$-69.34 + 6.81GH$	--	--	--	Poor
Highland- 7b	1	--	$68.79 + 6.81GH$	--	--	--	Poor
Highland- 7c	5	1.29	$-73.15 + 6.81GH$	0.74	33	0.06	Poor
Highland- 8	3	0.10	$-2.24 + 0.265GH$	0.96	14	0.13	Fair
Highland- 9	3	0.08	$-13.81 + 2.28GH$	0.98	24	0.10	Poor
Highland- 10	4	3.95	$-5.85 + 10.7GH$	0.99	17	0.01	Fair
Independent- 1a	19	4.71	$-536.26 + 22.6GH$	0.89	15	<0.01	Fair
Independent- 1b	5	9.33	$-872.40 + 36.5GH$	0.98	3.6	<0.01	Good
Independent- 2	3	3.12	$-4.93 + 17.5GH$	>0.99	5.0	0.03	Good
Independent- 3	3	0.80	$51.1GH^{2.97}$	>0.99	[2]3.5	0.01	Good
Independent- 4	3	1.15	$0.622\,(GH - 4.0)^{8.72}$	>0.99	[2]15	0.04	Fair
Independent- 5a	2	0.75	$-0.68 + 5.0GH$	--	--	--	Poor
Independent- 5b	5	1.04	$-1.03 + 3.75GH$	0.69	22	0.08	Poor
Sequim-Prairie- 1a	5	5.70	$-75.86 + 13.5GH$	>0.99	4.9	<0.01	Good
Sequim-Prairie- 1b	5	5.70	$-800.95 + 13.5GH$	>0.99	4.9	<0.01	Good
Sequim-Prairie- 2	4	0.54	$-0.80 + 4.58GH$	0.99	16	0.01	Gair
Sequim-Prairie- 3	3	5.72	$-7.04 + 20.6GH$	0.80	39	0.30	Poor
Sequim-Prairie- 4	3	3.05	$1.54\,(GH - 11.0)^{5.98}$	>0.99	[2]2.9	0.02	Good
Sequim-Prairie- 5	3	1.32	$0.00840\,(GH/8.0)^{51.4}$	0.93	[2]32	0.17	Poor
Sequim-Prairie- 6	3	0.64	$-66.24 + 6.00GH$	0.92	17	0.18	Fair

Table B2. Stage-discharge ratings for irrigation-ditch sites, Sequim-Dungeness area, Washington—Continued

Gaged site	Number of measurements	Mean discharge (ft^3/s)	Equation	R-square	Standard error of estimate (percent of mean discharge)	F-test p-value	Accuracy
Sequim-Prairie- 7	3	0.19	$-3.28 + 1.34GH$	0.99	7.6	0.07	Fair
Sequim-Prairie- 8a	2	0.49	$-1.9 + 7.7GH$	--	--	--	Poor
Sequim-Prairie- 8b	3	1.14	$0.63 + 6.94GH$	0.97	28	0.11	Poor
Sequim-Prairie- 8c	3	1.14	$-1.73 + 6.94GH$	0.97	28	0.11	Poor
Sequim-Prairie- 9	3	1.07	$-23.67 + 3.55GH$	0.86	43	0.25	Poor
Sequim-Prairie- 10	3	0.70	$-7.37 + 2.47GH$	0.96	30	0.13	Poor
Emery Creek - a	6	0.46	$4.67\,(GH - 8.01)^{1.79}$	0.99	[2]11	<0.01	Fair
Emery Creek - b	6	0.46	$4.67GH^{1.79}$	0.99	11	<0.01	Fair

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[1] Gaged sites with multiple ratings:

Agnew - 3	3a -- before 11-07-96	3b -- after 11-08-96	
Agnew - 4	4a -- before 03-21-96	4b -- after 03-22-96	
Agnew - 5	5a -- flow in main ditch	5b -- flow past McDonald Creek	
Agnew - 8	8a -- before 04-15-96	8b -- after 04-16-96	
	-- could not develop ratings using measured discharges because of extreme growth of vegetation during study period. Therefore, the average discharge of five measurements (0.6 ft^3/s) was used for the entire study period.		
Agnew - 10	10a -- before 05-08-96	10b -- after 05-09-96	
Agnew - 11	11a -- before 05-08-96 Same slope as 11c, shifted Intercept to match one Q	11b -- between 05-09-96 and 4-30-97 Same slope as 11c, shifted Intercept to match one Q	11c -- after 05-01-97
Agnew - 12	12a -- 02-27-96 to 03-19-96	12b -- between 03-20-96 and 01-21-97	12c -- after 01-22-97
Agnew - 13	13a -- before 12-05-96	13b -- after 12-06-96	
Cline - 1	1a -- for 75-ft gage	1b -- for 41-ft gage	
Cline - 3	3a -- before 04-29-97	3b -- after 04-30-97	
Eureka - 3	3a -- before 07-31-97	3b -- after 08-01-97	
Eureka - 5	5a -- with dam	5b -- without dam	
Highland - 5	5a -- before 09-11-96	5b -- after 09-12-96	
Highland - 7	7a -- before 03-21-96	7b -- between 03-21-96 and 1-1-97	7c -- after 01-01-97
	In Jan 1997, heavy runoff caused sediment deposition in the culvert below the gage and caused a change in the stage-discharge relation. Ratings before 1-1-97 are computed using same slope as post 01-01-97 and shifting the intercept to match one Q		
Independent - 1	1a -- $GH < 24.10$	1b -- $GH >= 24.10$	
Independent - 5	1a -- without any boards	1b -- with board in north outlet	
Seq-Prairie - 1	1a -- 5-6 ft gage	1b -- 59-ft gage	
Seq-Prairie - 8	8a -- before 02-15-97	8b -- between 02-16-97 and 7-31-97	8c -- after 08-01-97
Emery Creek	a -- before 03-21-96	b -- after 03-22-96	

[2] The standard error of estimate for multiplicative equations ($Q = aGH^b$) is not computed as a percent of the mean discharge, as the arithmetic equations are. It is computed as described in Riggs (1968).

Appendix C. Quality-Assurance of Water-Quality Data

APPENDIX C. QUALITY-ASSURANCE ASSESSMENT OF WATER-QUALITY DATA

To ensure that the water-quality data were of sufficient quality to meet study objectives, the quality-assurance plan for this study (B.E. Thomas, U.S. Geological Survey, written commun., 1995) outlined quality-control procedures for data collection and analysis. Whereas many of the procedures address only methodology, some procedures required the collection and analysis of quality-control samples. The resulting data were reviewed to determine the quality of the project water-quality data. Tables C1, C2, and C3, which show the quality assurance data and results of data analyses, are at the end of this appendix.

The majority of the water-quality data for this study appeared to be of sufficient quality by all measures used in this quality-assurance assessment. All water-quality data are, therefore, shown in this report. Errors associated with duplicate samples were within project criteria for all constituents except ammonia nitrogen and iron. A few duplicate pairs for those constituents exceeded the project criteria for percentage differences; however, the large percentage differences were for concentrations near detection limits with small absolute differences. Concentrations of constituents in blank samples were unimportant except for low concentrations of ammonia nitrogen and nitrate nitrogen. Because of potential problems with contamination of field samples by low concentrations of ammonia and nitrate, the reporting levels were raised to 0.04 mg/L for ammonia and 0.10 mg/L for nitrate.

Duplicate Samples

Duplicate pairs of samples were collected for all the laboratory analyses. Quality-assurance criteria for this study called for a difference of 10 percent or less for chloride and nitrogen and a difference of 20 percent or less for iron. To evaluate these data, the percentage differences between the concentrations of the sample pairs were determined for each constituent and an average absolute percentage difference was computed. Several sample pairs had one concentration below the detection limit and the other concentration near the detection limit. To compute a percentage difference for these pairs, the concentration below the detection limit was assumed to be equal to the detection limit.

The sample pairs for all constituents met the project criteria except two pairs for ammonia nitrogen and one pair for iron (table C1). These exceedances were considered unimportant because the absolute concentrations of the sample pairs were low—two sample pairs had ammonia nitrogen concentrations of 0.03 and 0.05 mg/L and 0.05 and 0.06 mg/L, and one sample pair had iron concentrations of 3.0 and 4.0 µg/L.

Blank Samples

Blanks of deionized water were processed in the same manner as field water samples and sent to the National Water Quality Laboratory (NWQL) for analysis (see pages 23 to 25); the resulting data are summarized in table C2. Although no criteria were set for constituent concentrations in blanks, the importance of any constituent present in a blank was based on (1) how close the constituent concentration was to the detection limit, (2) how close the median blank concentration was to the median sample concentration, and (3) the number of times the constituent was detected in blank samples. When compared with these three factors, the concentrations of blanks were unimportant for all constituents except ammonia nitrogen and nitrate nitrogen.

Ammonia nitrogen and nitrate nitrogen were present in five of the seven blank samples. The median concentration of the blanks was 0.02 mg/L for ammonia and 0.06 mg/L for nitrate. The maximum concentration of the blanks was 0.04 mg/L for ammonia and 0.12 mg/L for nitrate. There appears to have been a small contamination problem with these blanks. It is not known if the contamination was limited to blanks or if it was more widespread and some of the field samples were contaminated with small amounts of ammonia or nitrate. The cleaning of the flow chamber, manifold, tubing, and filters between sites may not have been thorough. Blank sample bottles were filled with deionized water when the field technician first arrived at a well site. Then, before the field sample was collected, the flow chamber, manifold, and tubing were flushed with well water for a minimum of 15 minutes. This thorough flushing of well water, therefore, might have reduced the potential problem of contamination of field samples.

Because of potential problems with contamination of the field samples by low concentrations of ammonia and nitrate, the reporting levels were raised from 0.015 to 0.04 mg/L for ammonia and from 0.05 to 0.10 mg/L for nitrate. The new reporting levels are about halfway between the highest and second highest concentrations of the blanks, which is about the 80th percentile of the blank data.

Interpretations of ammonia concentrations were made cautiously because only 31 percent of the field samples had concentrations higher than 0.04 mg/L. The nitrate data were judged to be valuable and were interpreted because 74 percent of the field samples had concentrations higher than 0.10 mg/L. Nitrate concentrations determined for this study were (1) compared to concentrations in 1980, (2) evaluated for magnitude and areal distribution, (3) compared to land use, and (4) compared to septic-system density. These interpretations are valid because of the raised reporting limit for the 1996 data.

Evidence that the field samples were not appreciably contaminated is the comparison of nitrate concentrations in the primary study area between the 65 samples collected in 1996 and the 316 samples collected in 1992 (Clallam County of Community Development, 1994). The median nitrate concentrations and the spread in concentrations were similar; 25th percentiles were 0.03 mg/L for 1992 and <0.10 mg/L for 1996, medians were 0.55 mg/L for 1992 and 0.46 mg/L for 1996, and 75th percentiles were 1.3 mg/L for 1992 and 1.4 mg/L for 1996. A rank-sum test (two-sided) showed no significant difference between the medians.

Checks on Field Values

The accuracy of field values of pH, specific conductance, dissolved oxygen, and temperature primarily depends on proper instrument calibration and field procedures. Values of pH and specific conductance are also determined in the laboratory as standard procedures in various analyses. Six of the 74 samples had laboratory and field values of pH differ by more than 0.3 units. The largest difference in pH was 0.6 units for one sample. Only one of the 74 samples had laboratory and field values of specific conductance differ by more than 5 percent, and that difference was 5.5 percent. These comparisons indicate the field values are reasonable.

Table C1. Average absolute differences in constituent concentrations determined for duplicate samples

Constituent	Number of duplicate pairs	Average absolute difference (percent)	Number of pairs exceeding difference criteria[1]
Chloride	9	2.2	0
Nitrite nitrogen	7	0.0	0
Nitrite plus nitrate nitrogen	7	1.1	0
Ammonia nitrogen	7	12.7	2
Ammonia plus organic nitrogen	7	0.0	0
Iron	9	7.6	1

[1] Percentage difference criteria are 10 percent for chloride and nitrogen and 20 percent for iron.

Table C2. Summary of constituent concentrations determined for blank samples

[µg/L, micrograms per liter; <, less than]

				Concentration, in milligrams per liter, unless otherwise noted		
Constituent	Number of blanks	Detection limit	Number of blanks equal to or exceeding detection limit	Median concentration of blanks	Maximum concentration of blanks	Median concentration of all field samples (n = 74)
Chloride	9	0.1	4	<0.1	0.3	6.2
Nitrite nitrogen	7	.01	0	<0.01	<0.01	<0.01
Nitrite plus nitrate nitrogen	7	.05	5	0.06	0.12	0.32
Ammonia nitrogen	7	.015	5	0.02	0.04	0.03
Ammonia plus organic nitrogen	7	.2	0	<0.2	<0.2	<0.2
Iron (µg/L)	9	3.0	2	<3.0	4.0	7.5

Table C3. Field measurements and concentrations of selected constituents in quality-assurance ground-water samples, July–August 1996, Sequim-Dungeness area, Washington

[--, no data; <, less than]

Local well number	Date	Type of sample	Specific conductance, field (microsiemens per centimeter)	Specific conductance, laboratory (microsiemens per centimeter)	pH, field (standard units)	pH, laboratory (standard units)	Chloride, dissolved, (milligrams per liter as Cl
30N/03W-06B01	08-01-96	Field	266	268	7.6	7.5	3.1
		Duplicate	--	268	--	7.6	3.1
		Blank	--	2	--	7.4	<0.1
30N/03W-08M01	08-08-96	Field	342	330	8.0	7.8	3.8
		Duplicate	--	331	--	7.8	3.8
30N/03W-09R01	08-23-96	Field	315	312	8.4	8.1	5.0
		Duplicate	--	312	--	8.1	4.9
		Blank	--	3	--	7.6	<.3
30N/03W-15G01	08-07-96	Field	341	331	8.3	8.0	4.5
		Duplicate	--	330	--	8.0	4.3
30N/03W-18M03	08-07-96	Field	297	294	7.9	7.7	4.0
		Duplicate	--	290	--	7.7	3.8
		Blank	--	--	--	7.7	.3
30N/03W-27B04	07-31-96	Field	597	595	7.6	7.6	15
		Duplicate	--	597	--	7.6	15
		Blank	--	3	--	7.5	.2
30N/03W-30K03	08-08-96	Field	487	476	7.1	7.4	16
		Blank	--	3	--	7.7	<.1
30N/04W-02M05	07-30-96	Field	378	375	7.6	7.5	6.0
		Duplicate	--	--	--	--	--
		Blank	--	2	--	7.5	<.1
30N/04W-20E01	07-25-96	Field	212	213	6.4	6.4	8.9
		Duplicate	--	213	--	6.5	9.2
		Blank	--	4	--	6.6	<.1
30N/05W-20G01	08-08-96	Field	366	357	7.4	7.5	6.4
		Duplicate	--	359	--	7.5	6.2
		Blank	--	4	--	7.4	.3
31N/04W-27P01	08-01-96	Field	303	304	7.7	7.7	6.3
		Duplicate	--	305	--	7.7	6.2
31N/04W-36E03	08-09-96	Field	268	263	7.4	7.5	5.2
		Blank	--	3	--	7.6	<.1

Table C3. Field measurements and concentrations of selected constituents in quality-assurance ground-water samples, July–August 1996, Sequim-Dungeness area, Washington—Continued

Local well	Type of	Nitrogen, nitrite, dissolved (milli-grams per liter	Nitrogen, nitrite plus nitrate, dissolved (milli-grams per liter	Nitrogen, ammonia, dissolved (milli-grams per liter	Nitrogen, ammonia, plus organic dissolved (milli-grams per liter	Iron, dissolved (micro-grams per liter
30N/03W-06B01	Field	<0.01	0.46	0.05	<0.2	38
	Duplicate	<.01	.46	.03	<.2	39
	Blank	--	--	--	--	<3.0
30N/03W-08M01	Field	<.01	1.7	<.015	<.2	<3.0
	Duplicate	--	--	--	--	<3.0
30N/03W-09R01	Field	<.01	<.05	.18	<.2	12
	Duplicate	<.01	<.05	.19	<.2	11
	Blank	<.01	<.05	<.015	<.2	<3.0
30N/03W-15G01	Field	<.01	.06	.08	<.2	25
	Duplicate	--	--	--	--	24
30N/03W-18M03	Field	<.01	3.2	.02	<.2	<3.0
	Duplicate	<.01	3.2	.02	<.2	<3.0
	Blank	<.01	.06	.02	<.2	<3.0
30N/03W-27B04	Field	.01	.19	.06	<.2	<3.0
	Duplicate	<.01	.18	.05	<.2	4.0
	Blank	<.01	.12	.04	<.2	<3.0
30N/03W-30K03	Field	<.01	1.4	<.015	<.2	<3.0
	Blank	--	--	--	--	4.0
30N/04W-02M05	Field	<.01	.09	.42	.4	370
	Duplicate	--	--	--	--	--
	Blank	<.01	.09	.03	<.2	<3.0
30N/04W-20E01	Field	.01	3.9	.03	<.2	15
	Duplicate	<.01	4.0	.03	.2	15
	Blank	<.01	.07	.03	<.2	3.0
30N/05W-20G01	Field	<.01	<.05	<.015	<.2	490
	Duplicate	<.01	<.05	<.015	<.2	470
	Blank	<.01	<.05	<.015	<.2	<3.0
31N/04W-27P01	Field	<.01	<.05	.16	.2	410
	Duplicate	<.01	<.05	.15	<.2	390
31N/04W-36E03	Field	<.01	.06	.05	<.2	150
	Blank	<.01	.06	.02	<.2	<3.0

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