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Hydrogeology, Ground-Water Quality, and Sources of Nitrate in Lowland Glacial Aquifers of Whatcom County, Washington, and British Columbia, Canada

Water-Resources Investigations Report 98-4195

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

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By Stephen E. Cox and Sue C. Kahle

U.S. GEOLOGICAL SURVEY

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District Chief
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Tacoma, Washington 98402

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CONTENTS

PLATES (Plates are located in pocket, inside back cover)

FIGURES

TABLES

APPENDIX TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
acre	2.47	hectare
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
acre-foot (acre-ft)	1,234	cubic meter
gallon per day per square foot (gal/day/ft^2)	0.1339	foot per day
pound per acre (lb/acre)	1.12	kilogram per hectare
degree Fahrenheit (°F)	$^{o}C = 5/9 \times (^{o}F-32)$	degree Celsius

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.

Hydrogeology, Ground-Water Quality, and Sources of Nitrate in Lowland Glacial Aquifers of Whatcom County, Washington, and British Columbia, Canada

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ABSTRACT

Ground water is an important source of domestic, municipal, and irrigation water supply throughout the Fraser-Whatcom Lowland, particularly for the 225-square mile agricultural area surrounding the Whatcom County communities of Lynden, Everson, Nooksack, and Sumas and the British Columbia communities of Abbotsford and Aldergrove. Population growth and developing ground-water-quality problems have increased the demand for additional sources of ground water. The U.S. Geological Survey, in cooperation with the Whatcom County Planning Department, collected water-level, lithologic, and water-quality data from 608 wells during 1990-92 to complete a regional appraisal of the ground-water system.

The study area is underlain largely by glacial sediments that vary from zero to more than 1,500 feet thick and overlie Tertiary bedrock. Ten hydrogeologic sections were constructed and used to delineate four principal hydrogeologic units: the Sumas aquifer and the Everson-Vashon, Vashon, and bedrock semiconfining units. The Sumas aquifer can supply large quantities of ground water to wells and is the major aquifer in the study area, whereas the semiconfining units supply limited quantities of ground water to some wells.

Precipitation ranges from 32 to more than 60 inches across the study area and is the primary source of ground-water recharge, which ranges from 11 to 45 inches per year. Most recharge occurs from October to March.

The chemical quality of most ground-water samples was generally good; however, nitrate concentrations exceeded the maximum contaminant level of 10 milligrams per liter (mg/L), established by the Environmental Protection Agency and Health Canada, in 15 percent of all wells sampled. For iron and manganese, concentrations exceeded drinking water guidelines based on esthetic consideration in 20 and 50 percent, respectively, of wells sampled for those constituents.

In the Sumas aquifer, nitrate concentrations ranged from less than 0.1 to greater than 40 mg/L as nitrogen, with a median concentration of 3.8 mg/L; in the other hydrogeologic units the median concentration was less than 0.1 mg/L. Nitrate concentrations in the Sumas aquifer exceeded the primary drinking water standard of 10 mg/L in more than 21 percent of the wells sampled, and in the other hydrogeologic units, in less than 2 percent of the wells sampled. The primary sources of nitrate in the shallow ground water includes the storage and application of barnyard manures, the application of nitrogen fertilizers to crops, and the use of domestic septic systems.

Nitrate concentrations in the Sumas aquifer showed significant short-term (seasonal) variation; long-term trends were difficult to discern, but concentrations appeared to be increasing in some areas. Nitrate concentrations in almost all wells in the Everson-Vashon, Vashon, and bedrock semiconfining units remained relatively unchanged over time.

Chloride concentrations ranged from 0.3 to 2,800 mg/L, and median chloride concentrations in the Sumas aquifer, Everson-Vashon, Vashon,

and bedrock semiconfining units were 9, 8, 187, and 37 mg/L, respectively. In the Sumas aquifer, more than 70 percent of wells sampled had concentrations larger than background chloride concentrations of 4 mg/L, suggesting that ground water in most of the aquifer has been affected by land-use activities. Large chloride concentrations found in many wells tapping the fine-grained glacial deposits are most likely associated with remnant seawater that was incorporated into these fine-grained deposits 13,000 to 20,000 years ago and has not been completely flushed by meteoric water. The widespread occurrence of remnant seawater in the deeper hydrogeologic units indicates that there is little chance of locating large, sustainable sources of fresh water within these units.

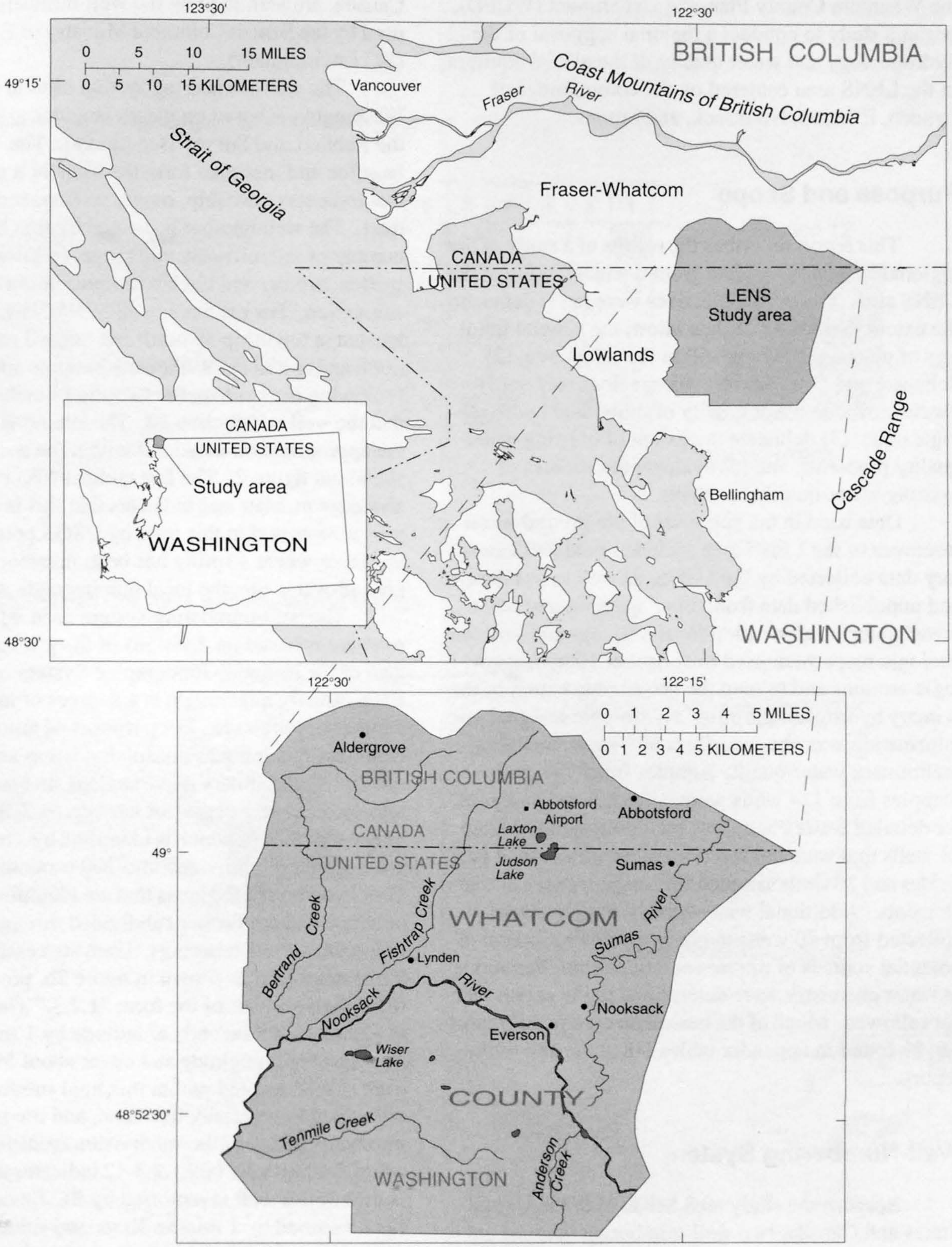
Ground-water samples from 24 wells open to the Sumas aquifer were analyzed for selected volatile organic compounds, triazine herbicides, and carbamate insecticides. One or more synthetic organic compounds were found in samples from four wells. Concurrent and subsequent sampling by other agencies also detected synthetic organic compounds.

Potential sources of nitrate in the ground water of the study area include dairy and poultry farming; fertilizers applied to croplands, lawns and gardens; residential septic systems; irrigation with ground water containing nitrates; land disposal of municipal biosolid wastes; and naturally occurring soil nitrogen, peat materials, and precipitation. About 75 percent of the area is used for agricultural activities, and evaluation of nitrate loading to ground water from these activities indicates that land application of manure, manure storage, and the use of fertilizers contribute the greatest quantities of nitrate. Residential sources contribute about 6 to 7 percent of total nitrogen input to ground water, but because this often occurs near areas where domestic wells are located, the impact of residential nitrate sources on concentrations of nitrates in some well water may be large. Even though agricultural sources contribute much larger quantities of nitrate to ground water than do residential sources, on a per-acre basis the rate of nitrate entering ground water from agricultural sources is about 1.5 to 3 times larger than for residential sources.

INTRODUCTION

The Nooksack River floodplain and the upper Sumas River Valley region of Whatcom County and British Columbia are located on glacial sediments of the Fraser-Whatcom Lowlands, much of which has been developed extensively as a major farming region. This study covers approximately 225 square miles of the southeastern portion of the Fraser-Whatcom Lowlands and is locally referred to as the LENS study, which refers to the Whatcom County communities of Lynden, Everson, Nooksack, and Sumas (fig. 1). Shallow ground water within these glacial sediments currently supplies much of the domestic, irrigation, and municipal water for the area. Early studies of the ground water within the LENS area (Newcomb and others, 1949; Washington State Division of Water Resources, 1960) considered the supply of shallow ground water to be ample and its quality "good." However, increasing numbers of water-quality problems were identified between 1973 and 1988 (Obbert, 1973; Black and Veatch, 1986; Liebscher and others, 1992; and Kwong, 1986). The study by Obbert (1973) and recent Whatcom County Health Department drinking water records show large concentrations of nitrate and iron commonly are found in ground water throughout the area. A trend of increasing nitrate concentration is also apparent in several wells where historical data are available. Areas of salty and corrosive water have been identified. Ethylene dibromide (EDB), a pesticide once commonly used in berry farming, also has been found in ground water at several locations. More recently, concerns have been raised regarding the extent and availability of ground water within the LENS area.

Declining water-quality conditions and an increasing population have resulted in an increased demand for supplies of potable ground water. Attempts to find additional sources of potable ground water have been hampered in part by inadequate knowledge of the hydrologic conditions of the area. Previous hydrologic investigations of this area have been limited in either scope or areal extent. Because of the need for a current, comprehensive hydrologic assessment of the area, the U.S. Geological Survey (USGS), in cooperation with



Base from U.S. Geological Survey digital data, 1:100,000, 1975
and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980 UTM Zone 10

Figure 1. Location of the Lynden-Everson-Nooksack-Sumas (LENS) study area in Whatcom County, Washington, and British Columbia, Canada.

the Whatcom County Planning Department (WCPD), began a study to conduct a regional appraisal of the hydrogeology and water quality of the glacial aquifers in the LENS area centered on the communities of Lynden, Everson, Nooksack, and Sumas.

Purpose and Scope

This report describes the results of a study of the regional hydrogeology and ground-water quality of the LENS area. The study objectives were to (1) define, to the extent that available data allow, the general lithology of glacial sediments within the study area; (2) delineate and characterize hydrogeologic units; (3) characterize the water quality of individual hydrogeologic units; (4) delineate the extent of existing water-quality problems; and (5) evaluate the sources of existing water-quality problems.

Data used in the appraisal of the ground-water resources of the LENS area included field and laboratory data collected by the USGS, as well as published and unpublished data from other agencies and other investigators. Information from well logs and surficial geologic maps were used to construct 10 hydrogeologic sections and to map the geographic extent of the primary hydrogeologic units. Hydrologic and geologic information was obtained from 608 wells, including preliminary water-quality samples from 356 wells. Samples from 124 wells were collected and analyzed for detailed water chemistry, including samples from 24 wells that were analyzed for concentrations of pesticides and 20 wells sampled for concentrations of trace elements. Additional water-quality samples were collected from 70 wells to aid in the determination of potential sources of nitrate contamination. Variations in water chemistry were determined to the extent that data allowed. Much of the basic data used in this report can be found in appendix tables 1-8 at the end of the report.

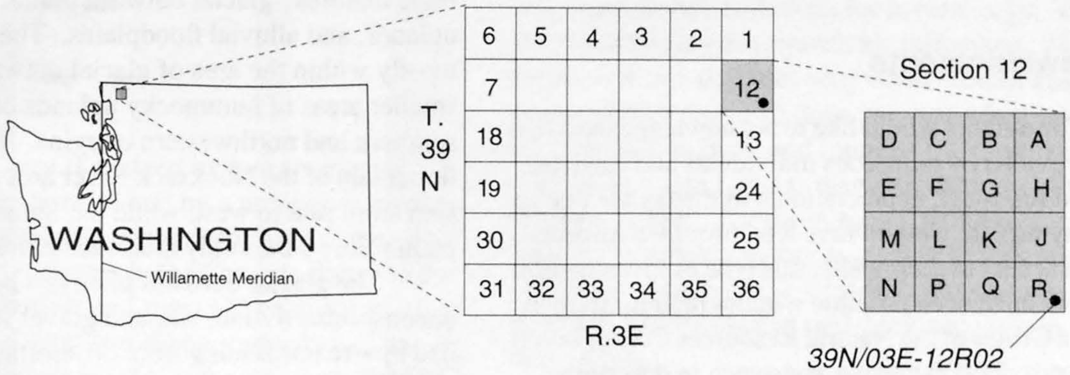
Well-Numbering System

Because the study area lies in both the United States and Canada, two well-numbering systems are used in this report. Both well-numbering systems are based on the geographic locations of the wells. Wells located within Whatcom County, Wash., are identified by the well-numbering system used in the State of Washington. Wells located within British Columbia, Canada, are identified by the well-numbering system used by the British Columbia Ministry of Environment (BC Environment).

The well-numbering system used in the State of Washington is based on the rectangular grid system of the Public Land Survey (see fig. 2a). The Willamette baseline and meridian form the basis of a grid system that indicates township, range, section, and 40-acre tract. The well number is created by first listing the number of the township and range, followed by the section number and the letter representing the 40-acre subsection. For example, well 39N/03E-12R02 is located in township 39 north and range 3 east, which is north and east of the Willamette baseline and meridian. Following the hyphen, the two-digit number indicates that the well is in section 12. The letter ("R") indicates the appropriate 40-acre tract within the section, as shown on figure 2. The last number (02) is the sequence number and indicates that this is the second well inventoried in this tract by USGS personnel. In instances where a spring has been inventoried as a ground-water site, the local number ends with an "S".

The well-numbering system used by BC Environment is based on divisions of the primary quadrangles of the National Topographic System of Canada. Each primary quadrangle is 4 degrees of latitude by 8 degrees of longitude. For purposes of numbering wells, the quadrangles are subdivided as shown in figure 2b. Each primary quadrangle is first subdivided into 16 areas of 1 degree of latitude by 2 degrees of longitude, each of which is identified by a letter. These areas then are subdivided into 100 6-minute by 12-minute numbered areas that are identified by 3-digit numbers and are further subdivided through a process of 3 successive quarterings. Each successive quartering is numbered as shown in figure 2b, producing a three-digit number of the form "1.2.3." The final subdivisions are 45 seconds of latitude by 1 minute and 30 seconds of longitude and cover about 590 acres each. Wells located within this final subdivision are numbered sequentially from one, and the sequential number is added to the subdivision identifier. For example, well 92G.008.1.2.3-12 indicates that this well is the twelfth well inventoried by BC Environment in the 45 second by 1 minute 30 second subdivision identified as 92G.008.1.2.3. In wells where nested piezometers have been installed, the individual piezometer cannot be distinguished by the well local number. In those cases the depth of the bottom of the screened-interval has been added to the end of the local

(a) State of Washington well-numbering system



(b) British Columbia well-numbering system

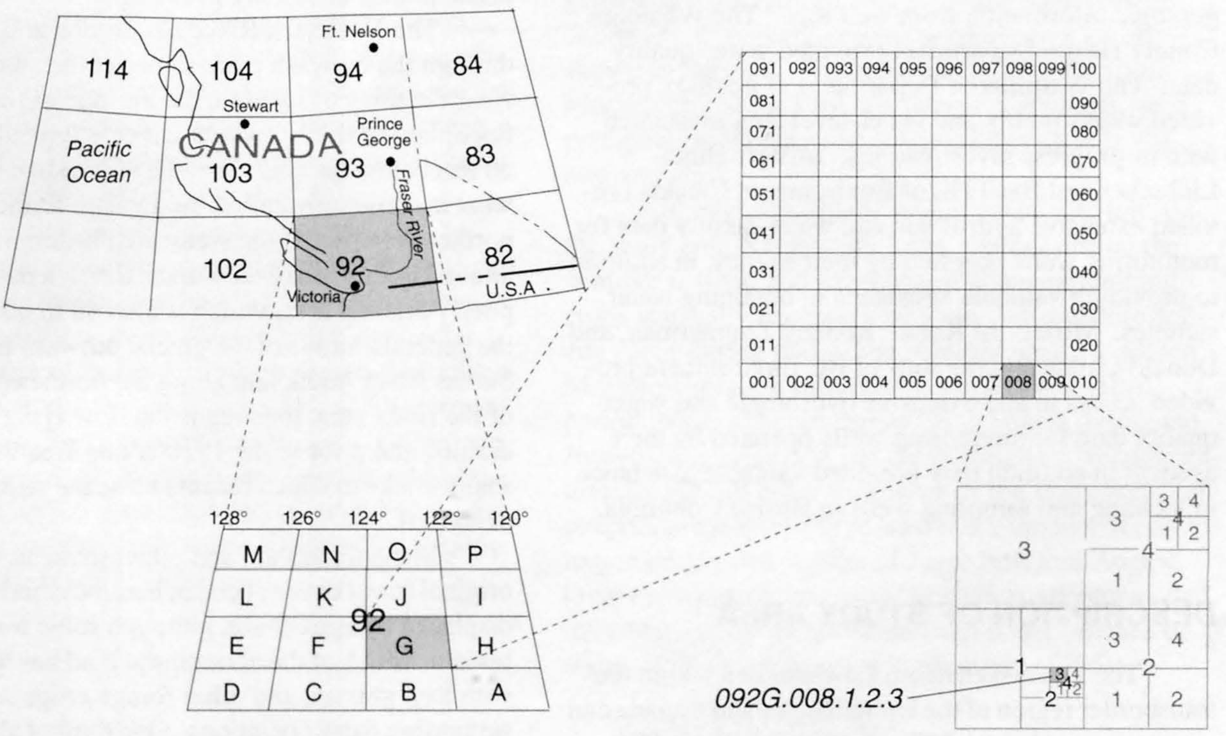


Figure 2. Well- and spring-numbering systems used in (a) Washington and (b) British Columbia.

number as in well 092G.009.1.1.1-12(25). Wells that did not have BC Environment assigned sequence numbers were designated as XX or in cases where the well in question was a monitoring well installed by Environment Canada (EC), the EC monitoring well number was used, as in 092G.008.1.1.4-ABB1.

Acknowledgments

The authors would like to acknowledge the assistance provided by numerous individuals and agencies. First and foremost, appreciation and thanks are due to the many private well owners who provided information and access to their wells; this type of investigation would not have been possible without their assistance. Mr. John Gillies of the Natural Resources Conservation Service provided extensive assistance in describing agricultural practices within the area and in evaluating agricultural sources of nitrate in ground water. Similar assistance was also provided by Craig McConnel, Washington State University Extension Service. Dr. Charles Flora provided access to 11 years of weekly water-quality data. Hayes Drilling Company provided geologic information from well logs. The Whatcom County Health Department provided water-quality data. The Washington Department of Ecology provided water-quality and water-level data associated with in-progress investigations. Misters Hugh Liebscher and Basil Hii of Environment Canada provided extensive hydrologic and water-quality data for monitoring wells operated by their agency, in addition to providing valuable assistance in obtaining water samples. Misters Al Kohut, Rodney Zimmerman, and Donald Childs and the staff of BC Environment provided access to and extensive hydrologic and water-quality data for monitoring wells operated by their agency; in addition they provided valuable assistance in locating and sampling wells in British Columbia.

DESCRIPTION OF STUDY AREA

The Fraser-Whatcom Lowland lies within the transborder region of the United States and Canada and encompasses about 1,000 mi^2 (square miles). This region is bounded by the Coast Mountains of British Columbia, the Cascade Range, and the Strait of Georgia (see fig. 1). The LENS study area is limited to about 225 mi^2 in the southeastern part of the Fraser Lowland near the Cascade foothills. Seventy-six percent of the study area is in Whatcom County, and the remaining area is in British Columbia.

The land surface of the study area is dominated by glacial features and can be characterized by three landforms that correspond to the major surficial geologic features: glacial outwash plains, hummocky uplands, and alluvial floodplains. The study area falls mostly within the area of glacial outwash plains, with smaller areas of hummocky uplands occurring on the southern and northwestern margins. The alluvial floodplain of the Nooksack River arcs across the study area from east to west, while the Sumas River floodplain follows the study area's eastern border.

The glacial outwash plain is a broad expanse of unconsolidated sand, silt, and gravel sediments deposited by streams issuing from the terminus of advancing and retreating continental glaciers. The surface of the outwash plain has limited relief except in places where it has been incised by streams, rivers, or glacial meltwater. Local depressions formed by glacial kettles are common, and because of the shallowness of the water table in this area, many of these kettles now contain lakes, ponds, or marshy peat bogs.

The Nooksack River has eroded and cut down through the outwash plain to bisect the study area. Near the town of Lynden, the altitude of the present floodplain of the Nooksack River is typically 40 to 60 feet below the altitude of the outwash plain, creating what is commonly called the Lynden terrace. The northeastern part of the study area is dominated by the alluvial floodplain of the Sumas River, a flat, low lying, poorly drained area, which is also 40 to 60 feet below the general altitude of the glacial outwash plain. In the Sumas River floodplain along the northeastern margin of the study area, the area is flat, low lying and poorly drained and prior to the 1920's, this area was part of a shallow lake in which recent lacustrine sediments were deposited.

In the floodplain and outwash areas, most of the original forest cover of cedar, hemlock, and fir has been displaced by agriculture, although some forested areas remain. Much of the agricultural land has been planted with hay, grasses, and other forage crops suitable for supporting dairy operations. One third of all the dairies in Washington State are located within the study area. In addition to pasture lands, berry production makes up a significant part of agricultural lands within the study area.

The hummocky upland areas occur above the level of accumulation of the glacial outwash sediments that make up the outwash plain. These areas are characterized by undulating topography, fine-grained soils, and generally poor drainage. During heavy winter rains, water tends to accumulate within the many depressions of these areas.

Drainage

The study area is drained by two rivers--the Nooksack and the Sumas--and by a number of creeks and drainage ditches that empty into these rivers. The Nooksack River originates in the Cascade Range to the east of the project area, and most (72 percent) of its drainage area lies upstream of the study area. The Nooksack River traverses the study area for a distance of 25 miles, with an average gradient of 10 feet per mile above and 4 feet per mile below the town of Everson. During floods, the Nooksack River often overflows its banks near the town of Everson, where part of the overbank flow then enters the Sumas River drainage to the Fraser River in British Columbia. Tributaries to the Nooksack River include Bertrand, Fishtrap, Tenmile, and Anderson Creeks. The Sumas River flows northward, draining the eastern part of the study area and the adjacent Cascade Range foothills before leaving the study area and discharging to the Fraser River 10 miles northeast of Abbotsford.

Because much of the study area initially was poorly drained, numerous surface drainage ditches and subsurface tile drains have been built to remove excess surface and shallow ground water, allowing greater agricultural use of the land. Surface-water features and the extent of artificially drained soils (U.S. Department of Agriculture, Soil Conservation Service, 1992b) are shown in figure 3. Soils within the Canadian part of the study area, which is generally found at higher altitudes, typically are undrained (Bernard Zebarth, Agriculture Canada, oral commun., 1993).

Climate

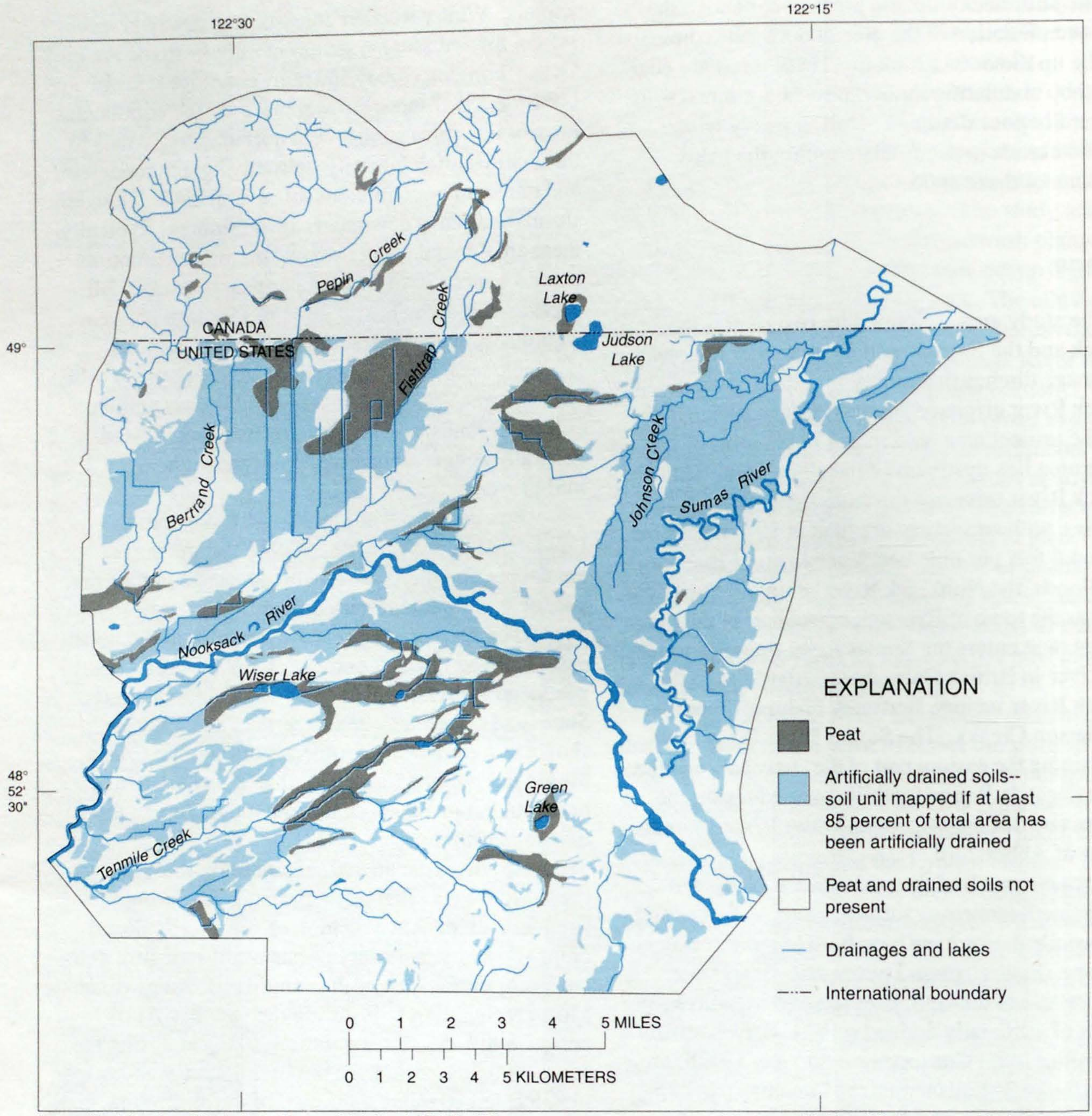
The climate of the Fraser-Whatcom Lowlands is strongly influenced by maritime air from the Pacific Ocean, which has a moist moderating effect (Phillips, 1966). The Cascade Range and Rocky Mountains typically shield the region from cold air masses moving southward from Canada. The region generally experiences warm, dry summers and mild, rainy winters. Winter weather consists of a steady progression of low-pressure systems entering from the Pacific Ocean, bringing cloudy and rainy conditions; however, occasional high-pressure systems over the continental interior introduce strong, cold northeasterly winds to the area. Rainfall intensity is usually light to moderate, and rains can be continuous for several days. Thunderstorms and heavy downpours are infrequent. Typically, there are 4 to 5 days per year when rainfall amounts exceed 1 inch, 20 to 25 days per year when rainfall exceeds half an inch, and roughly 150 days per year with measurable (greater than 0.01 inch) rainfall (Phillips, 1966). The mean annual temperature is 49°F, with the warmest weather occurring in July and the coldest in January. The frost-free growing season generally begins around mid-May and ends in mid-October.

Precipitation within the Fraser-Whatcom Lowlands is quite variable. Within the study area annual precipitation ranges from about 32 inches per year near the southwestern corner of the study area, to over 60 inches per year near Abbotsford, in the northeast. Isohyetal lines (contours of equal rainfall depth) generated from rainfall data provided from United States and Canadian weather service agencies are shown in figure 4. The influence of both the Coast Mountains and the Cascade Range is apparent, as precipitation increases near these mountains to the east and north.

Although the annual precipitation that falls on the study area is relatively large, rainfall during the summer is light, and irrigation of some agricultural crops is usually necessary because soil-moisture deficits occur during part of the summer growing season. Most precipitation falls during the October-April period, while evapotranspiration is largest during the June-to-August period. At the Bellingham weather station, located 20 miles southwest of the study area, pan evaporation is typically at least twice the rate of precipitation during the months of June, July, and August. Over the course of the growing season, recommended irrigation requirements range from 6 to 17 inches of water (U.S. Department of Agriculture, 1985).

Soils

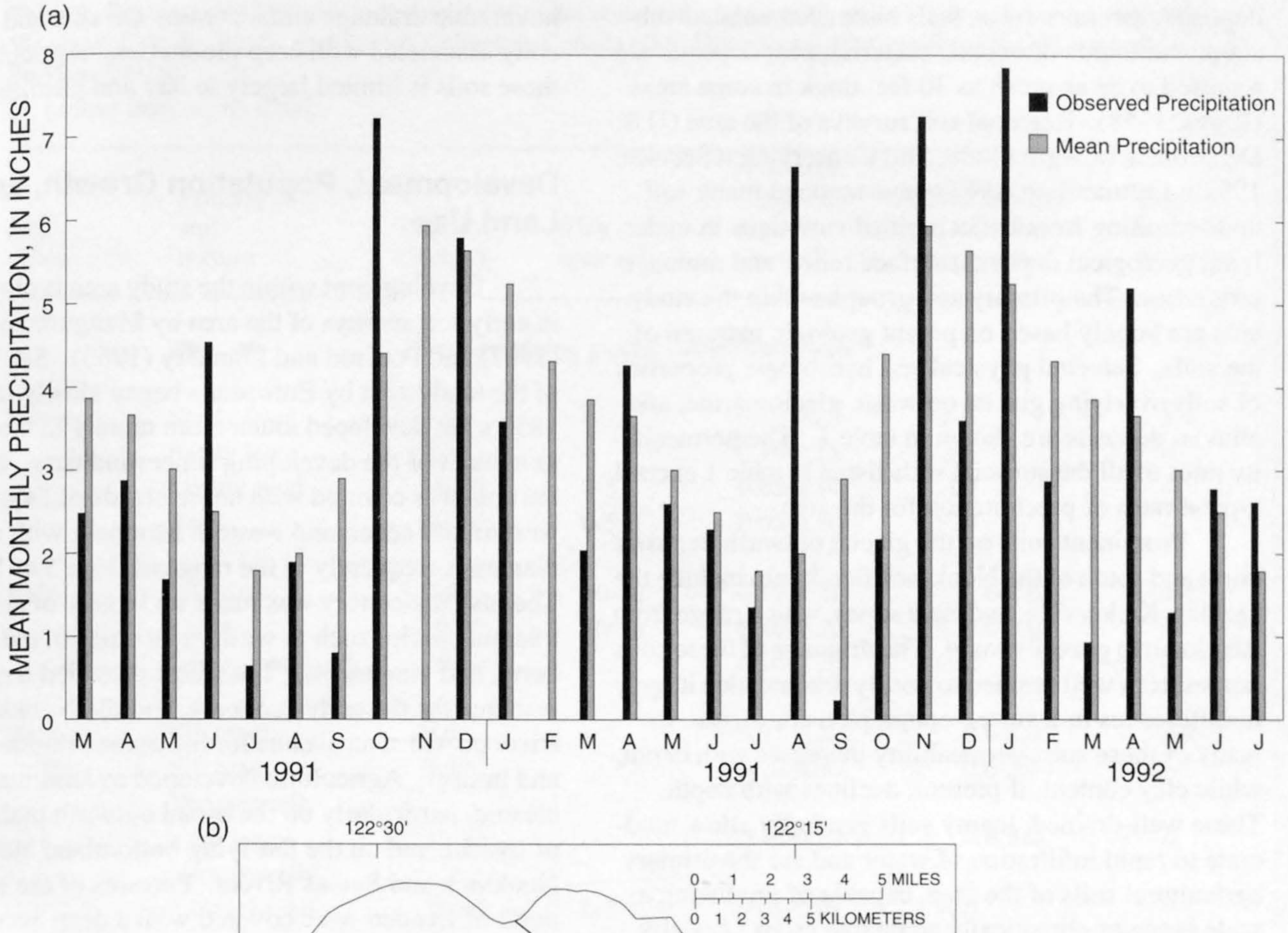
The physical characteristics of soil affect the quantity and quality of water recharging shallow aquifers. The soils within the study area were derived largely from the underlying glacial and alluvial



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Soils data modified from U.S. Department of Agriculture, 1992 and Lettmerding, 1981.

Figure 3. Surface drainage features and extent of peat and artificially drained soils in parts of the Lynden-Everson-Nooksack-Sumas (LENS) study area.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Data from U.S. Weather Bureau, and Environment Canada.

Figure 4. (a) Observed and mean monthly precipitation at the Clearbrook, Washington Weather Station, and (b) annual precipitation in inches per year for the Lynden-Everson-Nooksack-Sumas (LENS) study area.

deposits. In some areas, soils have accumulated substantial amounts of organic material; peat deposits are reported to be as much as 30 feet thick in some areas (Riggs, 1958). Regional soil surveys of the area (U.S. Department of Agriculture, Soil Conservation Service, 1992b; Luttmerding, 1981) have mapped many soil units resulting from the combined variations in underlying geological deposits, surface relief, and drainage properties. The primary soil groups within the study area are largely based on parent geologic material of the soils. Selected physical and hydrologic properties of soils overlying glacial outwash, glaciomarine, and alluvial deposits are shown in table 1. The permeability rates of all the surficial soils listed in table 1 exceed typical rates of precipitation for the area.

Prominent soils on the glacial outwash deposits north and south of the Nooksack floodplain include the Lynden, Kickerville, and Hale series, which range from silty loam to gravelly loam. The drainage of these soils ranges from well drained to poorly drained, due largely to differences in texture, topography, and slope. In many of these soils permeability increases with depth, while clay content, if present, declines with depth. These well-drained, loamy soils generally allow moderate to rapid infiltration of water and are the primary agricultural soils of the area, capable of producing a wide range of climatically adaptable crops. Locally, peat deposits have developed in depressions on some of these soils.

Soils derived from alluvial deposits in the floodplains of the Nooksack and Sumas Rivers and of Anderson Creek are generally loamy but can be further divided into excessively well-drained soils and the silt-clay soils that require artificial drainage. This soil distinction forms the basis for distinguishing surficial geologic deposits within the previously mapped alluvial unit of Easterbrook (1976a). In the Sumas Valley the silt-clay soils are extensive and hydrologically significant because they can create confined conditions in the shallow aquifer and because they are a barrier to ground-water recharge.

Soils along the southern and northwestern margins of the study area, such as the Whatcom and Skipapoa soils, are derived from glaciomarine deposits. These are heavy, deep soils that range from moderately well drained to poorly drained. In these soils, the clay content tends to increase with depth; while the permeability of these soils tends to decrease with depth. The hummocky, undulating land surface results in variable drainage and increases the cost and difficulty associated with crop production. Agriculture on these soils is limited largely to hay and pasture.

Development, Population Growth, and Land Use

Development within the study area is chronicled in early soil surveys of the area by Mangum and Hurst (1907) and Poulson and Flannery (1953). Settlement of the study area by Europeans began slowly in the 1850's but developed much more rapidly in the 1880's as a result of the developing timber industry. Initially the area was covered with dense stands of Douglas fir, western red cedar, and western hemlock, with tree diameters frequently in the range of from 5 to 15 feet. The lush understory was made up largely of shade-tolerant species such as western swordfern, red huckleberry, and vine maple. The forest provided a rich resource for the early economy, and the Nooksack River provided an avenue for the transportation of logs and lumber. Agriculture developed as land was cleared, particularly on the broad outwash plain north of Lynden and on the flat-lying bottomland along the Nooksack and Sumas Rivers. Portions of the plain north of Lynden were covered with a deep accumulation of organic matter, much of which was burned off once the area had been thoroughly drained. As of 1950, all of the lowland virgin forests had been cut, and the economy of the study area was based largely on agriculture.

The population within the study area and surrounding regions has been increasing steadily over the last 50 years (fig. 5). In 1990, the population within the study area was estimated to be about 35,000, much of it centered around the municipalities of Lynden, Everson, Nooksack, and Sumas in Whatcom County and of Abbotsford and Aldergrove in British Columbia. In 1990, the Whatcom County communities of Lynden, Everson, Nooksack, and Sumas had populations of 5,709, 1,490, 584, and 744, respectively; this accounts for about 33 percent of the total population within the Whatcom County part of the study area (Diane Harper, Whatcom County Planning Department, written commun., 1992). In general, population growth has been faster in the unincorporated parts of the county than in the municipalities and appears to be fastest in British Columbia.

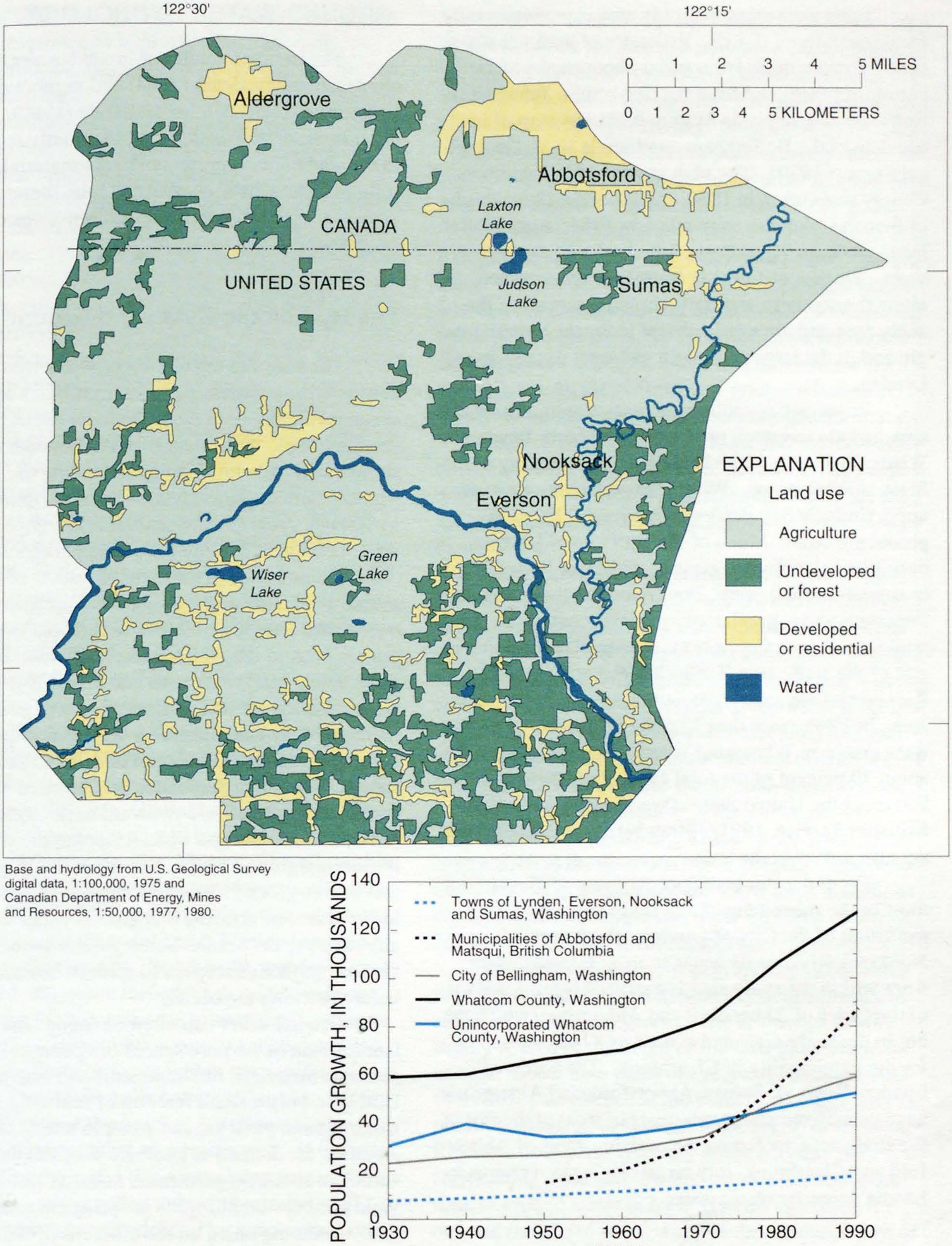
Table 1. Physical and hydrologic properties of major soils in the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada (U.S. Department of Agriculture Soil Conservation Service, 1992b)

[>, greater than; --, no data]

Soil series	Primary soil texture	Depth (inches)	Clay (percent)	Available water capacity (inches)	Permeability rate (inches per hour)	Organic matter (percent)
Soils overlying glacial outwash deposits						
Lynden	Sandy loam	0-8	--	0.15-0.25	2-6	3-9
	Sandy loam	8-18	--	0.10-0.15	2-6	--
	Loamy sand	18-30	0-5	0.05-0.10	>20	--
	Sand	30-60	0-5	0.05-0.10	>20	--
Hale	Silt loam	0-10	10-18	0.19-0.21	0.6-2.0	1-4
	Loam	10-26	10-18	0.16-0.20	0.6-2.0	--
	Loamy fine sand	26-60	0-5	0.16-0.20	>20	--
Kickerville	Silt loam	0-9	--	0.25-0.35	0.6-2.0	3-9
	Silt loam	9-22	--	0.20-0.30	0.6-2.0	--
	Very gravelly silt loam	22-32	--	0.15-0.20	0.6-2.0	--
	Very gravelly loamy sand	32-60	0-5	0.03-0.08	>20	--
Pangborn	Muck	0-15	--	0.40-0.50	0.6-2.0	40-90
	Muck	15-60	--	0.40-0.50	0.6-2.0	--
Tromp	Loam	0-11	--	0.20-0.30	0.6-2.0	3-9
	Loam	11-20	--	0.15-0.20	0.6-2.0	--
	Sandy loam	20-26	--	0.10-0.15	2.0-6.0	--
	Sand	26-46	0-5	0.10-0.15	6.0-20	--
	Sand	46-60	0-5	0.10-0.15	>20	--
Edmonds	Loam	0-11	--	0.30-0.40	0.6-2.0	3-9
	Loam	11-18	--	0.20-0.30	0.6-2.0	--
	Loamy sand	18-37	0-5	0.10-0.15	6.0-20	--
	Sand	37-60	--	0.10-0.14	>20	--
Clipper	Silt loam	0-9	10-18	0.25-0.35	0.6-2.0	2-9
	Silt loam	9-18	10-18	0.20-0.30	0.6-2.0	--
	Gravelly loam	18-30	5-15	0.15-0.20	2.0-6.0	--
	Very gravelly loamy sand	30-60	0-5	0.05-0.10	6.0-20	--

Table 1. Physical and hydrologic properties of major soils in the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada (U.S. Department of Agriculture Soil Conservation Service, 1992b)--Continued

Soil series	Primary soil texture	Depth (inches)	Clay (percent)	Available water capacity (inches)	Permeability rate (inches per hour)	Organic matter (percent)
			Soils overlying alluvial deposits			
Briscot	Silt loam	0-9	5-12	0.19-0.24	0.6-2.0	3-9
	Stratified silt loam	9-60	5-12	0.13-0.20	0.6-2.0	--
Puget	Silt loam	0-9	18-27	0.19-0.21	0.6-2.0	3-9
	Silty clay loam	9-60	18-35	0.19-0.21	0.2-0.6	--
Oridia	Silt loam	0-10	8-18	0.19-0.21	0.6-2.0	2-6
	Silt loam	10-60	8-18	0.19-0.21	0.6-2.0	--
Mt Vernon Fine	Sandy loam	0-7	--	0.13-0.15	0.6-2.0	3-9
	Very fine sandy loam	7-60	--	0.13-0.15	0.6-2.0	--
Sumas	Silt loam	0-8	18-27	0.19-0.21	0.6-2.0	3-9
	Silt loam	8-28	18-35	0.18-0.20	0.2-0.6	--
	Loamy sand	26-60	0-5	0.05-0.09	6.0-20	--
			Soils overlying fine-grained glaciomarine deposits			
Whatcom	Silt loam	0-9	--	0.30-0.40	0.6-2.0	3-9
	Silt loam	9-16	--	0.20-0.35	0.6-2.0	--
	Loam	16-26	18-35	0.15-0.20	0.2-0.6	--
	Loam	26-20	18-35	0.13-0.20	0.06-0.2	--
Skipapoa	Silt loam	0-8	--	0.30-0.40	0.6-2.0	3-9
	Silt loam	8-20	--	0.20-0.30	0.6-2.0	--
	Silty clay	20-60	35-60	0.15-0.20	<0.06	--



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 5. Major land use patterns in 1992 and population growth trends for the Lynden-Everson-Nooksack-Sumas (LENS) study area and parts of surrounding regions.

Land use within the study area is predominantly rural-agricultural (fig. 5). Estimates of land-use classifications were made from aerial photographs of the entire study area and from the Geographic Information Retrieval and Analysis System (GIRAS) map of land-use data of the Bellingham quadrangle (U.S. Geological Survey, 1979). The photographs of Whatcom County were taken in 1990, and the aerial photographs of British Columbia were taken in 1984. Agricultural lands made up 75 percent of the land area in those years. Patches of forest or brushland are common along the southern and northwestern margins of the study area, but are nearly absent along the eastern margin and in the large area north and west of the City of Lynden.

Important agricultural activities within the study area include livestock production and berry farming. Whatcom County is the leading dairying county in the State of Washington. Within the study area there are approximately 310 dairies with over 46,000 milk-producing cows. Much of the agricultural land has been planted with hay, grasses, and other forage crops to support these dairies. Poultry production is also an important agricultural activity; 60 percent of the poultry in British Columbia is produced in the northern part of the study area (Liebscher and others, 1992). Raspberries are a major agricultural crop in the study area. In 1990, more than 13,500,000 pounds of berries were grown in Whatcom County, which accounted for about 30 percent of the total 1990 production of raspberries in the United States (Washington Agricultural Statistics Service, 1991). Strawberries and blueberries are also grown in the area.

Ground water is the primary source of water for most of the inhabitants of the study area, with the exception of the City of Lynden, which uses the Nooksack River as its water source. Ground water from within the study area is exported for use in parts of the Cities of Abbotsford and Aldergrove, which are not in the study area, and is used as a back-up supply for the municipality of Clearbrook. The Cities of Lynden, Everson, Sumas, Abbotsford, and Aldergrove have centralized sewer systems, but most of the rest of the study area, including the outlying areas of Abbotsford and Clearbrook, rely on on-site septic systems to handle domestic waste water.

GROUND-WATER HYDROLOGY

The basic principles of ground-water hydrology are described by Heath (1983) and in more detail by Freeze and Cherry (1979) and Todd (1980). A brief description of how these principles apply specifically to the study area is presented in the material that follows. The reader is referred to the literature cited above for more comprehensive discussions of ground-water hydrology.

The Hydrologic Cycle and Ground Water

The constant circulation of water from the oceans to the atmosphere, to land, and back again to the ocean is referred to as the hydrologic cycle. An understanding of the movement of water beneath the land surface will be helpful in understanding the ground-water system of the study area. A description of the hydrologic cycle and the general occurrence of ground water is presented in the following paragraphs.

Precipitation in the form of rain or snow is the source of all fresh ground water. Precipitation that falls on the land surface can follow several pathways: evaporation back to the atmosphere, infiltration into the ground, or runoff to streams and lakes. Some of the water entering the soil is drawn up by plant roots and returned to the atmosphere by way of transpiration; some water can also be evaporated directly to the atmosphere. Water that percolates below the root zone and continues to percolate downward to the water table is referred to as recharge; when it reaches the water table, it becomes ground water. Gravity is the driving force that moves ground water from higher altitudes toward lower altitudes, insuring that ground water will eventually return to the ocean. Some ground water returns to the land surface as seepage to springs, lakes, or streams before reaching the ocean.

Ground water can often be found beneath the land surface in the pore spaces or openings of porous geologic materials, like sediments and fractured rock. However, only a small fraction of saturated geologic materials can yield ground water in usable quantities. Aquifers are defined as geologic deposits that contain sufficient saturated permeable material and which can yield ground water to wells or springs in usable quantities. Confining units, on the other hand, are geologic materials that, because of their low permeability, generally do not yield water in usable quantities and that also restrict the movement of ground water into and out of adjacent aquifers. Semiconfining units are deposits that have properties of both aquifers and confining units; in particular, small supplies of ground water can be extracted from semiconfining units, but in much smaller quantities than from aquifer deposits.

From this standpoint, all saturated geologic materials that underlie the Earth's surface can be classified as either aquifers, confining, or semiconfining units. The distinction, however, will vary from place to place. The variations arise from interpretation of what constitutes a usable quantity of water and from the scale or size of area under consideration. Geologic materials are not homogeneous, and highly permeable aquifers such as the ones throughout much of the study area contain localized areas of fine-grained, low-permeability materials that yield much smaller quantities of ground water than the unit as a whole. The reverse situation is also fairly common; confining units can have lenses of coarse-grained material that yield smaller quantities of ground water for limited periods. The term *semiconfining unit* is used herein to describe a geologic deposit which has bulk hydrologic properties typical of a confining unit but which also contains a sufficient number of localized occurrences of usable ground-water supplies.

Within aquifers, ground water occurs under two different conditions. In unconfined or water-table conditions, the aquifer is only partially saturated with water, and the upper surface of the saturated zone (the water table) is free to rise and fall with changes in recharge and discharge. Under these conditions the level of water within a well will be close to the level of the water table in the aquifer. Most of the wells within the study area are completed in the unconfined aquifer.

Confined conditions occur when the aquifer is completely filled with water and is bounded above and below by confining units. Because the aquifer is completely filled, the upper surface of the saturated zone cannot rise and fall in response to changes in recharge and discharge. This situation results in the development of hydrostatic pressure within the aquifer that causes water levels in wells completed in this unit to rise above the top of the aquifer. A well that is screened in such a system is called an artesian well. If the pressure is sufficient to raise the water above land surface, the well flows and is called a flowing artesian well. Confined ground water is defined by a pressure (potentiometric) surface analogous to the water-table surface, and, like the water table, this potentiometric surface fluctuates in response to changing recharge and discharge conditions.

The movement of ground water within an aquifer is dependent on the size and hydraulic conductivity of the aquifer and on the pressure gradient between different locations within the aquifer. The general rate of movement (velocity) can range from a few feet per second to less than a few feet per year, although ground-water velocities typically are on the order of a few feet to several hundred feet per year (Todd, 1980, p. 82).

Hydraulic conductivity refers to the capacity of a porous material to transmit water under a potential gradient. This characteristic is largely dependent on the size and interconnectedness of the voids (pore spaces) in the porous medium. In unconsolidated sediments such as glacial deposits, water will move in the pore spaces between the sedimentary grains, whereas in consolidated material such as bedrock ground water will move through fractures, joints, and solution channels. Hydraulic conductivity in unconsolidated deposits generally increases with increasing size of the pore spaces and with the degree of sorting of the sedimentary particles.

A pressure gradient is required to move water through the pore spaces of an aquifer and is referred to as the hydraulic gradient. The hydraulic gradient is derived from the difference in the altitudes of pressure heads at different points in the aquifer. A head is determined by measuring the altitude of the water level in a well. Water-level maps show contour lines of equal pressure head and as such show the areal distribution of pressure heads throughout the ground-water system. The flow of ground water is in the direction of the greatest hydraulic gradient, which on the water-level map will be in the direction that is perpendicular to the contour lines of pressure head. Flow lines that depict the idealized path of ground water can thus be drawn from maps of water-level contours.

In areas of irregular topography, ground-water flow paths within a ground-water system can vary in scale from local to regional. The difference is primarily related to the depth of the flow path within the aquifer. Local flow paths are generally shallow, with short flow paths between the point of recharge and point of discharge to springs, bogs, lakes, or streams. Regional flow paths typically occur between the regional highland and lowland areas. The residence time of ground water in local systems can be on the order of months to years, whereas the residence time of ground water in the regional ground-water system can be from tens to thousands of years.

Within the study area, ground water is found in both unconsolidated sediment and consolidated bedrock. In the loose, unconsolidated sediment, water moves through the numerous pore spaces between the individual particles. In dense, consolidated bedrock, water can only move through interconnected joints, fractures, and solution channels, which are generally much less numerous and less productive than the interstitial pore spaces of unconsolidated sediments. In general, water production in wells from bedrock units is much lower than in wells completed in sand and gravel aquifers, unless the bedrock well encounters large joints or fractures.

Hydrogeologic Framework

Many studies have contributed to our current understanding of the hydrogeologic framework of the study area. Previous geologic investigations or mapping of Pleistocene deposits include those by Armstrong (1960, 1976, 1977, and 1981), Armstrong and Hicock (1976), Armstrong and others (1965), Cameron (1989), and Easterbrook (1963, 1966a, 1966b, 1969, 1971, 1973, and 1976a). Studies of Eocene sedimentary bedrock include those of Daly (1912) and S.Y. Johnson (1984a, 1984b, and 1991). Discussion of hydrogeologic conditions in the area is included in Newcomb and others (1949), Washington State Division of Water Resources (1960), Halstead (1986), Kohut (1987), Creahan and Kelsey (1988), Johanson (1988), Lindsay (1988), Kohut and others (1989), and Kahle (1990).

Most of the hydrogeologic data used in this study to describe and delineate the ground-water system came from 608 wells (shown on plate 1) inventoried during the initial phase of the project. The well-inventory process included locating the well in the field and establishing its location on aerial photographs; determining the latitude, longitude, and land-surface altitude from topographic maps; where possible, measuring the water level in the well and collecting a reconnaissance water sample; verifying general well construction details listed on drillers' logs, such as casing diameter and material; and tabulating lithologic and hydraulic information provided on drillers' logs. These data were then coded and entered into the USGS National Water Information System (NWIS) data base. Basic data on well location and construction, water level, and reconnaissance water quality of the inventoried wells are tabulated in appendix table 1.

The selection of wells to be inventoried was based on several criteria. The primary consideration was to obtain adequate areal representation of the shallow surficial aquifer and more general representation of the deeper hydrogeologic units. In general, only wells having Washington State or British Columbia water-well drillers' reports were selected; however, in instances where well selection was limited, wells without official drillers' reports were also inventoried. Exploration wells drilled for coal, gas, or geotechnical purposes also were used to obtain lithologic information. In many instances, only one or two wells in a given section (1 square mile) were available to inventory. In instances where several wells were available and of similar construction, field personnel were given the discretion to choose wells that were more readily accessible.

The physical extent of the major hydrogeologic units was determined from a map of surficial geology and the 10 lithologic sections constructed for this study (plate 2). The surficial geologic map is based on existing geologic maps of western Whatcom County (Easterbrook, 1976a); New Westminster, British Columbia (Armstrong and Hicock, 1976); and Mission, British Columbia (Armstrong, 1976) and existing soils maps of Whatcom County (U.S. Department of Agriculture, Soil Conservation Service, 1992b) and southwestern British Columbia (Luttmerding, 1981). For the purpose of this study, several of the geologic units recognized by Armstrong (1976) were combined to form a single surficial geologic unit (plate 2). The Holocene alluvium mapped by Easterbrook (1976a) was divided into fine-grained and coarse-grained units based on soils maps (U.S. Department of Agriculture, Soil Conservation Service, 1992) and well records.

Ten hydrogeologic sections (see plate 2), oriented in a north-south and east-west grid, were constructed from surficial geologic maps, drillers' lithologic descriptions, soils maps, and descriptions of lithologic materials examined at outcrops. In the Canadian part of the study area, existing fence diagrams of the subsurface stratigraphy (Halstead, 1986) also were used in the construction of the hydrogeologic sections. Where sufficient data existed, primarily for the shallow deposits, hydrogeologic units were correlated from well to well. Correlating deeper hydrogeologic units was much more difficult because of fewer available logs and generally less-precise drilling records. Although adequate drilling records exist for wells in shallow unconsolidated deposits in the study area, records for wells exceeding 100 feet in depth are rare. Most of the logs available for deep wells were recorded during coal exploration, where the emphasis of drilling was to determine the location of coal-bearing strata within the Tertiary bedrock; changes in lithology of the overlying unconsolidated material, therefore, were often poorly documented. The location of the bedrock surface depicted in the hydrogeologic sections was taken from the deep drilling information mentioned previously and from a depth-to-bedrock map compiled by Jones (1996). In areas where lithologic descriptions were lacking for deposits below the numerous shallow wells and above the bedrock surface, the deposits were identified as undifferentiated deposits (see plate 2).

Regional Geologic Setting

The Fraser-Whatcom Lowlands represent the landward extension of a geological depression known as the Georgia Basin. The Georgia Basin is a large, elongate sedimentary trough that developed in response to tectonic activity beginning in Late Mesozoic time (England, 1991). This tectonic activity resulted in basin development (the Georgia Basin) in some areas and mountain building (the Coast and Cascade Ranges) in other areas. As the Coast and Cascade Ranges were uplifted, they underwent rapid weathering and erosion. This in turn resulted in enormous quantities of sediment being deposited in the Georgia Basin in fluvial, deltaic, and marine environments. Significant quantities of plant and other organic matter were deposited along with the sediment.

Post-depositional geologic activity resulted in the lithification and consolidation of the sediments into sandstone, mudstone, and conglomerate and the transformation of organic debris into hydrocarbon deposits, including coal. Locally the sedimentary formations have been described as the Huntingdon Formation (Daly, 1912) and the Chuckanut Formation (McLellan, 1927), both of which are Eocene in age. Post-depositional deformation resulted in folding and faulting of the sedimentary rock units, producing an irregular bedrock surface topography. Pleistocene glaciers subsequently eroded and smoothed this bedrock surface prior to depositing unconsolidated glacial sediments of variable thickness across the study area and much of the Puget Sound Lowlands. It is these overlying glacial sediments that comprise the principal aquifers of the study area.

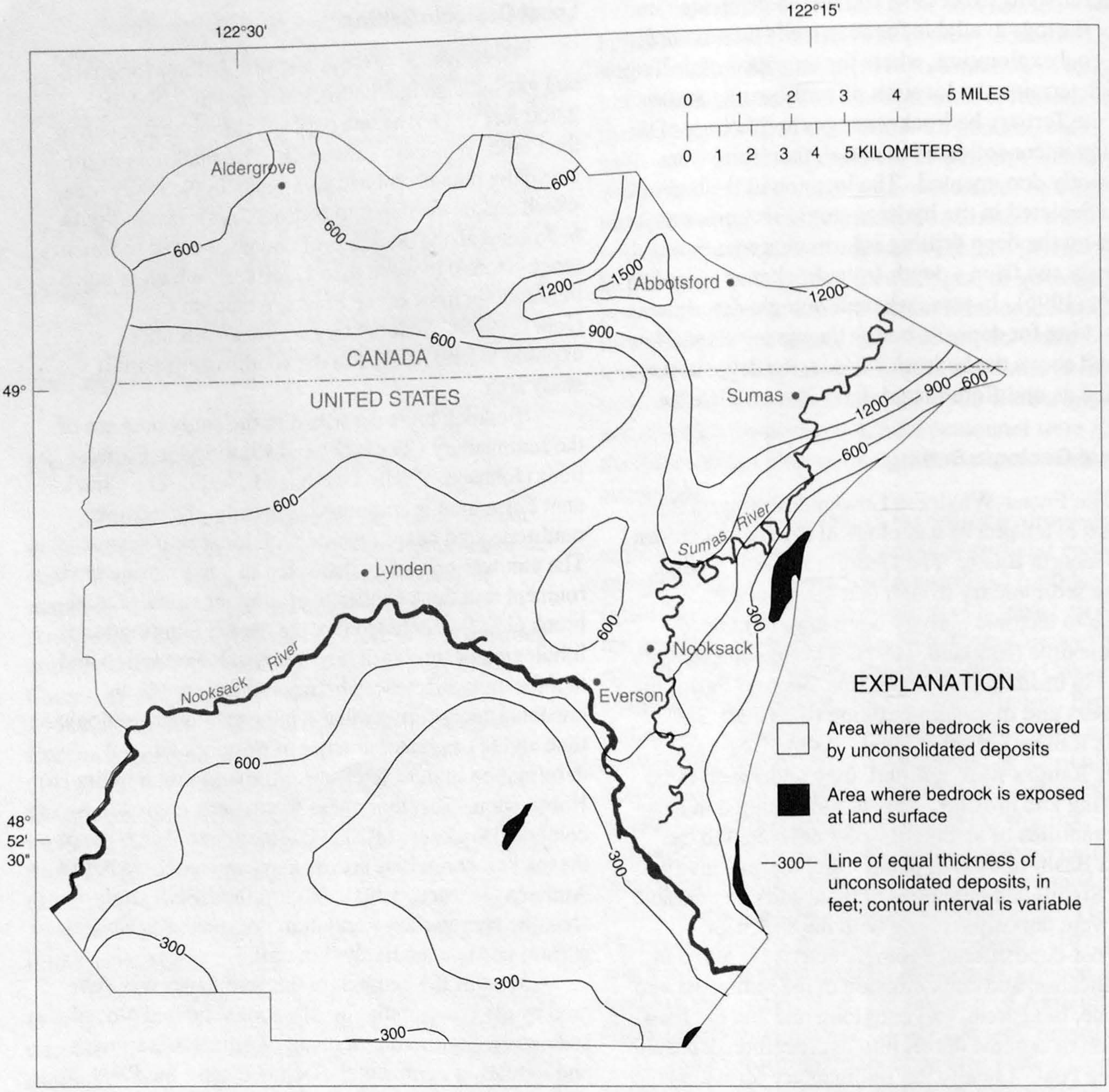
Local Geologic Setting

Geophysical surveys and test drilling for coal and gas indicate that bedrock is beneath 1,000 to 2,000 feet of Pleistocene deposits throughout much of the Fraser-Whatcom Lowlands. The thickness of the overlying unconsolidated sediments in the study area, which equals the depth to bedrock, is shown in figure 6. In general, the thickness of unconsolidated sediment ranges from 0 to more than 1,500 feet, which is much thinner than most of the Fraser-Whatcom Lowlands (Jones, 1996). Sedimentary bedrock formations are exposed at land surface in the southeastern part of the study area.

Bedrock units described in the study area are of the sedimentary Chuckanut and Huntingdon Formations (Johnson, 1984a, 1984b, and 1991). The Chuckanut Formation is composed primarily of sandstone, mudstone, and conglomerate with local coal seams. The unit was originally deposited in a nonmarine environment as a thick sequence of alluvial strata. Easterbrook (1973) concluded that the deeper Huntingdon is lithologically similar to the Chuckanut Formation and that the only differences between them are (1) an erosional unconformity that separates them in geologic time and (2) a greater amount of postdepositional deformation in the Chuckanut Formation than in the Huntingdon. Together, these formations approach a combined thickness of 20,000 feet and represent one of the thickest nonmarine sedimentary sequences in North America (Johnson, 1991). Within the LENS study area, the Huntingdon Formation is exposed at land surface and is a relatively thin unit.

Most of the bedrock in the study area was covered by thick accumulation of unconsolidated glacial sediments, deposited as a result of repeated advances and retreats of continental glaciers during the Pleistocene Epoch. Little is known about the oldest and deepest of these deposits in the study area because they are not exposed at land surface and descriptive drilling information is scarce. Deposits of the last major glaciation are, however, either exposed at land surface or have been penetrated extensively during drilling. The deposits of this final glaciation, known as the Fraser Glaciation, comprise most of the hydrogeologic units identified during this study.

The Fraser Glaciation began approximately 18,000 years ago and lasted about 10,000 years (Easterbrook, 1963, 1969). Three phases of this glaciation, from oldest to youngest, are the Vashon Stade, the



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Geology modified from Jones, 1996

Figure 6. Thickness of unconsolidated deposits within the LENS study area.

Everson Interstade, and the Sumas Stade. Glacial deposits from each of these phases are present in the study area.

During the Vashon Stade, from 18,000 to 13,500 years ago, two sedimentary units were deposited locally. The oldest, the Esperance Sand Member, is a cross-bedded outwash of sand and gravel that was deposited from meltwater streams emanating from the advancing Vashon Glacier. Vashon till, the younger of the two units, is a compact and poorly sorted mixture of cobbles, pebbles, and sand in a matrix of silt and clay, deposited beneath the ice of the advancing Vashon Glacier (Easterbrook, 1963, 1969). Within the study area, these deposits have limited surficial exposure, but likely occur extensively at depth below the younger Everson and Sumas deposits. Within the LENS study area, Vashon Drift (Qvd) occurs at land surface only along the flanks of Sumas Mountain, in the eastern part of the study area (plate 2).

Overlying the Vashon Stade deposits are deposits of the Everson Interstade that occurred from 13,500 to 11,000 years ago. As the Vashon Glacier retreated from its terminus in southern Puget Sound, it thinned, allowing seawater to reenter the basin and float the glacial ice. Everson interglacial deposits (Qed) represent debris that fell from the floating and melting glacial ice and was deposited in marine water. In the study area, deposits of the Everson Interstade are typically represented by glaciomarine drift, an unsorted mixture of pebbly silt and clay with some coarse-grained lenses deposited in seawater (Easterbrook, 1963, 1969). Everson-age deposits are exposed at land surface in the northwestern hummocky uplands area and in the rolling and hummocky hills in the south-central part of the study area. Everson-age deposits also are found within an outwash plain near the center of the study area, where they are characterized by parallel ridges and swales (plate 2). In the southern part of the study area, a relatively thick body of stratified sand with some clay and gravel occurs within the Everson glaciomarine drift. According to Easterbrook (1973), this interlayer, called the Deming Sand, was deposited during the Everson Interstade on floodplains and beaches when sea level dropped relative to the land. The lateral extent of the Deming Sand is generally not well known, but it has been identified locally at the Cedarville landfill, located in the northwest quarter of section 28, township 39 North-Range 3 East (Golder Associates, 1989; Harding Lawson Associates, 1990).

Following deposition of the Everson glaciomarine drift, glacial ice readvanced a short distance southward into northern Washington and deposited the Sumas Drift (Easterbrook, 1963, 1966a, 1966b, 1969, 1971, 1976a; Armstrong, 1977, and 1981; Armstrong and others, 1965). The Sumas Stade, occurred from 11,000 to 10,000 years ago. During that time, the main glacial terminus was just north of the present-day international boundary, with a lobe extending southward into Whatcom County into the Sumas River Valley. Sumas outwash (Qso) was deposited on top of Everson glaciomarine drift by meltwater streams carrying sand and gravel southward and southwestward. The resulting outwash plain extends from north of the international border southward to Lynden and continues towards the mouth of the Nooksack River (plate 2). The outwash grades from gravel and cobble near the border to sand with occasional clay lenses near Lynden.

A discontinuous morainal ridge, composed of ice-contact deposits (Qsi), marks the maximum extent of the Sumas lobe (plate 2). The deposits are a poorly sorted mixture of till and outwash with varying proportions of boulders, cobbles, pebbles, silt, and clay. Ice-marginal ponding resulted in localized deposits of lacustrine silt and clay within the Qsi. Just west of Sumas, Wash., ice-contact deposits are located on top of Sumas-age advance outwash sand and gravel. This sequence is similar to that found in the Fraser-Whatcom Lowland north of the international boundary, where moraine and ice-marginal debris overlie advance outwash or glaciomarine drift (Armstrong and others, 1965; Armstrong, 1981).

During the last 10,000 years (Holocene Epoch), the Nooksack River has incised a wide channel through Sumas Stade deposits, forming the nearly flat alluvial floodplain of the present Nooksack River Valley. Within the study area, Nooksack River alluvium grades from gravel in the upstream reaches near Cedarville to sand and silt in the downstream reaches near Lynden. Other fluvial deposits in the study area include alluvium of the Sumas River and of Bertrand, Johnson, and Fishtrap Creeks. At the same time that the modern Nooksack River was incising through Sumas Stade deposits, peat (Qp), composed of plant remains, was accumulating in former outwash channels and other low-lying depressions in the Sumas outwash. Peat-filled depressions in the study area are numerous and include Pangborn Bog and the basins of Wiser and L'Axton Lakes (plate 2).

Also during the late Holocene, a shallow lake occupied much of the Sumas Valley floor, eventually covering it with a relatively thin lacustrine silt and clay deposit (Armstrong, 1976; Cameron, 1989). The area most recently occupied by the lake is the northeastern, or Canadian, part of the Sumas Valley floor. Historical records show that the lake, known as Lake Sumas, existed just north of the border in British Columbia as late as the 1920's, at which time it was drained for land reclamation (Luttmerding, 1981). Sand and gravel found beneath the fine-grained lacustrine deposits are thought to be alluvium deposited by a northward-flowing Nooksack River, or a greatly enlarged Sumas River, following deglaciation of the area (Cameron, 1989).

For the purposes of this study, the Holocene sedimentary deposits were subdivided into two geologic units--coarse-grained alluvium (Qsc), which includes sand, gravel, and cobbles, and fine-grained alluvium (Qsf), which includes clay and silt. Peat, although Holocene in age, was mapped as a separate geologic unit because it is composed largely of organic material. The coarse-grained deposits dominate much of the Nooksack River channel, but fine-grained deposits become more prominent in downstream reaches. Fine-grained deposits also dominate most of the Sumas Valley floor (plate 2).

Principal Hydrogeologic Units

In this study, hydrogeologic units were distinguished primarily by their water-bearing characteristics and the geographic extent of the geologic deposit(s) comprising them. Two principal types of hydrogeologic units, aquifers and semiconfining units, were recognized. It is especially important to keep in mind the heterogeneity of the unconsolidated sediments in the study area; the general occurrence and movement of ground water can be influenced locally by small-scale variations in lithology.

Four principal hydrogeologic units were delineated in the study area. They are, in order of increasing geologic age (1) the Sumas aquifer; (2) the Everson-Vashon semiconfining unit; (3) the Vashon semiconfining unit; and (4) the bedrock semiconfining unit. The lithologic and hydrologic characteristics of these units are summarized in figure 7.

Sumas aquifer

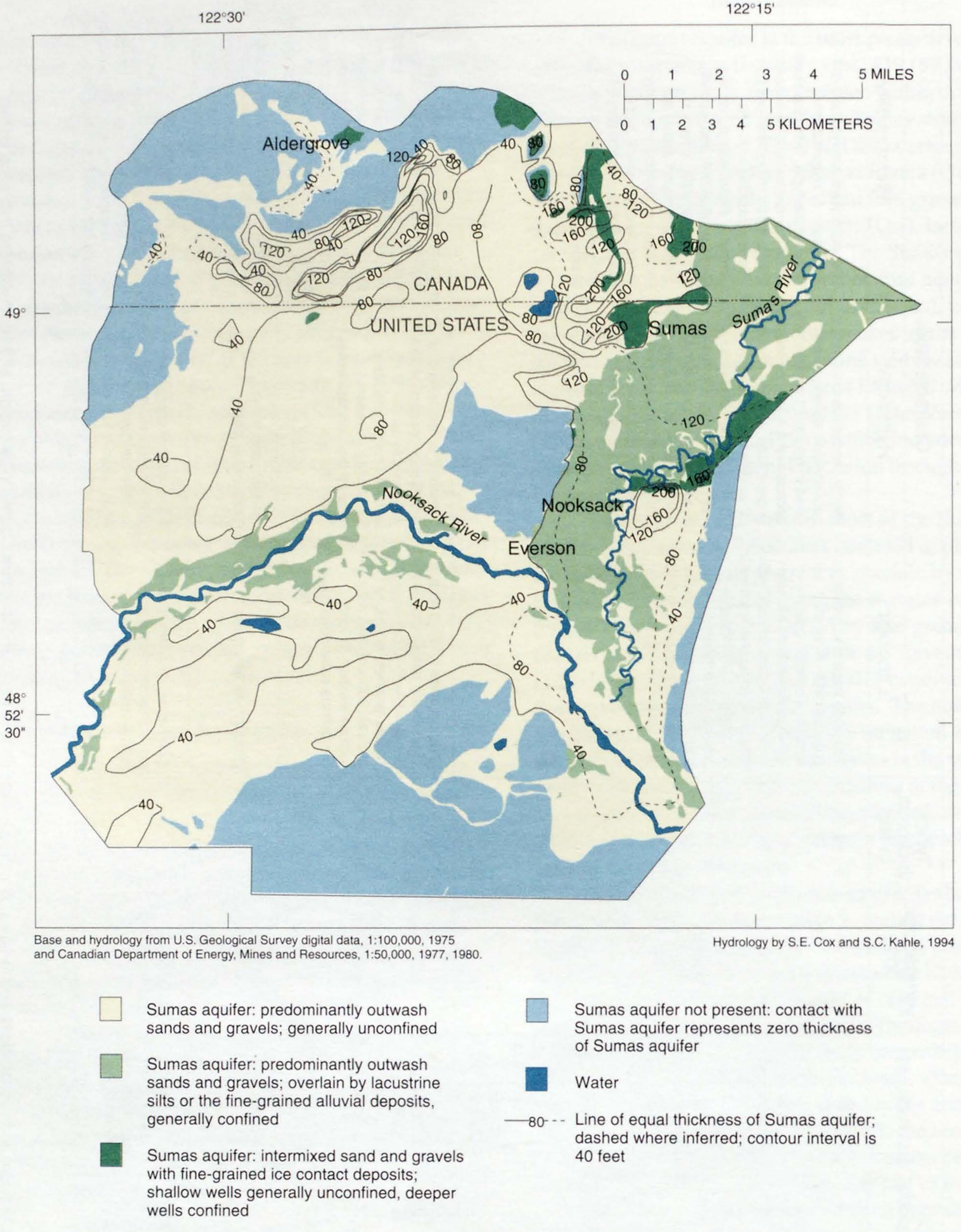
The Sumas aquifer is the most productive and widely used aquifer in the study area; 419 (69 percent) of the inventoried wells are completed within this unit. The aquifer is composed largely of Sumas stratified sand and gravel outwash (Qso) and the coarse-grained alluvium of the Nooksack and Sumas Rivers (Qsc), but also includes some locally important fine-grained deposits such as ice-contact deposits (Qsi), lacustrine silt and clay (Qsf), and peat (Qp). The Sumas aquifer is commonly referred to as the Abbotsford aquifer in British Columbia. The Sumas outwash (Qso), which is the predominate geologic unit that makes up the Sumas aquifer, extends west and south of the study area. On a regional basis, the Sumas aquifer is included with the Fraser aquifer of Vaccaro and others (John Vaccaro, USGS, written commun., 1993), which includes recessional outwash of the Fraser Glaciation throughout the Puget Sound Lowlands.

Although ground water in most of the Sumas aquifer is unconfined, it becomes confined in places in the Sumas River Valley where it is overlain by recent lacustrine silt and clay and along the margins of the Sumas Valley where it is overlain by fine-grained ice-contact deposits (see fig. 8 and plate 2). Several wells in the valley flow as a result of artesian conditions that develop during the wet winter months. The northwestern margin of the Sumas Valley is a transition zone in the aquifer--with unconfined conditions in the outwash plain on the west and confined conditions in the Sumas Valley floor on the east. In addition, clay lenses within the otherwise coarse-grained outwash can perch or confine ground water locally.

The thickness of the Sumas aquifer is shown on the hydrogeologic sections (plate 2) and on the Sumas aquifer-thickness map (fig. 8). All surficial coarse-grained materials shown on the sections are included in the Sumas aquifer, although lenses of clay and of peat can be found locally within the unit. The Sumas aquifer is present in most of the study area except in the northwestern and south-central highlands, along the eastern margin of the study area, and in the area northwest of Everson. As shown in figure 8, the unit is commonly about 40 to 80 feet thick, but can be more than 200 feet thick in the northeastern part of the study area where the unit includes ice-contact deposits. The unit is thinnest along the Nooksack River channel south of Lynden, where the river has eroded away all but about 15 feet of the sand and gravel outwash.

Period	Epoch	Geologic unit	Hydrogeologic unit	Typical thickness, in feet		Characteristics		
						Lithologic	Hydrologic	Water quality
Quaternary	Holocene	Qsp Peat	Sumas aquifer Qs	0 - 15	40 - 80	Stratified sand and gravel outwash with minor clay lenses. Outwash grades from pebble-cobble alluvium near Abbotsford to sand with fine-grained lenses southwest of Lynden. Unit includes Nooksack and Sumas River alluvium, till and ice-contact deposits, lacustrine and flood-plain silt and clay, and peat	Highly productive unconfined aquifer. Unit shows a weak trend in hydraulic conductivity because of a lateral decrease in grain size. Lenses of clay, till, or peat cause locally confined or perched ground-water conditions. The unit is confined in much of the Sumas Valley by overlying lacustrine silt and clay and underlying clay presumed to be glaciomarine drift	Ground waters are typically of a calcium- or magnesium-bicarbonate type, with dissolved solids concentrations between 110 and 190 milligrams per liter. These ground waters are generally dilute, slightly acidic with low alkalinity, and typically well oxygenated. Elevated concentrations of dissolved nitrates are common in many areas; in other areas high concentrations of dissolved iron and manganese restrict the use of some ground waters
		Qsf Fine-grained alluvium		0 - 15				
		Qsc Coarse-grained alluvium		0 - 20				
	Pleistocene	Qso Sumas Outwash		20 - 200				
		Qsi Sumas ice-contact deposits		20 - 60				
		Qed Everson glaciomarine drift	Everson-Vashon semiconfining unit Qev	100 - 200		Glaciomarine drift consisting of unsorted pebbly clay and sandy silt with occasional coarse-grained lenses as thick as 30 feet. Unit may include Vashon till and Esperance sand at its base	Generally a confining bed but coarse-grained lenses yield usable amounts of water to numerous wells. Salty water is present in most of the deepest wells within the unit	Concentrations of major ions are highly variable without a consistent water type. Dissolved solids typically range from 170 to 1,300 milligrams per liter of dissolved oxygen, and nitrate typically ranges from 0.1 to 1.5 milligrams per liter. Large concentrations of iron, manganese and chloride are common in many locations
		Qvd Vashon Drift	Vashon semiconfined unit Qv	- -		Primarily till and gravel	Limited aerial extent; yields are variable	Ground waters are not extensive and can be either a calcium-magnesium-bicarbonate or a sodium-chloride type with dissolved solids concentrations typically near 126 milligrams per liter
Tertiary	Paleocene-miocene	Tbr Huntingdon and Chuckanut Formations	Bedrock semiconfining unit Tbr	- -		Sandstone, mudstone, and conglomerate, with some coal-bearing strata	Water yield is controlled primarily by secondary fracture permeability. Water yield is low where the rocks are unfractured	Ground waters are typically of a sodium-bicarbonate or sodium-chloride type with dissolved solids concentrations between 300 to 1,800 milligrams per liter. Concentrations of dissolved oxygen and nitrate are typically less than 0.1 milligrams per liter

Figure 7. Lithologic and hydrologic characteristics of hydrogeologic units in northern Whatcom County, Washington, and southwestern mainland British Columbia, Canada.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Hydrology by S.E. Cox and S.C. Kahle, 1994

Figure 8. Extent, approximate thickness, and hydrologic condition of the Sumas aquifer.

Everson-Vashon semiconfining unit

The Everson-Vashon semiconfining unit is composed of (1) thick accumulations of Everson-age glaciomarine drift, consisting of unsorted pebbly clay and sandy silt with local coarse-grained lenses, and (2) discontinuous deposits of sand or till. The till, encountered at considerable depth, may be of Vashon age; some of the coarse-grained material encountered deep in the Everson-Vashon unit may be Vashon-age Esperance Sand rather than coarse-grained lenses within the glaciomarine drift. Distinguishing between the two types of coarse-grained deposits, however, was often not possible because of their similar lithologies, discontinuous nature, and a paucity of deep-drilling information. Till, which was recorded on several drillers' logs as being directly beneath the glaciomarine drift, is probably of Vashon age. This till was included with the Everson-Vashon unit because of its hydrologic similarities with the fine-grained glaciomarine drift.

Although the bulk of this unit is composed of fine-grained material, numerous wells within the unit are completed in lenses of coarse-grained materials. Such is the case in the northwestern and south-central highlands where domestic and some public-supply wells are completed in the unit. The productive zones of the Everson-Vashon unit in the south-central part of the study area are believed to be the Deming Sand--a relatively thick (30 feet) interlayer within the glaciomarine drift. The other productive zones are probably small lenses within the glaciomarine drift or, if at considerable depth, the Esperance Sand. One hundred and eleven (18 percent) of the inventoried wells are completed in the Everson-Vashon unit.

The glaciomarine drift of the Everson-Vashon semiconfining unit underlies nearly all of the Sumas aquifer and is found at land surface along the northwestern and south-central margins of the study area and near the center of the study area northwest of the town of Everson. As shown in figure 9, the top of the unit ranges from more than 400 feet above sea level to approximately 120 feet below sea level. The thickness of the Everson-Vashon semiconfining unit is largely unknown because few wells penetrate it entirely. According to available drilling records, a typical thickness of the unit is 100 to 200 feet.

Vashon semiconfining unit

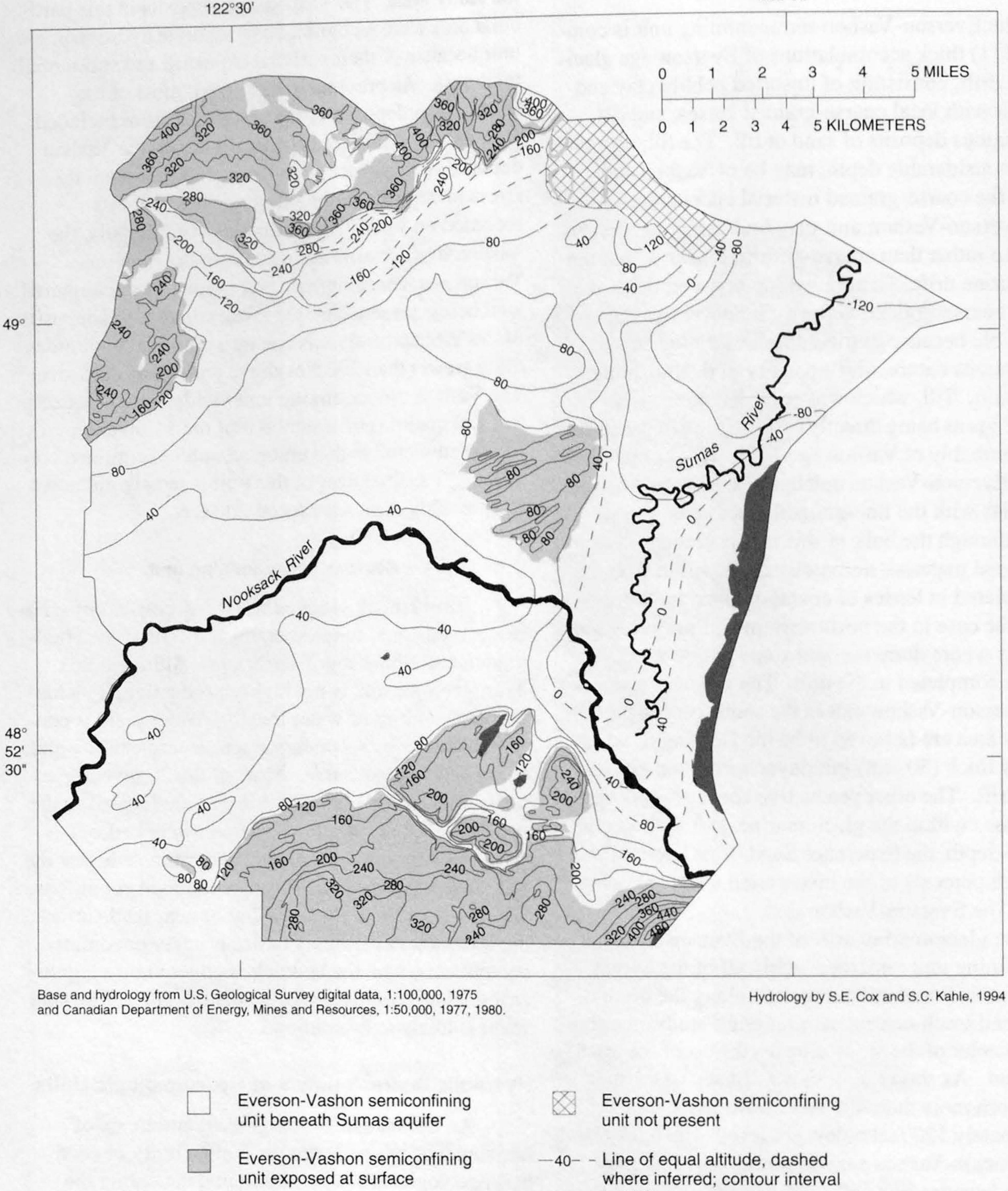
Within the study area, the Vashon semiconfining unit consists of a small band of poorly sorted Vashon drift and gravel that is exposed along the eastern part of the study area. The Vashon-age deposits in this particular area were recognized as a separate hydrogeologic unit because of their surficial exposure and substantial thickness. As previously discussed, most of the Vashon-age deposits in the study area were included with the Everson unit because, at depth, the Vashon deposits were generally indistinguishable from the Everson deposits in the lithologic descriptions recorded on well drilling reports. Additionally, the Vashon-age deposits included with the Everson-Vashon semiconfining unit were typically encountered well below present-day sea level, whereas the deposits of the Vashon semiconfining unit crop out at altitudes often greater than 200 feet above present-day sea level. The Vashon semiconfining unit yields variable quantities and qualities of water. All of the 11 inventoried wells completed in this unit encountered confined conditions. The thickness of this unit is mostly unknown, but probably does not exceed 200 feet.

Bedrock semiconfining unit

The bedrock semiconfining unit consists of sandstone, mudstone, conglomerate, and coal of the Huntingdon and Chuckanut Formations. Although this hydrogeologic unit is not highly productive, it yields usable quantities of water locally. Water yield is controlled chiefly by secondary fracture permeability and, as such, is unpredictable. Most of the 24 inventoried wells that are completed in this unit are located in the southeastern part of the study area where bedrock is shallow. Data are insufficient to determine whether the water occurs under unconfined or confined conditions. Where the bedrock is exposed at or near land surface, the ground water is likely to occur under unconfined conditions; where the bedrock is covered by a significant thickness of glaciomarine drift or till, the ground water is likely to be confined.

Hydraulic Characteristics of Hydrogeologic Units

An estimate of the magnitude and range of horizontal or lateral hydraulic conductivity of each hydrogeologic unit is helpful in understanding the movement and availability of ground water. Hydraulic conductivity is a measure of a hydrogeologic unit's ability to transmit water and is defined as the volume of water that will move in a unit of time under a unit of hydraulic gradient through a unit cross-sectional area. The unit used to report hydraulic conductivity is feet



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Hydrology by S.E. Cox and S.C. Kahle, 1994

□ Everson-Vashon semiconfining unit beneath Sumas aquifer

▨ Everson-Vashon semiconfining unit exposed at surface

■ Insufficient data to contour

⊠ Everson-Vashon semiconfining unit not present

—40— - Line of equal altitude, dashed where inferred; contour interval is 40 feet

Figure 9. Altitude of upper surface of Everson-Vashon semiconfining unit.

per day, which is the same as the units of velocity; however, values of hydraulic conductivity are equivalent to velocity only under the specialized conditions when the values of hydraulic gradient and porosity are equal to 1. For unconsolidated materials, hydraulic conductivity depends in large part on the size, shape, and arrangement of the sedimentary particles and the intervening pore spaces. Because these characteristics are highly variable within the glacial deposits of the study area, hydraulic conductivity values also can be expected to be highly variable.

Estimations of the horizontal hydraulic conductivity for each hydrogeologic unit were made using data from those wells that had the most complete and reliable set of specific-capacity information including discharge rate, drawdown, long-term aquifer test data, well-construction data, and a geologic log. Of the 608 wells inventoried, 218 had such information. The procedures used to calculate hydraulic conductivity are presented in the Appendix section at the end of this report. Hydraulic conductivity data were statistically summarized so that medians and ranges within and between hydrogeologic units could be determined. A summary of hydraulic conductivity data by hydrogeologic unit is presented in table 2. Individual values of hydraulic conductivity and the data from which they were calculated can be found in appendix table 2.

Hydraulic conductivity values calculated for the 170 wells completed in the Sumas aquifer covered three orders of magnitude, ranging from 6.8 to 7,800 feet per day and having a median value of 270 feet per day. Except for the extremes, the hydraulic conductivity data were log normally distributed. The range and median values of hydraulic conductivity observed throughout the entire extent of the Sumas aquifer for this study, (171 square miles) were similar to the range and median observed by Erickson (1991) for eight wells located within a subset of this study area of only several square miles west of Lynden; and also similar to the range reported for outwash and alluvial deposits of other studies within the Puget Sound Lowland, (Turney and others, 1995; John Vaccaro, USGS written commun., 1994). However, the median hydraulic conductivity calculated for the Sumas aquifer is generally larger than has been reported for similar outwash deposits within the Puget Sound Lowland and near the upper extreme of the range reported by Stephenson and others (1988) for glacial deposits of North America. This tends to indicate that the Sumas aquifer has a larger capacity to transmit water than is typical of similar glacial outwash deposits in the Puget Sound Lowland.

When hydraulic conductivity data for the Sumas aquifer were plotted to determine if an areal pattern of lower or higher values existed, no discernible pattern was found, and in some localities closely spaced wells displayed calculated hydraulic conductivity values that were vastly different. Because of the large spatial variability in the plotted data, a map of hydraulic conductivity values was deemed to be of limited usefulness and therefore was not included in this report. The plotted data did show several possible geographic trends,

Table 2. Summary of horizontal hydraulic conductivity values calculated from specific-capacity data, by hydrogeologic unit

Hydro-geologic unit	Number of wells	Hydraulic conductivity (feet per day) Minimum	25th percentile	Median	75th percentile	Maximum
Sumas aquifer	170	6.8	74	270	610	7,800
Everson-Vashon semiconfining unit	32	3	19	81	160	570
Vashon semiconfining unit	4	2.4	7.2	52	950	1,800
Bedrock semiconfining unit	12	0.01	0.02	0.55	4.6	77

with higher values near the international boundary and lower values toward the southwestern part of the study area. This trend is consistent with the observation of decreasing grain size in the Sumas outwash plain, as discussed earlier. In support of this theory, high hydraulic conductivity values were absent on the southern margins of the Sumas outwash plain south of the Nooksack River. Another apparent area of generally larger values of hydraulic conductivity is a band along the alluvial valleys occupied by the Sumas River and the upper reaches of the Nooksack River. This band of large hydraulic conductivity probably represents a buried river channel deposit, which would be characterized by well-sorted, coarse-grained material and may represent deposits of the ancestral Nooksack River.

In the Everson-Vashon semiconfining unit, the median hydraulic conductivity of 81 feet per day is larger than would be expected for a unit that is, for the most part, a fine-grained confining bed (Stephenson and others, 1988), but the median is similar to values calculated by similar methods for fine-grained units in other parts of the Puget Sound Lowland (John Vaccaro, USGS, written commun., 1994). The large hydraulic conductivity calculated for these fine-grained deposits is likely due to a bias in sampling that results from using wells that are screened in lenses of coarse-grained material that is not representative of the unit as a whole. It is reasonable to expect that successful wells were completed in the more productive parts of the unit and that any wells completed in less permeable zones either were subsequently abandoned or may not have produced enough water for an aquifer test to be practical.

Slug tests of the Everson-Vashon glaciomarine drift conducted by Sweet-Edwards (1984) resulted in estimates of horizontal hydraulic conductivity of 0.0014 and 0.027 feet per day, which are several orders of magnitude smaller than even the smallest hydraulic conductivity value generated from specific capacity data. Because the slug tests were conducted on two observation wells installed in the Everson glaciomarine drift to evaluate the potential for ground-water transport away from a landfill area, the results may be more representative of the hydraulic conductivity of the less productive parts of the Everson-Vashon semiconfining unit than estimates made from successful water producing wells. Four laboratory measurements of vertical hydraulic conductivity determined for core samples of clayey silt material from the same area were one to two orders of magnitude smaller than for slug-test values of horizontal hydraulic conductivity (Golder Associates, 1989) and (Harding Lawson Associates, 1990); these results coincide with the general trend in sedimentary materials in which vertical hydraulic conductivities are typically significantly smaller than horizontal hydraulic conductivities.

The lowest median hydraulic conductivity (0.55 feet per day) was found in the bedrock semiconfining unit. Because ground water in bedrock occurs primarily in fractures, the low value of hydraulic conductivity observed in this unit indicated that the bedrock semiconfining unit generally does not contain sufficient open fractures and joints to transmit large quantities of water.

The high bias in the estimate of hydraulic conductivity probably occurs in varying degrees within all of the hydrogeologic units, depending largely upon the heterogeneity of the lithologic material making up each unit. As such, all of the median hydraulic conductivity values may be somewhat high; however, the bias in the estimate of hydraulic conductivity for the Everson-Vashon is probably largest because that unit displays the greatest variation in lithologic composition. An examination of the minimum hydraulic conductivities for the hydrogeologic units shows that there are indeed poorly producing wells in each unit. Also, the range of hydraulic conductivities is at least three orders of magnitude for most units, indicating a substantial degree of heterogeneity.

Ground-Water Flow System

The ground-water flow system includes the movement of water within and between individual hydrogeologic units and the movement of water into and out of the ground-water system. Typically, precipitation is the source of most ground water, and the general movement of ground water is from areas of recharge, generally found in the uplands, to areas of discharge, typically found at lower altitudes along river and stream channels. The ground-water flow path can range in scale from local flow paths that are generally short and shallow to regional flow paths that cover great distances and travel deep within the ground-water system. The movement of ground water is controlled by the topography, the geometry of the hydrogeologic framework, and the areal distribution and rate of ground-water recharge and discharge.

Information on the ground-water flow system was derived primarily from water-level data taken from wells throughout the study area. These data were used to construct a contour map depicting the altitude of ground-water levels in 1990 (plate 3). Seasonal variations in ground-water levels were determined from monthly water-level measurements in 29 wells within the study area from October 1990 to October 1991. Historic water-level information from the U.S. Geological Survey, BC Environment, and EC was also used to quantify seasonal variations in ground-water levels.

Water-Level Distribution and Movement of Ground Water

Water-level data, mostly from the Sumas aquifer and partly from the Everson-Vashon semiconfining unit, were combined so that a water-level map could be drawn for most of the study area (plate 3). The water-level map was constructed from water-level altitudes measured in 450 wells at the time of well inventory, plus additional water-level information contained in Johanson (1988) and Kohut (1987). Information on stream elevations determined from topographic maps was also used to construct the map. The inventory water levels, which were collected over a 6-month period, were adjusted to account for seasonal variation. Water levels measured in wells within the Everson-Vashon semiconfining unit in the upland margins were included in the construction of this map because the Sumas aquifer is absent in these areas and the Everson-Vashon water levels are considered analogous to the water table of the Sumas aquifer in the central parts of the study area. Ground water within the Everson-Vashon semiconfining unit most probably flows laterally from the uplands into the Sumas aquifer at lower altitudes.

The water-level contours for the Sumas aquifer shown on plate 3 reflect regional water-table (unconfined) conditions everywhere except parts of the lower (northern) Sumas Valley and in the area northwest of the town of Sumas. In these areas ice contact deposits and the fine-grained alluvium--lacustrine silt and clay--that overlies much of the valley floor have created confined conditions, resulting in numerous wells being under artesian and even flowing conditions.

The general direction of ground-water flow can be inferred from the contours on plate 3, which show the configuration of water levels throughout the study area. The horizontal movement of ground water is perpendicular to the water-level contours, from areas of higher head to areas of lower head. The general pattern of ground-water flow in the study area is toward the Nooksack and Sumas Rivers, which are the primary areas of ground-water discharge. Smaller scale flow patterns can be seen near creeks that also act as ground-water discharge areas. On a local scale, which is not apparent on plate 3, ground water can flow toward drainage ditches and buried tile drains. This type of flow, however, occurs on a relatively small scale as compared to the regional ground-water flow systems.

The hydraulic gradient is the difference in water-level altitude between two locations and is an expression of the driving force that enables the movement of ground water. Lateral hydraulic gradients within the Sumas aquifer, as determined from the water-level contours shown on plate 3, are typically about 15 feet per mile (equivalent to 0.0028) across much of the outwash plane north of Lynden but range from about 5 to 100 feet per mile. In the Everson-Vashon semiconfining unit, lateral hydraulic gradients are often about 35 feet per mile (equivalent to 0.0066) but range from 10 to 100 feet per mile. The lower hydraulic conductivity of the Everson-Vashon semiconfining unit requires larger hydraulic gradients to move similar quantities of ground water. Topography plays a large role in producing variations in hydraulic gradient and is the primary cause of the variations observed within each unit. Hydraulic gradients are generally small in areas of low relief and large in areas of high relief.

Ground-Water Velocity

The average rate at which ground water moves through porous geologic material, referred to as average interstitial velocity, is important, particularly in areas where water-quality problems may occur. Calculated estimates of lateral ground-water velocities within the Sumas aquifer range from 0.2 to 29 feet per day, depending on the data used; however, a best estimate of the horizontal velocities of much of the aquifer is that they are on the order of 2.5 feet per day. Similar rates may occur in the Everson-Vashon semiconfining unit, where smaller values of hydraulic conductivity are compensated for by larger hydraulic gradients. The estimated horizontal velocities are based on the hydraulic conductivity and hydraulic gradient data described above and the literature values for the effective porosity of the geologic material making up the aquifer and semiconfining unit.

The equation representing average ground-water velocity is derived from Darcy's Law and the velocity equation and was amended to account for the effective porosity of the geologic material. It takes the form of

$$(v) = K(dh/dl)/n_e \quad , \qquad (1)$$

where

v = average interstitial ground-water velocity;
K = horizontal hydraulic conductivity;
(dh/dl) = hydraulic gradient, or the change in water-level head divided by the intervening distance; and
n_e = effective porosity, or the ratio of the volume of pore spaces to total volume.

Because data in the previous sections have shown that values of hydraulic conductivity and hydraulic gradients vary throughout the ground-water system, average ground-water velocities also vary. Consequently, several values of each parameter were used to illustrate the range of ground-water velocities in the Sumas aquifer and the Everson-Vashon semiconfining unit shown in table 3. Hydraulic conductivity values for the Sumas aquifer and the coarse-grained lenses of the Everson-Vashon semiconfining unit were taken from the 25th, 50th, and 75th percentile values of the calculated values in table 2; values for the fine-grained material in the unit were taken from measurements reported by Sweet-Edwards/EMCON (1989). Values of the hydraulic gradient were determined from the spacing of water-level contours on plate 3.

Table 3. Calculated estimates of ground-water velocity in the Sumas aquifer and the Everson-Vashon semiconfining unit using selected values of hydraulic conductivity, hydraulic gradient, and porosity

Hydraulic conductivity (feet per day)	Hydraulic gradient (feet per mile)	Velocity (feet per day)		
		porosity (n_e)	porosity (n_e)	porosity (n_e)
Sumas Aquifer		(n_e=0.25)	(n_e=0.38)	(n_e=0.50)
74	5	0.28	0.18	0.14
	15	0.84	0.55	0.42
	75	4.2	2.8	2.1
270	5	1.0	0.67	0.51
	15	3.1	2.0	1.5
	75	15	10	7.7
610	5	2.3	1.5	1.2
	15	6.9	4.6	3.5
	75	35	23	17
Everson-Vashon (coarse-grained material)		(n_e=0.35)	(n_e=0.42)	(n_e=0.50)
19	15	0.15	0.13	0.11
	35	0.36	0.30	0.25
	125	1.3	1.1	0.90
87	15	0.71	0.59	0.49
	35	1.6	1.4	1.2
	125	5.9	4.9	4.1
Everson-Vashon (fine-grained material)		(n_e=0.35)	(n_e=0.42)	(n_e=0.50)
0.0014	15	0.00001	0.00001	0.00001
	35	0.00003	0.00002	0.00002
	125	0.00009	0.00008	0.00007
0.027	15	0.00022	0.00018	0.00015
	35	0.00051	0.00043	0.00036
	125	0.00180	0.00150	0.00130

These estimates included a value that was typical for much of the area and also values from areas of both high and low hydraulic gradient. Values of porosity used in the calculations of average ground-water velocity were taken from the ranges reported by Freeze and Cherry (1979) for sandy material of 0.25 to 0.50; for silty material 0.35 to 0.50, along with the average of the values of porosity in sandy and silty glaciofluvial deposits reported by Morris and Johnson (1967), which were 0.38 and 0.42, respectively.

In the Sumas aquifer, calculated average ground-water velocities ranged from 0.14 to 35 feet per day, and the general value based on the median or typical values of the variables controlling ground-water velocity resulted in an average velocity of about 2 feet per day. An independent estimate of ground-water velocity based on the arrival time of chloride in piezometers down gradient of a newly installed dairy lagoon resulted in an estimated average ground-water velocity of 1 to 2 feet per day Erickson (1992). The regional hydraulic gradient in the area of Erikson's chloride study, roughly 3 miles north of Lynden, is about 15 feet per mile; thus, the two estimates are in good agreement. If 2 feet per day is used as a reasonable estimate of average ground-water velocity, then ground water could be expected to travel on the order of 700 feet per year, and the average travel time along regional flow paths of 5 to 10 miles would be on the order of 20 and 40 years, respectively.

Estimates of average ground-water velocity in the Everson-Vashon semiconfining unit were based on hydraulic conductivity values of both the coarse-grained material encountered by water wells installed in this unit and the hydraulic conductivity of fine-grained material encountered in some observation wells. In the coarse-grained Everson-Vashon material, hydraulic conductivities are lower, while hydraulic gradients are larger than in the Sumas aquifer. As a result, average velocities of ground water in this material were roughly half as large as estimates for the Sumas aquifer. However, in the fine-grained material of the Everson-Vashon semiconfining unit, the much smaller hydraulic conductivities resulted in ground-water velocities on the order of 0.0001 to 0.002 feet per day. The hydraulic gradient in the fine-grained material may be somewhat larger than measured in the coarse-grained material, which was used in both estimates in the Everson-Vashon material; but physical constraints of the ground-water system would limit the range to something less than a factor of two, which would only increase the velocity by the same factor. Consequently, average ground-water velocities in the fine-grained Everson-Vashon material are much slower than in either the coarse-grain Everson-Vashon material or the Sumas aquifer, and hence distances traveled by ground water in the fine-grained material during a year's time would be much less, on the order of a fraction of a foot.

Variations in Ground-Water Levels

Water levels in the Sumas aquifer typically show yearly oscillations of about 6 feet. The yearly rise and fall in ground-water levels coincide with the seasonal patterns in monthly precipitation amounts. Water levels in wells completed in shallow aquifers such as the Sumas aquifer typically respond more quickly to precipitation and experience larger fluctuations than wells completed in stratigraphically lower hydrogeologic units. Comparison of current and historic water-level data did not show definite signs of long-term change except in the area between the towns of Sumas and Abbotsford, where water levels appear to be declining. Information on the long-term trend in water-level variations was obtained from historical water-level records and the comparison of 1990 water-level contours to maps depicting water-level conditions in 1949 and 1960 (plate 3). Long-term water-level data were not available for the semiconfining units.

Analysis of the seasonal variation in ground-water levels included the monthly measurement of water levels in 29 wells and the analysis of historical monthly water-level data for 16 wells having periods of record longer than 3 years. Seasonal variations observed from measurements made during 1990-1991 in the Sumas aquifer typically ranged from 4 to 8 feet, while variation observed from historic data (table 4) ranged from 3 to 8 feet. The maximum seasonal fluctuation observed was on the order of 16 feet. Ground-water levels were typically lowest between October and December and highest between February and April. The period of rapidly rising water levels coincides with the period of heaviest precipitation. Most of the Sumas wells that showed water-level fluctuations between 7 to 8 feet were located in the outwash plain between Lynden and Abbotsford. This area of the Sumas aquifer receives the greatest amount of precipitation, and, thus, it is probable that the larger range in water-level fluctuations represents greater

Table 4. Summary of seasonal water-level fluctuations in wells with 3 or more years of monthly observations

Well number	Depth of well (feet)	Altitude of land surface (feet)	Period of record	Length of record (years)	Average yearly fluctuation (feet)	Maximum yearly fluctuation (feet)	Minimum yearly fluctuation (feet)	Most common month of highest water level	Most common month of lowest water level
40N/04E-05D01	61	183	1940-1976	37	3.98	6.37	1.20	March	November
40N/03E-19M01[a]	22	88	1952-1961	13	3.31	4.33	2.35	March	October
39N/03-10L01	15	96	1976-1978	3	4.00	4.96	3.38	February	November
092G.009.1.2.3-CDA1	25	190	1990-1993	4	8.46	10.50	5.54	March	December
092G.009.1.2.3-CDA2	25	190	1990-1993	4	8.50	10.60	5.51	March	December
092G.008.2.2.2-ABB1	26	150	1990-1993	4	3.64	5.68	2.45	February	October
092G.009.1.1.2-ABB2	25	167	1990-1993	4	7.27	7.91	5.71	February	November
092G.009.1.2.1-ABB3	96	190	1990-1993	4	8.17	10.47	5.18	March	November
092G.009.1.2.1-ABB4	58	190	1990-1993	4	7.18	8.76	4.76	March	December
092G.009.1.1.1-ABB5	29	151	1990-1993	4	6.40	8.46	4.79	February	November
092G.009.1.1.4-ABB6	30	180	1990-1993	4	8.00	8.89	5.97	March	October
092G.009.1.2.3-10	63	180	1966-1991	25	8.33	16.37	4.26	March	October
092G.009.2.1.3-47	87	175	1989-1990	14	5.68	12.63	2.30	May	December
092G.009.1.3.3-08	52	180	1988-1991	4	7.58	4.34	8.05	February	October
092G.008.2.4.1-41	135	320	1988-1991	4	12.40	16.20	11.10	February	October

[a] Measured intermittently until 1971, well destroyed, not listed in Appendix Table 2.

recharge in that area. Smaller seasonal fluctuations, typically from 1 to 5 feet, were more often observed in the semiconfining units.

Typically, water levels in wells completed in shallow water table aquifers, such as most of the Sumas aquifer, respond more quickly to precipitation and show larger fluctuations than do deeper wells that are completed in confined or semiconfined aquifers. The smaller range of water-level fluctuations found in the these units is probably related more to the fact that wells in these units are generally deeper, typically over 100 feet, than wells in the Sumas aquifer, which are typically less than 50 feet deep. Water-level fluctuations were about 4.5 feet in two Everson-Vashon wells approximately 60 feet deep and were only 1 to 2 feet in two other Everson-Vashon wells about 150 feet deep. However, in contrast, the second largest seasonal fluctuation (13.3 feet) was observed in the one shallow well in the Everson-Vashon semiconfining unit (39N/03E-36B03). The large fluctuations in this well could be the result of focused recharge, a characteristic of fine-grained deposits that have uneven, hummocky surfaces, such as the Everson-Vashon semiconfining unit. Water tends to pond in depressions in the uneven surface, thereby concentrating recharge into these areas. This concentration could result in large water-level variations in shallow wells in these areas.

Fluctuations of water levels in wells within the study area are caused largely by variation in monthly precipitation amounts. The direct relation between variations in precipitation and fluctuating ground-water levels can be seen in figure 10, which compares monthly precipitation recorded at the Clearbrook weather station to monthly ground-water levels in well 40N/04E-05D01. The well and the weather station are about a mile apart. Between 1945 and 1976, water-level altitude in this well fluctuated seasonally from 126 to 136 feet above sea level. The mean seasonal water-level fluctuation during this period was 3.9 feet per year. During this same period, annual precipitation at the Clearbrook weather station ranged from 32.0 to 65.6 inches per year, with an annual mean of 47.5 and a monthly mean of 3.96 inches. The difference between measured monthly precipitation and the 31-year average monthly precipitation (3.96 inches) is the monthly precipitation departure from the mean. Because precipitation is the major factor in determining recharge to the shallow aquifer, the cumulative precipitation departure then is a summation of the antecedent recharge conditions for the area surrounding the weather station.

The trend in ground-water levels in well 40N/04E-05D01 follows the trend of the line depicting the cumulative precipitation departure, particularly during the periods of below average precipitation. Years in which the total precipitation were substantially less than the mean annual precipitation occurred during 1949, 1952, 1958, 1963, 1970, 1973, and 1975; water levels in well 40N/04E-05D01 were noticeably lower during the months following these low-precipitation periods for all years except 1963 for which water-level data are incomplete (figure 10). Corresponding periods of high water tables following periods of precipitation excess are not as noticeable, probably because higher ground-water levels lead to higher natural discharge rates, thereby preventing large rises of the water table.

Information on long-term variation in ground-water levels was gathered from three sources: comparison of water levels measured prior to 1960 with water levels measured in the same wells in 1990, comparison of water-level contours prepared in 1949 and 1960 with those prepared for 1990, and monitoring data from observation wells. Most wells used in this study were constructed after 1970; pre-1960 water-level data were available for 26 wells where water levels were measured in 1990. Comparison of the 1990 measurements to pre-1960 measurements ranged from 4 feet lower to 11 feet higher. Most 1990 water levels were within 2 feet of the pre-1960 water level, the median water-level change being about 1 foot higher in 1990. In general, the observed differences could easily be attributed to seasonal variations, and thus these data are inconclusive with respect to determination of long-term water-level changes.

Water-level contours from previous studies by Newcomb and others (1949) and the Washington State Division of Water Resources (1960) are similar to those generated for this study from data collected in 1990. The source of the water-level data used by Newcomb and others (1949) was measured water levels obtained from several hundred wells during the summer of 1947 and 1948. The source of the water-level data used by the Washington State Department of Conservation (1960) is believed to be largely data collected by Newcomb and others (1949) plus additional data collected between 1948 and 1960. The area where the three water-level contour maps overlap is restricted to the central part of the study area surrounding the town of Lynden. To show the comparison of the three water-level maps, selected water-level contours (50, 60, 100,

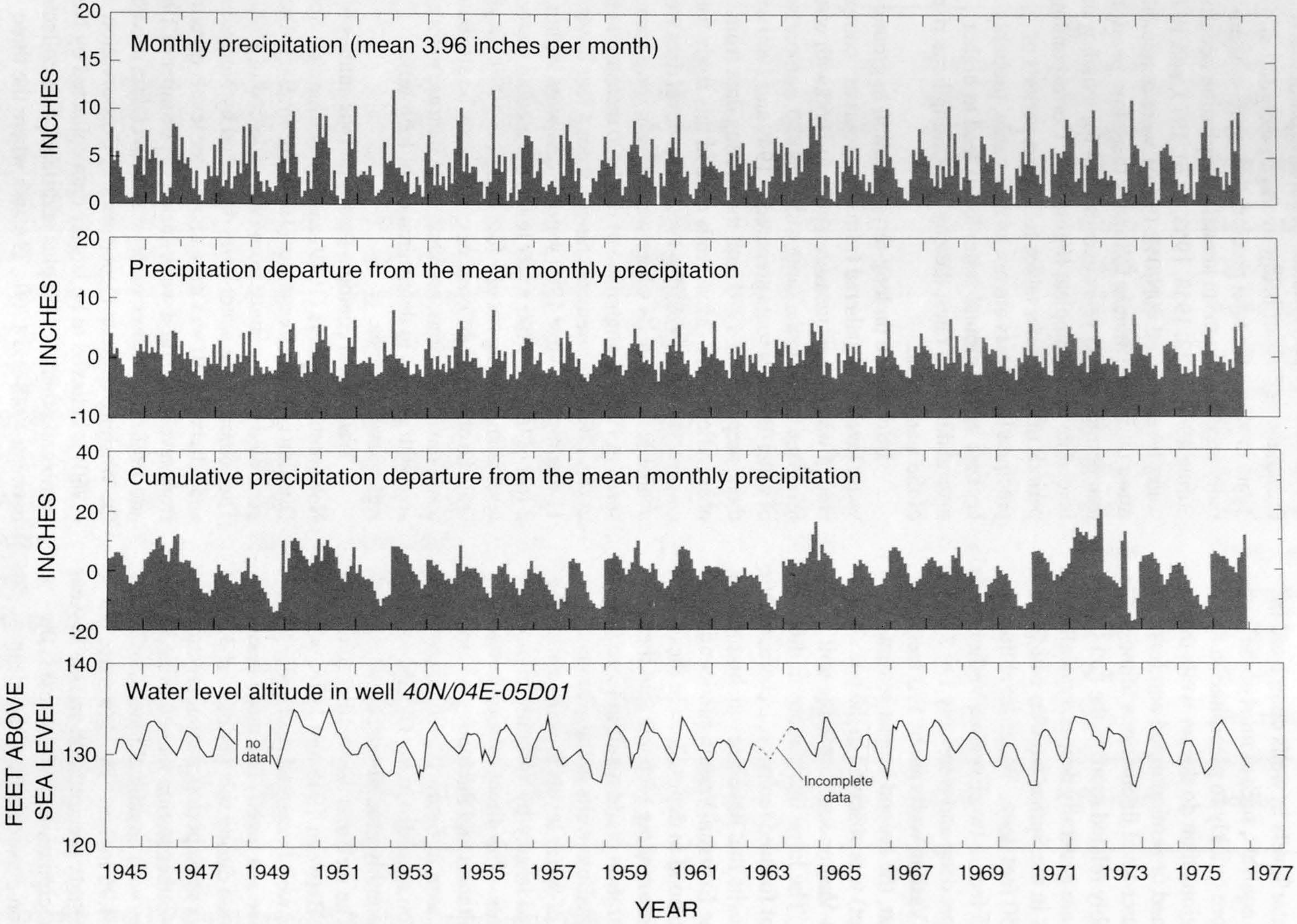


Figure 10. Concurrence of low ground-water levels and cumulative precipitation deficits of the Lynden-Everson-Nooksack-Sumas (LENS) study area, Whatcom County, Wash., and British Columbia, Canada.

120, and 140 feet above sea level) are shown on plate 3. The locations of 100-, 120-, and 140-foot contours were similar in many respects for all three data sets, particularly in the area north of the town of Lynden. For contours below 100 feet elevation, the 1990 water levels tended to be higher than both the 1960 and the 1949 water levels. Some differences in the placement of the three sets of water-level contours is to be expected because the individual sets of contours were drawn from water-level data which differed both in the number and spacing of water-level data points. Considering the potential differences in the data sets, the differences in water-level contours appear neither large enough nor consistent enough to indicate that water levels have changed substantially in the intervening time between the collection of data for each map.

Water levels in long-term observation wells appear to be declining in some areas. The two long-term observation wells within the Whatcom County portion of the study area (see table 4 and fig. 10) do not show patterns of long-term water-level change that are outside the range of seasonal variations; however, measurements of both observation wells were discontinued in the 1970s. Several long-term observation wells currently operated by BC Environment in the area northwest of the town of Sumas have provided current information on the long-term trend in water levels in that area. Kohut (1987), in his analysis of the ground-water supply capability of the Abbotsford aquifer (equivalent to the outwash of the Sumas aquifer within British Columbia), noted declining water levels in several of these observation wells. The water-level decline was most notable in wells near the eastern margin of the outwash plane where the Fraser Valley Trout Hatchery and the towns of Sumas and Abbotsford have large ground-water production facilities along the eastern bluff of the Sumas outwash deposit. Kohut's (1987) analysis of water-level and precipitation records showed high correlation of precipitation and ground-water levels from the early 1960s until 1976 to 1979, a period of below-average precipitation. During this period of below-average precipitation, water-level declines in observation wells exceeded the range expected from declining precipitation, particularly in wells located near the heavy pumpage along the eastern flank of the outwash deposits. The declining water levels were noticeable beginning in about 1977, which coincided with the beginning of the operation of the Fraser Valley Trout Hatchery. Further, Kohut noted in a water budget analysis of the Abbotsford aquifer for 1985 that ground-water withdrawal by the hatchery and the District of Abbotsford accounted for over 70 percent of all ground-water withdrawal from the Abbotsford aquifer, or about 20 percent of the total recharge to the Abbotsford aquifer. His budget did not include pumpage for the City of Sumas, which would increase the figures for the amount of ground-water withdrawal from that area. Together, this information suggests that the long-term trend of declining water levels observed in observation wells near the Sumas-Abbotsford pumping center is real and related to the pumpage of ground water.

The extent to which the declining ground-water levels extend away from the pumpage area is uncertain; however, water-level declines that are most likely related to pumpage along the eastern flank of the upland can be seen in BC Environment's observation well 2 (092G.009.1.2.3-10), located about 3 miles west of the pumping center. Average water levels declined in this well about 10 feet during the late 1970s, when below-average precipitation and increased pumpage began. In the mid 1980s when annual precipitation was again at or above average levels and the trout hatchery was continuing to pump large quantities of ground water, average water levels in the observation well rose about 5 feet, which was about 5 feet below the pre-stress level. Ground-water pumpage from that area has remained at or above the levels of the late 1970s.

Human activities that alter rates of ground-water recharge or discharge can also lead to long-term changes in water levels. Several activities noted within the study area that may lead to such changes include development and urbanization and the installation of shallow drainage systems. Development and urbanization generally include the building of roads, parking lots, buildings, and other impervious surfaces that can substantially reduce the amount of water that can infiltrate the soil surface and recharge the aquifer below. Developed areas make up only about 1 percent of the total study area (Lindsey, 1988). Thus for the study area as a whole, development that has occurred up until the early 1990s is not expected to substantially change regional water levels; however, in those areas where development is concentrated, particularly near the town of Lynden and the City of Abbotsford, the reduced recharge may be sufficient to decrease local ground-water levels.

Lower ground-water levels in parts of the study area may have been caused by the installation of shallow surficial drainage systems, which occur throughout much of the Whatcom County portion of the study area (fig. 3). Shallow subsurface drains are installed to reduce muddy or swampy conditions that inhibit the use of land. Drains change the timing of ground-water discharge, and when they are placed in areas that are not year-round ground-water discharge zones, the early discharge of ground water from the system will effectively reduce the amount of ground-water storage in the aquifer. This reduction will be most noticeable in the fall when ground-water levels are naturally lowest. This reduction in ground-water storage by early discharge will cause seasonally low ground-water levels to be even lower than they would be naturally. In turn, the low ground-water levels can also reduce base-flow to streams or in some areas eliminate streamflow altogether. The extent to which drainage features have affected the ground-water system of the study area is beyond the scope of this report; however, the anecdotal reports of reduced flow in small streams in the study area may in part be the result of drainage features.

Recharge and Discharge

Ground water in the form of recharge and discharge is constantly being added or removed from hydrogeologic units that make up the ground-water system. Quantitative estimates of recharge and discharge throughout the study area, essentially a water budget of the ground-water system, are beyond the scope of this study. Nevertheless, a review of existing information on recharge rates and characterization of the factors that control recharge and discharge processes in the study area should provide insight on how these processes affect ground-water supplies.

Recharge to the ground-water system is due largely to the infiltration of precipitation. Smaller quantities of recharge are derived from losing reaches of streams and other waterways, irrigation of croplands and lawns, and leachate from septic systems and manure storage lagoons. Recharge occurs to some degree throughout the study area, with the possible exceptions of areas of perennial ground-water discharge and impervious surfaces such as asphalt and concrete. The principal hydrologic factors that control recharge are (1) precipitation, which varies in both space and time; (2) surficial geology and topography, which is spatially variable; and (3) evapotranspiration, which is both spatially and temporally variable. Thus, the rate of recharge will also vary in both space and time. In extreme situations, some areas can, at different times of the year, either recharge or discharge water from the ground-water system.

Most precipitation falling on the study area has adequate opportunity to infiltrate the soil. Rainfall intensity is typically light to moderate. Rainfall intensity for durations longer than 1 hour typically occurs at rates of less than 0.5 inch per hour, although occasional short-term cloud bursts may be higher (Miller and others, 1973). The permeability of most soils overlying the Sumas aquifer (table 1) is typically from 0.6 to 2.0 inches per hour or greater (U.S. Department of Agriculture, Soil Conservation Service, 1992b), allowing most precipitation falling on these areas ample opportunity to infiltrate the soil.

The rate of ground-water recharge varies seasonally, depending on the amount of precipitation and evapotranspiration. Generally, moisture that is not lost from the soil because of evapotranspiration will continue to slowly percolate through the unsaturated zone and become ground water. However, during the summer growing season, evapotranspiration returns substantial amounts of moisture back to the atmosphere. Because the hydraulic conductivity of soils is reduced exponentially at water contents below saturation (Campbell, 1985), little if any recharge is expected unless there is sufficient moisture to saturate most of the soil profile. Monthly soil water budgets for the Clearbrook and Abbotsford weather stations in table 5 (from Washington State Division of Water Resources, 1960, and Kohut, 1987) indicate that evapotranspiration typically exceeds precipitation between May and September and that the precipitation exceeds evapotranspiration from October to April. Consequently, most of the recharge is expected during October to April; additionally, this is the period during which water levels rise rapidly in shallow wells, also indicating recharge is occurring.

Estimates of recharge rates have been computed for portions or all of the study area during previous or concurrent studies. Halstead (1959) estimated 14.4 inches of recharge per year for a 20-square-mile area of the Sumas aquifer near the Abbotsford Airport. Kohut (1987) reported a recharge estimate of 24.4 inches per year based on the analysis of natural discharge of springs in the 6-square-mile area of the Sumas aquifer northwest of the town of Sumas. Kohut (1987) further calculated estimates of recharge for the

Table 5. Monthly distribution of average precipitation, estimated potential evapotranspiration, and ground-water recharge at two weather stations within the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada

[Data from Washington State Division of Water Resources, 1960, and Kohut, 1987]

	Clearbrook Weather Station, Whatcom County			Abbotsford Weather Station, Abbotsford Airport, British Columbia		
Month	Average precipitation, (inches)	Potential evapotranspiration (inches)[1]	Average ground-water recharge (inches)[1]	Average precipitation, (inches)	Potential evapotranspiration (inches)[2]	Average ground-water recharge (inches)[2]
January	5.6	0.2	5.4	8.2	0.2	8.0
February	4.6	0.5	4.1	6.3	0.6	5.6
March	4.1	1.2	3.9	5.5	1.1	4.4
April	3.2	2.1	1	4.0	1.9	2.1
May	2.6	3.2	0	3.1	3.0	0.1
June	2.6	3.6	0	2.5	3.8	0
July	1.5	4.5	0	1.6	4.5	0
August	1.7	4.1	0	2.2	4.1	0
September	2.8	2.9	0	3.5	3.0	0.5
October	5.2	1.7	3.5	6.0	1.7	4.3
November	5.6	0.9	4.7	7.6	0.8	6.8
December	6.6	0.4	6.2	9.0	0.4	8.6
Total annual	46.1	25.4	27.8	59.5	25.2	40.4

[1] Estimated by the Washington Department of Natural Resources, 1960.

[2] Estimated by Kohut, 1987.

area studied by Halstead (1959) using the water balance method of analysis by Thornthwaite and Mather (1957) and an analysis of long-term water-level records in two wells. The water balance analysis, based on 30 years of meteorological data from Abbotsford Airport weather station and a soil-moisture capacity of 100 milliliters per meter, resulted in an estimate of recharge of 37.5 inches per year. The recharge estimates were based on analysis of 10 years of water-level records from well 092G.009.2.1.3-47 using specific storage values of 0.1, 0.2, and 0.3, which resulted in recharge estimates of 10.7, 22, and 32 inches per year, respectively. Well 092G.009.1.2.3-47 also is reported to penetrate only sand and gravel that is expected to have a specific storage value in the range of from 0.1 to 0.3, which would result in recharge estimates in this area ranging from 32 to 48 inches per year. Well 092G.009.1.2.3-10, which is located near the area of ice-contact deposits, is reported to have encountered silty material in addition to sand and gravel. The estimate of recharge for this well based on the analysis of water levels and specific storage values of 0.1 and 0.2 is in the range of from 11 to 32 inches per year. Similar duration and specific storage values were used for water levels from well 092G.009.1.2.3-10, which resulted in recharge estimates of 16, 32, and 48 inches, respectively. The specific storage for gravelly sand deposits typically is between 0.2 and 0.3, whereas deposits with more intermixed fines would generally be 0.2 or less (A. I. Johnson, 1967).

Estimates of long-term average recharge for the Puget Sound region are part of the on-going Regional Aquifer Systems Analysis (RASA) of the glacial aquifers in that area (John Vaccaro, USGS, written commun., 1994). The RASA analysis has found that spatial variations in precipitation and underlying geology could explain most of the known local variations in regional recharge rates. Local variations aside, the

RASA analysis has found that, in general, recharge in areas underlain by fine-grained deposits constitutes about 36 percent of annual precipitation, while recharge in areas underlain by coarse-grained deposits constitutes about 63 percent of annual precipitation.

The regional estimates of Vaccaro, based primarily on precipitation amount and underlying geology, compare favorably with the point estimates reported by Kohut (1987) that are based on site-specific data. Kohut's estimate of 37.5 inches per year is based on the water budget analysis of meteorological data from the Abbotsford Airport, located in an area where the regional estimate of recharge is between 31 and 40 inches per year. Regional estimates of recharge in the area surrounding well 092G.009.1.2.3-10 vary from 16 to 30 inches per year. The estimate reported by Kohut (1987) of 24 inches per year, based on spring discharge data from the base of the bluff along the Sumas Valley, also includes this area where the regional estimates vary from 16 to 30 inches per year.

The portion of Vaccaro's recharge map that depicts the distribution of recharge within the study area is shown in figure 11 along with the point estimates from Kohut (1987). As shown, estimated mean annual recharge within the study area varies from 11 to 50 inches per year, reflecting in large part the large range in precipitation across the study area. In the area where the Sumas aquifer is extensive, estimated recharge rates are generally in the range of from 21 to 30 inches per year, while recharge in areas of the Everson-Vashon unit is estimated to be from 11 to 20 inches per year.

Local hydrologic features, which were not included in Vaccaro's regional estimates but will affect the local recharge rates, are peat deposits and artificially drained soils. Peat deposits are generally present in low-lying areas where ground water discharges to streams. Recharge may not occur or will be substantially reduced in these areas. Artificially drained soils are present in some areas where extensive networks of surface and buried drains maintain the water table below the root zone during the growing season by removing ground water from the ground-water system, primarily during the winter and spring periods, which effectively reduces the amount of yearly recharge in that area. Most of the areas artificially drained by either surface drainage ditches or buried tile drains are also shown on figure 3. Flow in these drainage systems occurs primarily during the winter and early spring and stops once the water table has declined below the level of the drain. The drained soil areas are no longer discharge areas when the water table drops below the level of the drainage feature. The magnitude of the effect of these features on the regional recharge estimate is not known.

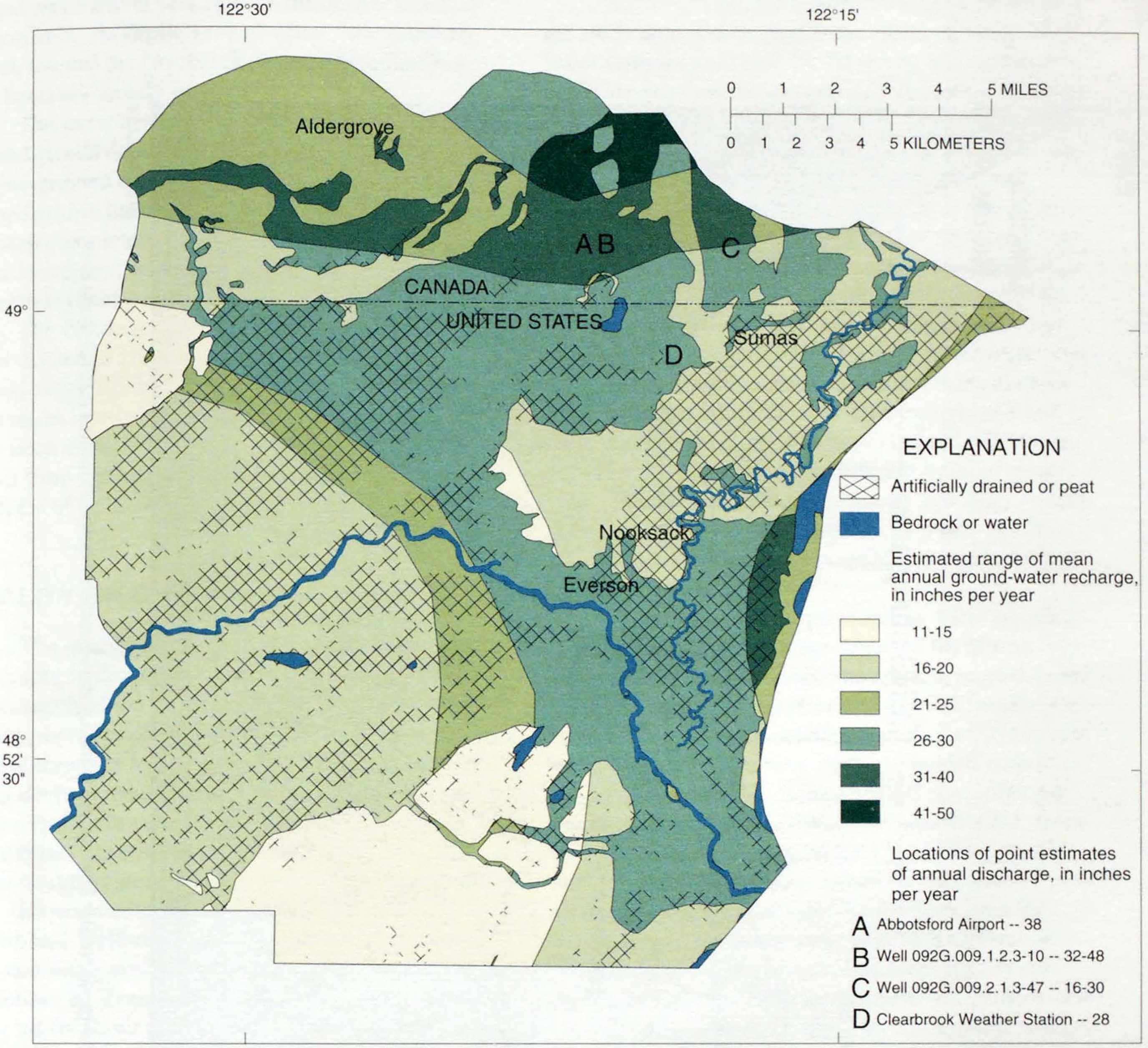
In addition to artificial drainage, typical ground-water discharge occurs as spring flow, transpiration by plants, evaporation, withdrawals from wells, and seepage to rivers, lakes, and streams. Natural ground-water discharge areas are generally immediately adjacent to receiving surface-water bodies. The area of ground-water discharge is generally much smaller than the area of recharge.

Conceptual Model of the Ground-Water System

Based on the foregoing description of the ground-water flow system, a simplified conceptual model of the study area's ground-water system is shown in figure 12. The study area can be characterized as a broad expanse of glacial deposits filling a topographic depression bounded by uplands on all sides, except where the channels of the Nooksack and Sumas Rivers drain the area. Because the area is generally low lying, within a few hundred feet of sea level, deep wells often draw ground water from altitudes below sea level.

The ground-water system within the study area comprises a sequence of glacial deposits that overlie bedrock. The bedrock is composed of fractured consolidated continental sediments and constitutes a low-yielding aquifer. Overlying the bedrock is the predominately fine-grained, low-permeability glaciomarine drift and older undifferentiated deposits that underlie virtually all of the study area. The glaciomarine drift is generally a confining unit except where lenses of more permeable sands produce sufficient water for low-yielding wells. Overlying the glaciomarine drift are glacial outwash sediments that compose the most extensively used aquifer in the study area. In the uplands along the study area boundaries, outwash is largely absent, and the glaciomarine drift is the important source of ground water.

Some precipitation falling on the area infiltrates past the plant root zone and becomes recharge to the ground-water system. Ground water in such upland areas as the Cascade Range and boundary uplands moves vertically downward and laterally to discharge points. Most ground water enters the shallow Sumas aquifer, then travels laterally. Lesser amounts of



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975
and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Soils data modified from U.S. Department of Agriculture, 1992
and Lettmerding, 1981.

Figure 11. Estimated rates of ground-water recharge of the LENS study area, Whatcom County, Washington, and British Columbia, Canada (from Vaccaro and others, 1996, and Kohut, 1989).

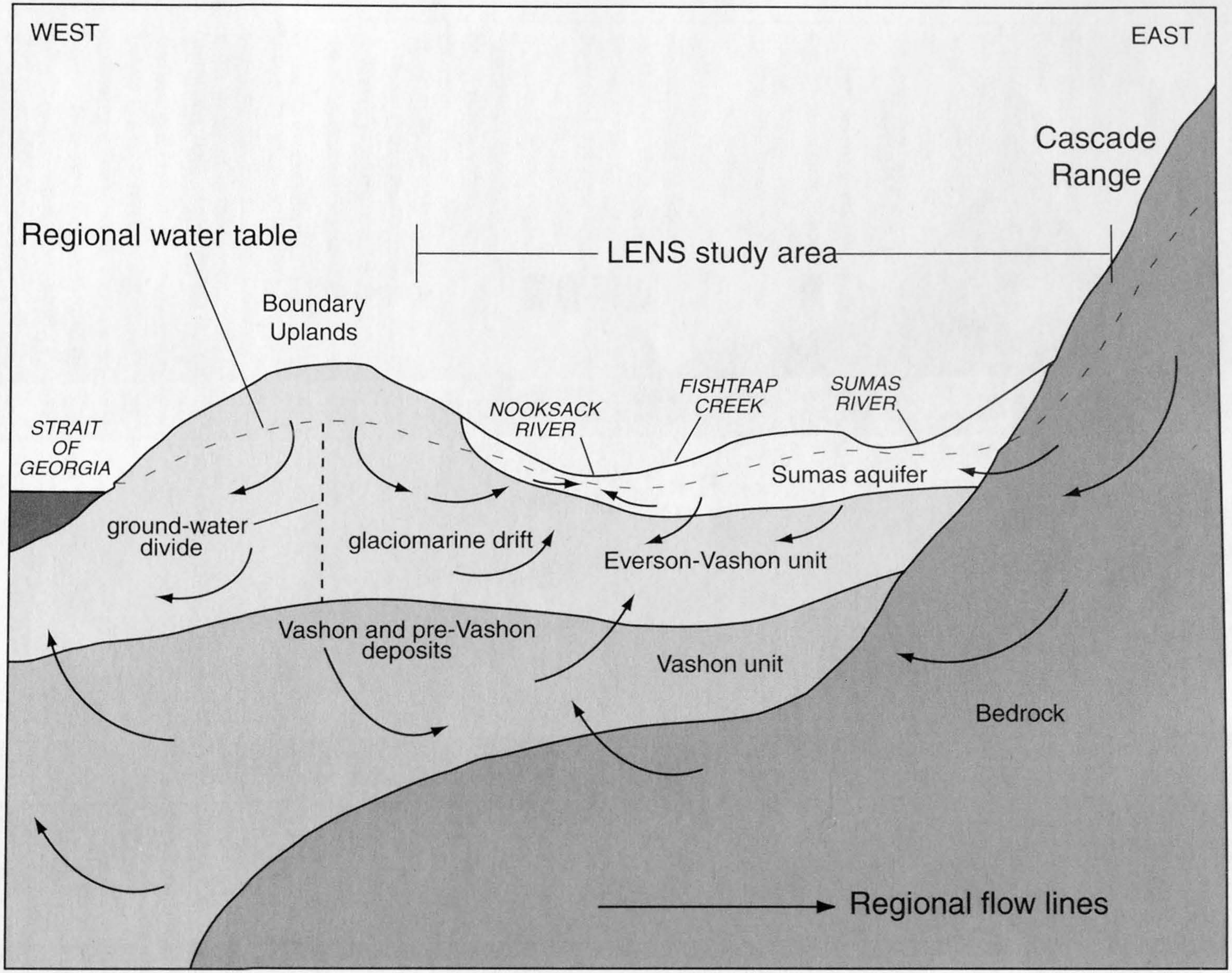


Figure 12. Conceptual model of the ground-water flow system of the Lynden-Everson-Nooksack-Sumas (LENS) study area.

ground water travel vertically to the deeper Everson-Vashon unit. At depth, ground-water flow is mostly lateral, toward the Nooksack River, where the flow then becomes mostly upward.

The movement of ground water within the fine-grained glacial deposits is slow. In several areas within the fine-grained deposits, connate seawater that was trapped within these sediments during deposition has not been completely flushed. By comparison, ground-water movement within the coarse-grained glacial outwash is rapid.

The Nooksack River is the regional ground-water discharge zone within the study area. Local ground-water discharge also occurs, generally along streams, in low-lying boggy areas, and in areas that have been artificially drained. Ground water withdrawn from wells for domestic and irrigation purposes is a form of artificial discharge.

QUALITY OF GROUND WATER

The quality of the ground water in the study area's four hydrogeologic units varies substantially. While much of the ground water sampled was of good quality, there are several areas where substantial water-quality concerns have resulted in some ground water being deemed unsuitable for specific uses. The concentration of nitrate in 15 percent of all wells sampled had nitrate concentrations larger than the drinking water health guideline of 10 mg/L established by the U.S. Environmental Protection Agency (USEPA) and Health and Welfare Canada (HC). Concentrations of iron and manganese exceeded drinking water aesthetic guidelines in 20 and 50 percent, respectively, of wells sampled for those constituents. Some water-quality problems within the study area are of natural origin; others are directly related to present and historic land-use practices.

The term *water quality* refers to the chemical and biological characteristics of water, the primary gage of which is the analysis of the chemicals and minerals dissolved in water. Water-quality assessment also depends on the uses for which the water is intended--human consumption, agricultural irrigation, industrial and commercial processes, and so forth. In this study, water quality is mainly compared to human-health and aesthetic-based standards established by the USEPA and HC for drinking water.

In this section, the quality of the ground water in the study area is described from chemical analyses of water samples collected for this study and readily available data from other studies. Summary data tables of the chemical analyses are included in the text, while complete data tables are located at the end of the report. Chemical concentrations and characteristics are discussed and related to geographic areas and hydrogeologic units where possible. Before this study was conducted, there already were public concerns about possible contamination of ground-water supplies by nitrate, chloride, iron, and organic compounds; thus, the frequency of occurrence, the areal distribution, and the possible sources of these constituents are discussed in more detail. Maps of areal distributions and box plots show patterns in concentrations and differences between ground water from different hydrogeologic units. Temporal variations of nitrate and other constituents are described using time series plots. A subsequent chapter will address potential sources of nitrate in ground water.

Data used in this report include water samples from 368 wells, which were analyzed for nitrate, chloride, and specific conductance; later, more detailed chemical analyses were obtained from 125 wells. Collection of samples for detailed chemical analysis from wells in British Columbia was coordinated with BC Environment and EC. Samples were also collected monthly, from August 1990 to November 1991, from 25 wells and were analyzed for total nitrate, chloride, and specific conductance. EC also collected and analyzed monthly water-quality samples from its network of observation wells in British Columbia.

Additional data from concurrent studies conducted by Ecology, BC Environment, and EC have also been included where appropriate. During this study, Ecology was conducting investigations of chemical inputs to ground water from manure storage lagoons (Erickson, 1991 and 1992 and Garland and Erickson, 1994). Water-quality data from those studies were incorporated into this report where appropriate. In 1987 BC Environment established three nested piezometer sites south of the Abbotsford Airport for the purpose of long-term, semiannual monitoring of nitrates at various depths in the Abbotsford aquifer, which is the upland portion of the Sumas aquifer north of the border between the United States and Canada. Selected results from BC Environment's monitoring are reported in several sections of this report to demonstrate vertical variations in water quality; however, it should be noted that these wells were installed in an area of known nitrate contamination and that some of the variations in chemistry may be due to the nitrate contamination. EC also provided data from its ongoing study of pesticide and nitrates in the Canadian portion of the Sumas aquifer (Liebscher and others, 1992).

It should also be noted that for many constituents, some concentrations may be reported as "less than" (<) a given value, where the value given is the reporting limit of the analytical method. For example, the concentrations of many organic compounds are reported as <0.2 µg/L (microgram per liter) where the reporting limit is 0.2 µg/L. The correct interpretation of such concentrations is that the constituent was not detected at or above that particular concentration. The constituent could be present at a lower concentration, such as 0.1 µg/L, or it may not be present at all, but that determination is beyond the capabilities of the analytical method used.

Data that describe the quality of the ground water are statistically summarized in the text, and complete data tables are given in the Appendix section at the end of the report. Table 6 compares median values for each of the common constituents by hydrogeologic unit. Tables 7-10 show variability of common constituents within each hydrogeologic unit by listing minimum, median, and maximum values, along with 25th- and 75th-percentile values. Data on the variability of nitrate concentrations in ground water are presented in tables 11 and 12. Statistical summaries of the concentrations of trace elements and synthetic organic compounds are presented in tables 13-15. Relative cumulative frequency and boxplot diagrams show the distribution of sample concentrations. The distribution of nitrate and chloride concentrations in ground water within the Sumas aquifer and Everson-Vashon unit was analyzed and divided into four concentration groups and plotted on plates 4 and 5, along with relative cumulative frequency diagrams.

Water-Quality Methods

The sampled wells were selected to provide broad areal coverage and to be representative of all hydrogeologic units. The number of wells selected for sampling within each hydrogeologic unit was approximately proportional to the total number of wells inventoried in each unit. Wells from which samples were analyzed for concentrations of pesticides and volatile organic compounds were selected largely on the basis of the predominant land use in the vicinity of the well, the susceptibility of the hydrogeologic unit to contamination, and previous water-quality analysis.

During the initial well inventory, water-quality samples were collected from pumping or recently pumped wells. These samples were intended to maximize the areal extent of preliminary water-quality information, and, hence, they are referred to as *reconnaissance water-quality samples*. The constituents analyzed in the reconnaissance water-quality samples were nitrate, chloride, and specific conductance. These constituents are generally considered to be stable in solution, and the concentrations are not expected to alter substantially within the well or pumping system of wells that are routinely used. Unfiltered samples were collected after limited flushing (2 to 5 minutes) of the well and pumping system. See the Appendix section at the end of this report for additional details on reconnaissance water-quality sampling.

Nitrate samples were preserved with mercuric chloride and stored on ice prior to analysis by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., while chloride samples were analyzed by the Bureau of Reclamation Laboratory (BR) in Boise, Idaho. Specific conductance was analyzed in the USGS Field Laboratory at the district office in Tacoma, Washington. A total of 368 reconnaissance samples were collected. The data from these samples formed the basis for mapping the areal distribution of nitrate and chloride within the study area and were used to guide the selection of sampling sites at which more detailed chemical analyses would be completed.

Table 6. Median values and concentrations of water-quality constituents in ground waters from four hydrogeologic units

[The number of samples from each hydrogeologic unit is variable; deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter

	Hydrogeologic units [1]			
Water-quality constituent	Sumas aquifer	Everson-Vashon semiconfining unit	Vashon semiconfining unit	Bedrock semiconfining unit
Temperature (deg C)	10	10.8	9.6	11.5
Specific conductance, field (µS/cm)	233	309	844	710
Specific conductance, lab (µS/cm)	231	480	1,190	1,380
pH, field (standard units)	6.5	8.0	8.3	8.4
pH, lab (standard units)	6.7	8.1	7.8	8.3
Dissolved oxygen (mg/L)	4.0	0.2	0.4	0.1
Hardness, total (mg/L as $CaCO_3$)	86	68	130	26
Calcium, dissolved (mg/L)	22	16	35	9.9
Magnesium, dissolved (mg/L)	6.4	7.0	12	0.7
Sodium, dissolved (mg/L)	6.0	98	190	220
Sodium (percent)	13	77	48	95
Sodium adsorption ratio	0.3	5	6	24
Potassium, dissolved (mg/L)	1.4	3.8	2.2	1.2
Alkalinity (mg/L as $CaCO_3$)	45	190	75	230
Sulfate, dissolved (mg/L)	15	2.7	5.0	1.3
Chloride, dissolved (mg/L)	8.8	7.7	182	37
Fluoride, dissolved (mg/L)	<0.1	0.3	0.2	0.4
Silica, dissolved (mg/L)	19	19	17	9.9
Total dissolved solids (mg/L)	147	252	132	567
Iron, dissolved (µg/L)	26	80	54	48
Manganese, dissolved (µg/L)	8	17	20	13
Ammonia as nitrogen, dissolved (mg/L)	0.02	0.15	0.03	0.30
Ammonia as nitrogen, total (mg/L)	0.01	0.31	0.16	0.14
Nitrite as nitrogen, dissolved	<0.01	<0.01	<0.01	<0.01
Nitrite as nitrogen, total	<0.01	<0.01	<0.01	<0.01
Ammonia plus organic nitrogen, dissolved (mg/L)	0.30	0.40	0.40	0.70
Ammonia plus organic nitrogen, total (mg/L)	0.20	0.40	0.42	0.50
Nitrate plus nitrite as nitrogen, total (mg/L)	3.8	0.10	<0.10	<0.10
Nitrate plus nitrite as nitrogen, dissolved (mg/L)	3.7	<0.05	<0.10	<0.05
Phosphate, ortho as phosphorus, dissolved (mg/L)	<0.01	0.26	0.02	<0.01
Phosphate, ortho as phosphorus, total (mg/L)	<0.01	0.73	0.09	0.03
Dissolved organic carbon (mg/L)	0.7	0.6	1.7	1.2
Boron, dissolved (µg/L)	20	120	30	60
Bromide, dissolved (mg/L)	0.03	0.03	<0.01	1.1

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[1] The number of samples for each constituent from each hydrogeologic unit are shown in tables 7 to 10.

Table 7. Statistical summary of values and concentrations of water-quality constituents in the Sumas aquifer

[deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Constituent name	Number of samples	Mean	Median	Minimum	Maximum	25th percentile	75th percentile
Temperature (deg C)	79	10	10	8.0	14	10	11
Specific conductance, field (µS/cm)	224	246	233	50	1,770	161	289
Specific conductance, lab (µS/cm)	101	264	231	72	1,220	168	294
pH, field (standard units)	78	6.7	6.5	5.6	12	6.2	6.9
pH, lab (standard units)	97	6.8	6.7	5.8	8.7	6.4	7.1
Dissolved oxygen (mg/L)	74	6.8	4.2	0	12.6	1.6	7.1
Hardness, total, (mg/L as $CaCO_3$)	97	98	86	27	400	59	120
Calcium, dissolved (mg/L)	97	24	22	6.5	94	14	31
Magnesium, dissolved (mg/L)	97	9.1	6.4	1.8	51	4.7	9.4
Sodium, dissolved (mg/L)	97	8.9	6.0	3.1	61	4.7	8.7
Sodium (percent)	97	16	13	6	42	11	19
Sodium adsorption ratio	97	0.4	0.3	0.1	3	0.2	0.4
Potassium, dissolved (mg/L)	97	4.2	1.4	0.5	110	0.9	2.6
Alkalinity (mg/L as $CaCO_3$)	97	64	45	10	560	26	70
Sulfate, dissolved (mg/L)	100	18	15	0.1	120	7.3	24
Chloride, dissolved (mg/L)	331	13	8.8	0.3	210	5.6	13
Fluoride, dissolved (mg/L)	100	<0.1	<0.1	<0.1	0.4	<0.1	0.1
Silica, dissolved (mg/L)	97	22	19	8.7	53	16	24
Total dissolved solids (mg/L)	93	169	147	53	760	109	190
Iron, dissolved (µg/L)	117	2,100	26	<3	36,000	6	140
Manganese, dissolved (µg/L)	97	160	8	<1	3,500	2	110
(per milliliter)	22	6.7	7.05	1.5	12	4.0	9.0
Ammonia as nitrogen, dissolved (mg/L)	97	1.1	0.02	<0.01	63	<0.01	0.06
Ammonia as nitrogen, total (mg/L)	65	1.3	0.01	<0.01	46	<0.01	0.03
Nitrite as nitrogen, dissolved (mg/L)	97	0.02	<0.01	<0.01	0.37	<0.01	0.01
Nitrite as nitrogen, total (mg/L)	65	0.02	<0.01	<0.01	0.34	<0.01	0.01
Ammonia plus organic as nitrogen, dissolved (mg/L)	96	1.5	0.30	<0.2	63	0.20	0.60
Ammonia plus organic as nitrogen, total (mg/L)	39	2.6	0.20	<0.20	50	0.20	0.51
Nitrate plus nitrite as nitrogen, total (mg/L)	230	5.6	3.8	<0.05	43	0.60	8.8
Nitrate plus nitrite as nitrogen, dissolved (mg/L)	108	6.0	3.7	<0.05	43	0.44	9.8
Phosphate, ortho as phosphorus, dissolved (mg/L)	81	<0.10	<0.01	<0.01	3.3	<0.01	0.01
Phosphate, ortho as phosphorus, total (mg/L)	65	<0.01	<0.01	<0.01	0.14	<0.01	0.01
Dissolved organic carbon (mg/L)	71	2.0	0.7	0.2	39	0.5	1.2
Methylene blue active substances, MBAS (mg/L)	56	<0.02	<0.02	<0.02	0.09	<0.02	<0.02
Boron, dissolved (µg/L)	59	20	20	10	120	10	30
Bromide, dissolved (mg/L)	33	0.15	0.03	0.01	3.1	0.01	0.04

Table 8. Statistical summary of values and concentrations of water-quality constituents in the Everson-Vashon semiconfining unit

[deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Constituent name	Number of samples	Mean	Median	Minimum	Maximum	25th percentile	75th percentile
Temperature (deg C)	28	12	10.8	9.0	17	10.5	12
Specific conductance, field (µS/cm)	83	618	336	99	10,100	244	548
Specific conductance, lab (µS/cm)	20	1,200	480	198	9,950	296	1,070
pH, field (standard units)	27	7.7	8	0.3	8.9	7.1	8.5
pH, lab (standard units)	19	8.0	8.1	6.6	8.8	7.7	8.6
Dissolved oxygen (mg/L)	19	1.3	0.2	0	6.4	0.1	1.5
Hardness, total (mg/L as $CaCO_3$)	19	130	68	10	1,000	28	120
Calcium, dissolved (mg/L)	19	23	16	2.0	140	4.0	27
Magnesium, dissolved (mg/L)	19	17	7.0	0.9	160	4.3	12
Sodium, dissolved (mg/L)	19	220	98	4.7	1,800	33	230
Sodium (percent)	19	64	77	11	97	35	89
Sodium adsorption ratio	19	10	5	0.2	31	1	14
Potassium, dissolved (mg/L)	19	6.8	3.8	1.0	44	2.9	5.9
Alkalinity (mg/L as $CaCO_3$)	19	210	190	47	440	130	300
Sulfate, dissolved (mg/L)	22	44	2.7	0.1	620	0.2	11
Chloride, dissolved (mg/L)	87	98	7.9	0.8	2,800	4.8	30
Fluoride, dissolved (mg/L)	22	0.4	0.3	<0.1	1.1	0.2	0.5
Silica, dissolved (mg/L)	19	20	19	13	31	16	23
Total dissolved solids (mg/L)	14	905	252	136	5,630	173	1,280
Iron, dissolved (µg/L)	25	190	80	<3	960	30	260
Manganese, dissolved (µg/L)	19	87	17	<1	360	6	140
Ammonia as nitrogen, dissolved (mg/L)	22	0.28	0.15	0.01	1.2	0.01	0.47
Ammonia as nitrogen, total (mg/L)	7	0.34	0.31	0.02	0.76	0.28	0.41
Nitrite as nitrogen, dissolved (mg/L)	22	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Nitrite as nitrogen, total (mg/L)	7	<0.01	<0.01	<0.01	0.01	0.01	0.01
Ammonia plus organic nitrogen, dissolved (mg/L)	21	0.32	0.40	<0.01	1.2	<0.01	0.40
Ammonia plus organic nitrogen, total (mg/L)	7	0.45	0.40	0.20	0.93	0.20	0.50
Nitrate plus nitrite as nitrogen, total (mg/L)	81	0.68	0.10	<0.05	10	0.10	0.25
Nitrate plus nitrite as nitrogen, dissolved (mg/L)	21	13	<0.05	<0.05	9.9	<0.05	1.4
Phosphate as phosphorus, dissolved (mg/L)	22	0.46	0.26	0.01	2.3	0.01	0.81
Phosphate as phosphorus, total (mg/L)	7	0.72	0.73	0.01	1.8	0.14	1.2
Dissolved organic carbon (mg/L)	12	1.4	0.65	0.3	6.8	0.4	2.0
Methylene blue active substances (mg/L)	7	<0.02	<0.02	<0.02	0.03	<0.02	<0.02
Boron, dissolved (µg/L)	15	230	120	<10	890	30	360
Bromide, dissolved (mg/L)	10	0.38	0.03	0.01	1.90	0.02	0.49

Table 9. Statistical summary of values and concentrations of water-quality constituents in the Vashon semiconfining unit

[deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent name	Number of samples	Mean	Median	Minimum	Maximum	25th percentile	75th percentile
Temperature (deg C)	3	9.5	9.5	8.0	10.5	8.0	10.5
Specific conductance, field (µS/cm)	8	651	844	210	2,290	320	1,850
Specific conductance, lab (µS/cm)	4	1,220	1,190	208	2,290	210	2,260
pH, field (standard units)	3	7.8	8.3	6.5	8.6	6.5	8.6
pH, lab (standard units)	4	7.7	7.8	6.9	8.3	7.0	8.3
Dissolved oxygen (mg/L)	3	2.4	0.4	0.1	6.8	0.1	6.8
Hardness, total (mg/L as $CaCO_3$)	4	130	130	90	170	92	170
Calcium, dissolved (mg/L)	4	32	35	13	46	17	45
Magnesium, dissolved (mg/L)	4	12	12	7.0	16	7.8	16
Sodium, dissolved (mg/L)	4	190	190	3.4	400	4.1	390
Sodium (percent)	4	47	48	7	84	8	84
Sodium adsorption ratio	4	7	6	0.2	14	0.2	14
Potassium, dissolved (mg/L)	4	2.6	2.2	1.2	4.7	1.2	4.3
Alkalinity (mg/L as $CaCO_3$)	4	76	75	57	95	60	92
Sulfate, dissolved (mg/L)	4	7.8	5.0	<0.1	21	0.3	18
Chloride, dissolved (mg/L)	8	270	182	1.7	750	13	580
Fluoride, dissolved (mg/L)	4	0.2	0.2	<0.1	0.4	0.1	0.4
Silica, dissolved (mg/L)	4	18	17	15	21	15	20
Total dissolved solids (mg/L)	2	132	132	127	137	127	137
Iron, dissolved (µg/L)	4	80	50	10	190	20	160
Manganese, dissolved (µg/L)	4	33	20	<1	90	6	72
Ammonia as nitrogen, dissolved (mg/L)	3	0.10	0.03	<0.01	0.25	<0.01	0.25
Ammonia as nitrogen, total (mg/L)	1	0.16	0.16	0.16	0.16	0.16	0.16
Nitrite as nitrogen, dissolved (mg/L)	3	<0.01	<0.01	<0.01	0.01	<0.01	0.01
Nitrite as nitrogen, total (mg/L)	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia plus organic nitrogen, dissolved (mg/L)	3	0.33	0.40	0.20	0.40	0.20	0.40
Ammonia plus organic nitrogen, total (mg/L)	1	0.42	0.42	0.42	0.42	0.42	0.42
Nitrate plus nitrite as nitrogen, total (mg/L)	8	0.86	<0.10	0.08	6.2	<0.10	0.10
Nitrate plus nitrite as nitrogen, dissolved (mg/L)	4	1.3	<0.10	<0.05	5.0	<0.10	3.8
Phosphate, ortho as phosphorus, dissolved (mg/L)	3	0.02	0.02	<0.01	0.03	0.01	0.03
Phosphate, ortho as phosphorus, total (mg/L)	1	0.09	0.09	0.09	0.09	0.09	0.09
Dissolved organic carbon (mg/L)	1	1.7	1.7	1.7	1.7	1.7	1.7
Methylene blue active substances (mg/L)	1	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Boron, dissolved (µg/L)	1	30	30	30	30	30	30
Bromide, dissolved (mg/L)	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10. Statistical summary of values and concentrations of water-quality constituents in the bedrock semiconfining unit

[deg C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Constituent name	Number of samples	Mean	Median	Minimum	Maximum	25th percentile	75th percentile
Temperature (deg C)	8	12	11.5	10	14	10.5	13
Specific conductance, field (µS/cm)	14	937	710	88	4,020	250	1,060
Specific conductance, lab (µS/cm)	6	1,730	1,380	360	4,200	746	2,720
pH, field (standard units)	7	8.4	8.4	7.7	9.2	7.8	9.1
pH, lab (standard units)	5	8.2	8.3	7.6	8.6	7.9	8.4
Dissolved oxygen (mg/L)	7	0.1	0.1	<0.1	0.3	<0.1	0.2
Hardness, total (mg/L as $CaCO_3$)	5	56	26	13	200	13	110
Calcium, dissolved (mg/L)	5	18	9.9	4.0	61	4.3	36
Magnesium, dissolved (mg/L)	5	2.4	0.7	0.2	9.7	0.4	5.3
Sodium, dissolved (mg/L)	5	330	220	67	760	140	570
Sodium (percent)	5	92	95	82	98	86	97
Sodium adsorption ratio	5	24	24	5	46	12	35
Potassium, dissolved (mg/L)	5	2.0	1.2	0.8	5.3	0.8	3.4
Alkalinity (mg/L as $CaCO_3$)	5	310	230	150	600	160	490
Sulfate, dissolved (mg/L)	5	14	1.3	<0.1	79	0.3	23
Chloride, dissolved (mg/L)	14	210	37	1.4	1,200	15	210
Fluoride, dissolved (mg/L)	5	0.4	0.4	0.3	0.5	0.3	0.5
Silica, dissolved (mg/L)	5	10	9.9	7.6	13	8.4	12
Total dissolved solids (mg/L)	4	907	567	208	2,290	294	1,860
Iron, dissolved (µg/L)	5	350	50	<3	1,500	10	840
Manganese, dissolved (µg/L)	5	48	13	6	110	8	100
Ammonia as nitrogen, dissolved (mg/L)	5	0.63	0.30	<0.01	2.0	0.02	0.8
Ammonia as nitrogen, total (mg/L)	3	0.16	0.14	0.13	0.20	0.13	0.20
Nitrite as nitrogen, dissolved (mg/L)	5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrite as nitrogen, total (mg/L)	3	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Ammonia plus organic nitrogen, dissolved (mg/L)	5	0.94	0.70	<0.20	2.4	0.30	1.7
Ammonia plus organic nitrogen, total (mg/L)	3	0.53	0.50	<0.20	0.90	0.20	0.90
Nitrate plus nitrite as nitrogen, total (mg/L)	14	0.18	<0.10	<0.05	1.6	<0.10	0.18
Nitrate plus nitrite as nitrogen, dissolved (mg/L)	5	0.07	<0.05	<0.05	0.16	<0.05	0.10
Phosphate, ortho as phosphorus, dissolved (mg/L)	5	0.02	0.01	<0.01	0.04	<0.01	0.04
Phosphate, ortho as phosphorus, total (mg/L)	3	0.07	0.03	<0.01	0.18	<0.01	0.18
Dissolved organic carbon (mg/L)	2	1.2	1.2	1.0	1.4	1.0	1.4
Boron, dissolved (µg/L)	4	120	60	60	310	60	30
Bromide, dissolved (mg/L)	3	1.4	1.1	0.4	2.6	0.4	0.01

Table 11. Temporal variability of nitrate concentrations in ground waters with multiple observations

[G, USGS; F, Flora, written communications; S, City of Sumas; C, Environment Canada; B, British Columbia Ministry of Environment; W, Washington State Department of Ecology; SUMS, Sumas aquifer; EVRS, Everson-Vashon unit; VSHN, Vashon unit; --, no data; <, less than]

Well number	Hydro-geologic unit	Depth (feet)	Period of record	Number of obser-vations	Data source	Nitrate concentrations, in milligrams per liter				Standard deviation	Coeffi-cient of variation (percent)
						Range	Minimum	Maximum	Average		
39N/02E-01P02	SUMS	34	8/90-10/91	12	U	2.9	5.3	14	8.5	2.3	26
39N/02E-10F01	SUMS	20	8/90-10/91	14	U	13	1.6	15	7.7	4.0	52
39N/02E-27F03	SUMS	44	10/90-10/91	14	U	12	1.6	14	12	2.8	25
39N/03E-01C01	SUMS	49	10/90-10/91	12	U	0.1	0.26	0.37	0.30	0.03	9.7
39N/03E-10L01	SUMS	35	81-86	237	F	8.9	0.27	9.2	2.8	1.4	51
39N/03E-10L01	SUMS	35	10/90-10/91	11	U	2.7	0.14	2.8	1.4	0.98	70
39N/03E-19N01	EVRS	62	10/90-10/91	10	U	0.3	1.1	1.4	1.3	0.12	9.9
39N/03E-26P02	EVRS	155	10/90-10/91	11	U	0	<0.1	<0.1	--	--	--
39N/04E-03P01	VSHN	117	3/90-9/91	12	U	0	<0.1	<0.1	--	--	--
40N/02E-03C01	EVRS	100	11/90-9/91	10	U	0	<0.1	<0.1	--	--	--
40N/02E-27B01	SUMS	41	7/90-9/91	13	U	5.7	6.3	12	8.2	2.7	33
40N/03E-03B01	SUMS	29	7/90-12/91	15	U	5.2	5.8	11	7.54	2.52	33
40N/03E-5M05	SUMS	12	2/90-4/93	18	W	96	2.5	99	34	33	96
40N/03E-5N01	SUMS	18	1/90-5/92	7	W	4.4	0.2	4.6	1.7	1.6	92
40N/03E-5N02	SUMS	24	1/90-8/92	11	W	1.6	0.8	2.4	1.2	0.71	59
40N/03E-16H02	SUMS	29	7/90-9/91	13	U	12	2.7	15	10	4.0	40
40N/03E-32M01	SUMS	26	8/90-9/91	15	U	4.1	8.9	13	11	1.0	9.1
40N/03E-20F01	SUMS	18	11/90-12/91	12	U	1.4	<0.1	1.5	0.54	0.51	95
41N/03E-32Q1	SUMS	25	6/90-7/91	5	W	26	16	43	24	13	54
41N/04E-31J02	SUMS	80	10/90-9/91	13	U	11.1	2.9	14	11	3.0	28
41N/04E-33H01	SUMS	58	12/88-11/91	34	S	3.3	1.7	5	2.2	0.5	22
41N/04E-33H01S	SUMS	--	12/88-11/91	33	S	3.5	3.9	7.4	5.4	0.65	12
41N/04E-33H02	SUMS	58	12/88-11/91	35	S	3.8	4	7.8	5.5	0.8	15
41N/04E-33H03	SUMS	58	12/88-11/91	35	S	3.6	4.6	8.2	6.1	0.7	13

Table 11. Temporal variability of nitrate concentrations in ground waters with multiple observations--Continued

Well number	Hydro-geologic unit	Depth (feet)	Period of record	Number of obser-vations	Data source	Nitrate concentrations, in milligrams per liter: Range	Minimum	Maximum	Average	Standard deviation	Coeffi-cient of variation (percent)
41N/04E-33H04	SUMS	69	12/88-11/91	35	S	2.7	3.7	6.4	5.2	0.58	11
092G.009.1.1.1-06-20	SUMS	20	6/88-6/90	13	B	24	10	41	20.3	8.6	42
092G.009.1.1.1-06-35	SUMS	35	6/88-6/90	12	B	17	17	34	20	4.8	24
092G.009.1.1.1-07-55	SUMS	55	6/88-6/90	13	B	5.7	6.3	12	8.4	2.0	24
092G.009.1.1.1-07-75	SUMS	75	6/88-6/90	13	B	1.8	2.3	4.1	3.2	0.6	18
092G.009.1.1.2-11-25	SUMS	25	6/88-6/90	13	B	19	4.0	23	12	5.2	43
092G.009.1.1.2-11-35	SUMS	35	6/88-6/90	13	B	10	13	23	18	3.2	18
092G.009.1.1.2-12-55	SUMS	55	6/88-6/90	13	B	8.2	3.8	12	7.5	2.6	35
092G.009.1.1.2-12-75	SUMS	75	6/88-6/90	13	B	5.0	0.2	5.2	2.4	1.8	75
092G.009.1.1.4-18-25	SUMS	25	6/88-6/90	12	B	7	3.3	11	4.9	1.9	39
092G.009.1.1.4-18-35	SUMS	35	6/88-6/90	12	B	2.4	3.5	5.9	4.6	0.8	18
092G.009.1.1.4-19-55	SUMS	55	6/88-6/90	12	B	1.1	4.3	5.6	5.0	0.41	8.0
092G.009.1.1.4-19-75	SUMS	75	6/88-6/90	12	B	1.4	5.5	7.0	6.6	1.2	19.
092G.009.1.2.4-34	EVRS	163	3/73-5/92	40	E	5.0	5.0	10	6.9	1.4	20
092G.009.1.2.3-39	SUMS	81	3/71-8/91	40	E	7.0	11	18	15	1.6	11
092G.008.2.2.2-ABB1	SUMS	25	1/90-5/91	22	E	25	2.6	28	12.2	5.1	42
092G.009.1.1.2-ABB2	SUMS	25	1/90-8/92	22	E	11	6.7	18	11.0	3.2	29
092G.009.1.2.1-ABB3	SUMS	58	11/89-8/92	22	E	22	5.3	27	17.0	5.6	33
092G.009.1.2.1-ABB4	SUMS	96	1/90-8/92	21	E	11	18.3	29	25.3	4.0	16
092G.009.1.1.1-ABB5	SUMS	29	11/82-8/92	22	E	9	16	25	20.3	3.25	16
092G.009.1.1.4-ABB6	SUMS	30	11/89-8/92	21	E	6.4	8.6	15	11.6	1.84	16

Table 12. Nitrate concentrations in water samples obtained from the same well 3 years apart
[--, undefined; <, less than]

	Nitrate concentrations, in milligrams per liter		
Local number	August 1988	August 1991	Percent difference
40N/02E-14P02	8.94	13	+45
40N/02E-15A01	24.4	3.2	-87
40N/02E-15C01	0.28	0.12	-57
40N/02E-15H01	1.04	0.07	-93
40N/02E-15P01	3.63	1.4	-61
40N/02E-15R02	5.16	8.2	+59
40N/02E-21D01	1.49	0.59	-60
40N/02E-21J05	1.14	4.8	+321
40N/02E-21N01	3.92	8.2	+109
40N/02E-22E02	4.32	4.8	+11
40N/02E-22N02	10.2	13	+28
40N/02E-22N07	5.43	5.0	-8
40N/02E-23A03	<0.1	6.7	--
40N/02E-23B02	13.6	11	-19
40N/02E-23D04	15.2	13	-14
40N/02E-23P01	10.3	20	+93
40N/02E-26C03	4.6	2.2	-52
40N/02E-26D02	1.66	5.6	+237
40N/02E-27C01	8.24	7.8	-5
40N/02E-27D02	7.03	7.2	+2
40N/02E-28G01	4.97	7.4	+49
Median	5.0	6.7	+2

Table 13. Summary of concentrations of trace elements in ground water from four hydrogeologic units

[--, no U.S. Environmental Protection Agency (USEPA) drinking water guideline; HC = Health Canada; < = less than]

Element	Number of wells with analysis reported	Number of wells with elements detected	Number of wells with elements not detected in analysis	Detected concentrations, dissolved, in micrograms per liter			USEPA and (HC) drinking water reference* (µg/L)	Number of wells exceeding standard
				Minimum	Median	Maximum		
Arsenic	48	6	42	1	1.5	**6	50 (50)	0
Barium	43	40	3	3	12	1,100	2,000 (1,000)	0 (1)
Beryllium	18	0	18	--	--	--	4	0
Cadmium	46	2	44	1	2	3	5 (5)	0
Chromium	46	1	45	2	2	2	100 (50)	0
Cobalt*	28	1	27	3	3	3	--	0
Copper	46	35	11	1	6	190	1,300b (1,000)	0
Lead	44	2	34	1	1	1	15b (10)	0
Lithium	6	2	4	4	11	18	--	0
Mercury	18	0	18	--	--	--	2 (1)	0
Molybdenum*	28	3	25	10	20	40	--	0
Nickel	28	0	19	--	--	--	100 (10)	0
Selenium	30	1	29	1	1	1	50	0
Silver	36	9	27	1	1	2	100a	0
Strontium	18	18	0	49	102	1,700	--	0
Vanadium	28	3	25	3	5	6	--	0
Zinc*	46	43	3	6	30	240	5,000a (5,000)	0

* Primary drinking water standard, unless noted, a = secondary standard, b = action level.

** Two wells reported non-detects at 250 µg/L, not included in concentration range.

Table 14. Summary of total recoverable concentrations, analytical reporting limits, and health advisory levels for pesticides and volatile organic compounds included in the analysis of selected ground-water samples

[µg/L, micrograms per liter; <, less than; --, no data; THM, trihalomethane; n.d., not detected]

Common name	Trade name(s)	Minimum analytical reporting level (µg/L)	Health advisory level (µg/L)	Number of wells sampled	Number of analyses greater than or equal to reporting level	Largest detected concentration (µg/L)
Triazines and other nitrogen containing herbicides						
Alachlor	Lasso	0.1	60	24	0	n.d.
Ametryn	Evik/Ametrex	0.1	--	24	0	n.d.
Atrazine	AAtrex	0.1	3	24	1	0.1
Cyanazine	Bladex	0.1	10	24	0	n.d.
Metolachlor	Dual	0.1	100	24	0	n.d.
Metribuzin	Lexone/Sencor	0.1	200	24	0	n.d.
Prometon	Pramitol	0.1	100	24	0	n.d.
Prometryn		0.1		24	0	n.d.
Propazine	Milogard	0.1	10	24	0	n.d.
Simazine	Princep/Simadex	0.1	1	24	0	n.d.
Simetryn	Simetryne	0.1	--	24	0	n.d.
Trifluralin	Treflan	0.1	5	24	0	n.d.
Carbamate insecticides and metabolites						
Aldicarb	Temik	0.05	10	24	0	n.d.
Aldicarb sulfone	Standak	0.05	10-40	24	0	n.d.
Aldicarb sulfoxide	metabolite *	0.05	10	24	0	n.d.
Carbaryl	Sevin	0.05	700	24	0	n.d.
Carbofuran	Furadan	0.05	40	24	0	n.d.
3-Hydroxy carbofuran	metabolite *	0.05	--	24	0	n.d.
Methomyl	Lannate/Nudrin	0.05	200	24	0	n.d.
1-Naphthol		0.05		24	0	n.d.
Oxamyl	Vydate	0.05	200	24	1	0.05
Propham	Chem-Hoe	0.05	100	24	0	n.d.
Volatile organic compounds						
Chloromethane		<0.2	--	24	0	n.d.
Dichloromethane		<0.2	5	24	0	n.d.
Trichloromethane		<0.2	--	24	0	n.d.
Tetrachloromethane		<0.2	--	24	0	n.d.
Bromomethane		<0.2	--	24	0	n.d.
Dibromomethane		<0.2	--	24	0	n.d.
Tribromomethane		<0.2	1(THM)	24	0	n.d.
Bromodichloromethane		<0.2	1(THM)	24	0	n.d.
Dibromochloromethane		<0.2	1(THM)	24	0	n.d.

Table 14. Summary of total recoverable concentrations, analytical reporting limits, and health advisory levels for pesticides and volatile organic compounds included in the analysis of selected ground-water samples--Continued

Common name	Trade name(s)	Minimum analytical reporting level (µg/L)	Health advisory level (µg/L)	Number of wells sampled	Number of analyses greater than or equal to reporting level	Largest detected concen-tration (µg/L)
		Volatile organic compounds--Continued				
Trichlorofluoromethane		<0.2	--	24	0	n.d.
Dichlorodifluoromethane		<0.2	--	24	0	n.d.
Chloroethane		<0.2	--	24	0	n.d.
1,1-dichloroethane		<0.2	--	24	0	n.d.
1,2-dichloroethane		<0.2	5	24	0	n.d.
1,1,1-trichloroethane		<0.2	200	24	0	n.d.
1,1,2-trichloroethane		<0.2	5	24	0	n.d.
1,1,1,2-tetrachloroethane		<0.2	--	24	0	n.d.
1,1,2,2-tetrachloroethane		<0.2	--	24	0	n.d.
1,2-dibromoethane		<0.2	0.05	24	1	0.3
Chloroethene, vinyl chloride		<0.2	2	24	0	n.d.
1,1-dichloroethene		<0.2	7	24	0	n.d.
Cis 1,2-dichloroethene		<0.2	70	24	0	n.d.
Trans 1,2-dichloroethene		<0.2	100	24	0	n.d.
Trichloroethene		<0.2	?	24	0	n.d.
Tetrachloroethene		<0.2	--	24	0	n.d.
1,2-dichloropropane		<0.2	5	24	2	5.6
1,3-dichloropropane		<0.2	--	24	1	0.2
2,2-dichloropropane		<0.2	--	24	0	n.d.
1,2,3-trichloropropane		<0.2	--	24	1	1.4
1,2-dibromo-3-chloropane		<0.2	0.2	24	0	n.d.
1,1-dichloropropene		<0.2	--	24	0	n.d.
Cis 1,3-dichloropropene		<0.2	--	24	0	n.d.
Trans 1,3-dichloropropene		<0.2	--	24	0	n.d.
Benzene		<0.2	5	24	0	n.d.
Chlorobenzene		<0.2	--	24	0	n.d.
1,2-dichlorobenzene		<0.2	0.600	24	0	n.d.
1,3-dichlorobenzene		<0.2	0.600	24	0	n.d.
1,4-dichlorobenzene		<0.2	75	24	0	n.d.
Bromobenzene		<0.2	--	24	0	n.d.
Toluene		<0.2	1,000	24	0	n.d.
Chlorotoluene		<0.2	--	24	0	n.d.
p-chlorotoluene		<0.2	--	24	0	n.d.
Dimethylbenzene		<0.2	--	24	0	n.d.
Ethylbenzene		<0.2	--	24	0	n.d.
Ethenylbenzene		<0.2	--	24	0	n.d.

* metabolite of parent compound

Table 15. Compilation of detection of organic pesticide compounds in ground waters of the study area from selected studies conducted between 1985-1993

[ppb, parts per billion; mg/L, milligrams per liter; µg/L, micrograms per liter; DSHS, Department of Social and Health Services; USGS, U.S. Geological Survey; USEPA, U.S. Environmental Protection Agency; EC, Environment Canada; CDN, Canadian; RU, restricted use only by licensed and certified applicators; GU, non-restricted, available for commercial and public use; --, not applicable; n.d., not detected; n.g., no guideline]

Compound	General use of compound	Usage restriction or date of cancellation or non-renewal of registration		Source of information	Number of wells sampled	Number of wells with detectable concentration	Range of detected concentration (ppb or µg/L)	USEPA maximum contaminant level or health advisory level (µg/L)[c]	Health Canada maximum acceptable concentration or health advisory level (µg/L)[d]	Number of wells with detected concentration above USEPA health advisory level	Number of wells with detected concentration above Canadian health advisory level
		US	CDN								
Etheleyne dibromide (EDB)	Soil fumigant	1983[a]	1984	DSHS 1985[g]	35	5	0.28-4.3	0.05	n.g.	4	--
				Black and Veatch 1986	24	8	0.05-2.3	0.05	n.g.	8	--
				Sweet-Edwards/EMCON 1989	26	6	0.03-1.64	0.05	n.g.	6	--
				Erickson and Norton 1990	27	3	0.02-2.95	0.05	n.g.	2	--
				USGS 1991-1992	24	1	0.3	0.05	n.g.	1	--
				Hulsman June 1993[f]	25	7	0.03-2.9	0.05	n.g.	6	--
1,2 Dichloropropane (1,2 DCP)	Soil fumigant	1988	1985	Erickson and Norton 1990	27	9	0.3-24	5	n.g.	5	--
				Liebscher and others 1992	107	27	<0.1-5.5	5	n.g.	1	--
				USGS 1991-1992	24	2	1.6-5.6	5	n.g.	1	--
				Hulsman 1993[f]	25	4	1.0-9.3	5	n.g.	2	--
1,3-Dichloropropene	Soil fungicide and nematacide	RU	GU	Liebscher and others 1992	39	1	3.5	n.g.	n.g.	--	--
				USGS 1991-92	24	1	0.2	n.g.	n.g.	--	--
				Hulsman 1993[f]	26	0	n.d.	n.g.	n.g.		
Dibromochloro propane	Soil fumigant	RU	1978	Erickson and Norton 1990	27	1	0.36	0.2	n.g.	1	--
				USGS 1991-1992	24	0	n.d.	0.2	n.g.	n.d.	--
				Hulsman 1993[f]	25	1	0.2	0.2	n.g.	0	--
Carbofuran	Insecticide and nematacide	RU	RU*	Erickson and Norton 1990	27	1	2.4	40	90	0	0
				Liebscher and others 1992	39	8	0.1-12	40	90	0	0
				USGS 1991-1992	24	0	n.d.	40	90	n.d.	n.d.
				Hulsman 1993[f]	26	2	0.01-0.03	40	90	0	0
Prometon	Soil sterilant	RU and	RC	Erickson and Norton 1990	27	2	0.5-0.9	100	n.g.	0	--
				USGS 1991-1992	24	0	n.d.	100	n.g.	n.d.	--
				Hulsman 1993[f]	26	0	n.d.	100	n.g.	n.d.	n.d.

Table 15. Compilation of detection of organic pesticide compounds in ground waters of the study area from selected studies conducted between 1985-1993--Continued

Compound	General use of compound	Usage restriction or date of cancellation or non-renewal of registration		Source of information	Number of wells sampled	Number of wells with detectable concentration	Range of detected concentration (ppb or µg/L)	USEPA maximum contaminant level or health advisory level (µg/L)[c]	Health Canada maximum acceptable concentration or health advisory level (µg/L)[d]	Number of wells with detected concentration above USEPA health advisory level	Number of wells with detected concentration above Canadian health advisory level
		US	CDN								
Dinoseb	Wide spectrum herbicide	1986[t]	RU	Erickson and Norton 1990	27	0	n.d.	7	10	n.d.	--
				Liebscher and others 1992	39	9	0.1-1.95	7	10	0	0
				Hulsman 1993[f]	26	2	0.15-1.2	7	10	0	0
Simizine	General herbicide	RU	GU	Erickson and Norton 1990	27	0	n.d.	4	10	n.d.	--
				Liebscher and others 1992	39	7	0.1-1.25	4	10	1	0
				USGS 1991-1992	24	0	n.d.	4	10	n.d.	--
				Hulsman 1993[f]	26	1	0.2	4	10	0	0
Alachlor	Preemergent weed control in corn, soy beans	RU	1985	Erickson and Norton 1990	27	0	n.d.	2	5	n.d.	--
				Liebscher and others 1992	39	1	0.1	2	5	0	0
				USGS	24	0	n.d.	2	5	n.d.	--
				Hulsman 1993[f]	26	0	n.d.	2	5	n.d.	--
Atrazine	Broadleaf weed and grass control	RU	GU	Erickson and Norton 1990	27	0	n.d.	3	5+	n.d.	--
				Liebscher and others 1992	39	11	0.1-4	3	5+	1	0
				USGS 1991-1992	24	1	0.1	3	5+	0	0
				Hulsman 1993[f]	26	4	0.02-0.32	3	5+	0	0
Dimethoate	Systemic insecticide	GU	RU	Erickson and Norton 1990	27	0	n.d.	n.g.	20	--	n.d.
				Liebscher and others 1992	39	3	0.05-0.24	n.g.	20	0	0
				Hulsman 1993[f]	26	0	n.d.	n.g.	20	--	n.d.
Diazinon	Insecticide	GU RU	GU RU	Erickson and Norton 1990	27	0	n.d.	0.6	20	n.d.	n.d.
				Liebscher and others 1992	39	7	0.05-2	0.6	20	2	0
				Hulsman 1993[f]	26	0	n.d.	0.6	20	n.d.	n.d.

Table 15. Compilation of detection of organic pesticide compounds in ground waters of the study area from selected studies conducted between 1985-1993--Continued

Compound	General use of compound	Usage restriction or date of cancellation or non-renewal of registration		Source of information	Number of wells sampled	Number of wells with detectable concentration	Range of detected concentration (ppb or µg/L)	USEPA maximum contaminant level or health advisory level (µg/L)[c]	Health Canada maximum acceptable concentration or health advisory level (µg/L)[d]	Number of wells with detected concentration above USEPA health advisory level	Number of wells with detected concentration above Canadian health advisory level
		US	CDN								
Chlordane	Insecticide	1988	1990	Erickson and Norton 1990	27	0	n.d.	2	7	n.d.	n.d.
				Liebscher and others 1992	39	1	0.03	2	7	0	0
				Hulsman 1993[f]	26	0	n.d.	2	7	n.d.	n.d.
Endosulfan	Insecticide	GU and RU	GU	Erickson and Norton 1990	27	0	n.d.	0.13	n.g.	n.d.	--
				Liebscher and others 1992	39	3	0.02-0.13	0.13	n.g.	1	--
				USGS 1991-1992	24	0	n.d.	0.13	n.g.	n.d.	--
				Hulsman 1993[f]	26	0	n.d.	0.13	n.g.	n.d.	--
DDT	Insecticide	1972	1985	Liebscher and others 1992	39	1	0.01	0.1[e]	30	0	0
				Hulsman 1993[f]	26	0	n.d.	0.1	30	n.d.	n.d.
Oxamyl	Insecticide and	RU	RC	Erickson and Norton 1990	27	0	n.d.	200	n.g.	n.d.	--
				Hulsman 1993[f]	26	0	n.d.	200	n.g.	n.d.	--
				USGS 1991-1992	24	1	0.05	200	n.g.	0	--

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* USEPA 1992 maximum contaminant levels, unless noted with an a for lifetime exposure level.

[t] Exemption: existing stocks of Dinoseb could be used on caneberries in non-coastal counties of Oregon and Washington through 1989.

[a] Exemption: existing stocks for beehive supers and honeycombs.

[c] U.S. Environmental Protection Agency (1993).

[d] Health Canada (1993).

[e] Risk specific dose for lifetime exposure of 150 pound person, Nowell and Resek (1994).

[f] Stephen Hulsman, Washington State Department of Health, written commun., 1994.

[g] DSHS 1985 data reported in Sweet-Edwards/EMCON, 1989.

Samples for detailed water-quality analysis were analyzed for two or more of six suites of water-quality constituents. The six suites and the number of sampling sites for each suite are listed below. The detailed-level sampling took place during August 1990, April and May 1991, and October 1991.

Suites of water-quality constituents and number of sites sampled within the LENS study area.

Suite	Sites
Field-measured water-quality constituents	115
Major ions	125
Nutrients only	75
Nutrient and septage-related compounds	111
Trace elements	23
Pesticides and volatile organic compounds	24

Field-measured water-quality constituents were collected at 115 of the 125 detailed chemistry sampling sites; these included temperature, specific conductance, pH, and dissolved oxygen. The major-ion suite included calcium, magnesium, potassium, sodium, chloride, sulfate, alkalinity, silica, nitrate, iron, and manganese. The nutrient suite included nitrate, nitrite, organic nitrogen, ammonia, and orthophosphate. The septage-related compounds included boron, dissolved organic carbon (DOC), bromide, and methylene blue active substances (MBAS, or detergents). Trace elements included barium, beryllium, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, silver, strontium, vanadium, and zinc. The pesticide and volatile organic compounds included 12 triazines and other nitrogen-containing herbicides, 10 carbamate insecticides or metabolites, and 43 volatile organic compounds such as ethylene dibromide (EDB), 1,2-dichloropropane (DCP), and trichloroethene (TCE).

The sampling and analytical methods used for the detailed water-quality samples collected for this study follow standard guidelines of the USGS. These procedures are described in Techniques of Water-Resources Investigations (TWRI) reports (Britton and Greeson, 1988; Wood, 1981; Friedman and Erdmann, 1982; Fishman and Friedman, 1989; and Wershaw and others, 1987). After collection, samples were immediately preserved and stored according to standard USGS procedures (Pritt and Jones, 1989). All sampling equipment was cleaned and rinsed as appropriate before subsequent samples were collected. Samples requiring laboratory analysis were sent to the NWQL by first-class mail on the next work day. Analytical procedures used at the NWQL are described by Fishman and Friedman (1989) and Wershaw and others (1987).

Water samples were collected largely from the existing water-distribution systems of wells equipped with electric pumps. Considerable effort was made to obtain each sample from a tap close to the wellhead and before the water entered a pressure tank; however, water samples from about 40 percent of the wells sampled had passed through a pressure tank. In some wells, particularly observation wells, which did not have pumps installed, centrifugal, peristaltic, or submersible pumps were temporarily installed to obtain water-quality samples. All samples were collected prior to any water treatment, such as chlorination or softening. Water from the routinely used well system was allowed to run for a period of time deemed sufficient to flush water lines and the pressure tank. The water flow was directed from the tap to a closed-system flow chamber equipped to monitor temperature, specific conductance, pH, and dissolved oxygen continuously. Sample bottles were filled after the flushing period and only after the constituents monitored in the flow chamber were stable for a period of at least 5 minutes.

As part of the quality-assurance program for this study, field instruments for the measurement of specific conductance and pH were calibrated with known standards at the beginning of each work day. The dissolved-oxygen meters were calibrated daily using the water-saturated air technique. Five percent of the samples to be analyzed by the NWQL and the BR laboratory were collected in duplicate on a random basis. Reference samples for most inorganic constituents were submitted as blind samples by the NWQL into the sample stream; reference samples also were submitted from the field for chloride and MBAS. As a result of laboratory problems encountered in analyzing the MBAS samples, the resulting data were corrected for analytical bias. At the laboratory, appropriate standards were spiked into each sample for organic analysis to determine the percentage of constituent recovered. As a further quality-assurance measure, selected water samples were split between NWQL and laboratories used by BC Environment and EC.

The resulting analytical data from the NWQL initially were reviewed by laboratory staff and then released to the local USGS district office in Tacoma, Wash., where the data were reviewed further by district personnel who are more familiar with the hydrologic environment from which the samples were collected. All of the laboratory data were judged to be of good quality for the intended use.

Field-Measured Water-Quality Constituents

Determinations of pH, specific conductance, alkalinity, and dissolved-oxygen concentration were made in the field using methods outlined by Wood (1981). Dissolved-oxygen concentrations were also determined by meter; however, concentrations below 1 mg/L were verified using either a Winkler titration (American Public Health Association, 1989) or Rhodazine-D colorimetric method (White and others, 1990). The dissolved-oxygen meter was not used at wells where water had a strong hydrogen sulfide (rotten egg) smell. The distribution and median concentration of these constituents in ground water from the four hydrogeologic units of the study area are shown in figure 13.

Specific Conductance

Specific conductance is a general indicator of the amount of dissolved minerals in water. Dissolved minerals that possess electrical charge in water allow the water to conduct electrical current, and as the concentration of these dissolved minerals increases, so does the electrical conductance. Thus, electrical conductance is a good indication of the amount of dissolved material in water. Because electrical conductance will vary with temperature, measurements of electrical conductance are reported at a standard temperature of 25°C, which is referred to as specific conductance. The unit of measurement for specific conductance is microsiemens per centimeter (µS/cm), which is equivalent to the older unit of micromhos per centimeter.

The values in microsiemens per centimeter (µS/cm) of the 351 samples analyzed for specific conductance ranged from 50 to 10,100, and had a median of 258; those data are tabulated in appendix table 1. For comparison, median values of specific conductance observed in the 12 Puget Sound counties in 1983 ranged from 113 to 950 µS/cm (Turney, 1986). Median values of specific conductance, in µS/cm, within the four hydrogeologic units were 233 in the Sumas aquifer, 336 in the Everson-Vashon unit, 844 in the Vashon unit, and 710 in the bedrock unit (table 6). The data indicate a general trend of increased dissolved material in hydrogeologic units that are stratigraphically deeper and that generally have deeper median well depths and smaller hydraulic conductivities, as shown below.

Median values of specific conductance, well depth, and hydraulic conductivity for four principal hydrogeologic units in the LENS study area

Hydrogeologic unit	Specific conductance (µS/cm)	Well depth (feet)	Hydraulic conductivity (feet per day)
Sumas aquifer	233	33	270
Everson-Vashon unit	336	129	81
Vashon unit	844	55	52
Bedrock unit	710	130	0.55

The larger specific conductance values, and hence the larger quantity of dissolved minerals, found in the deeper hydrogeologic units are most likely the result of longer residence times of ground water on generally deeper flow paths through less permeable geologic materials. The resulting longer residence times provide greater opportunity for ground water to dissolve minerals from the surrounding porous material.

pH

pH is an indicator of the acidity or basicity of a substance and is actually a measure of the concentration (or activity) of hydrogen ions in solution. In water, pH is measured on a scale from 0 to 14. A pH of 7.0 is considered neutral and is the pH of pure water at 25°C; smaller values are acidic and larger values are basic. The pH scale is the negative logarithm of the hydrogen ion concentration; therefore, a pH of 6.0 indicates that a water is 10 times as acidic as water with a pH of 7.0.

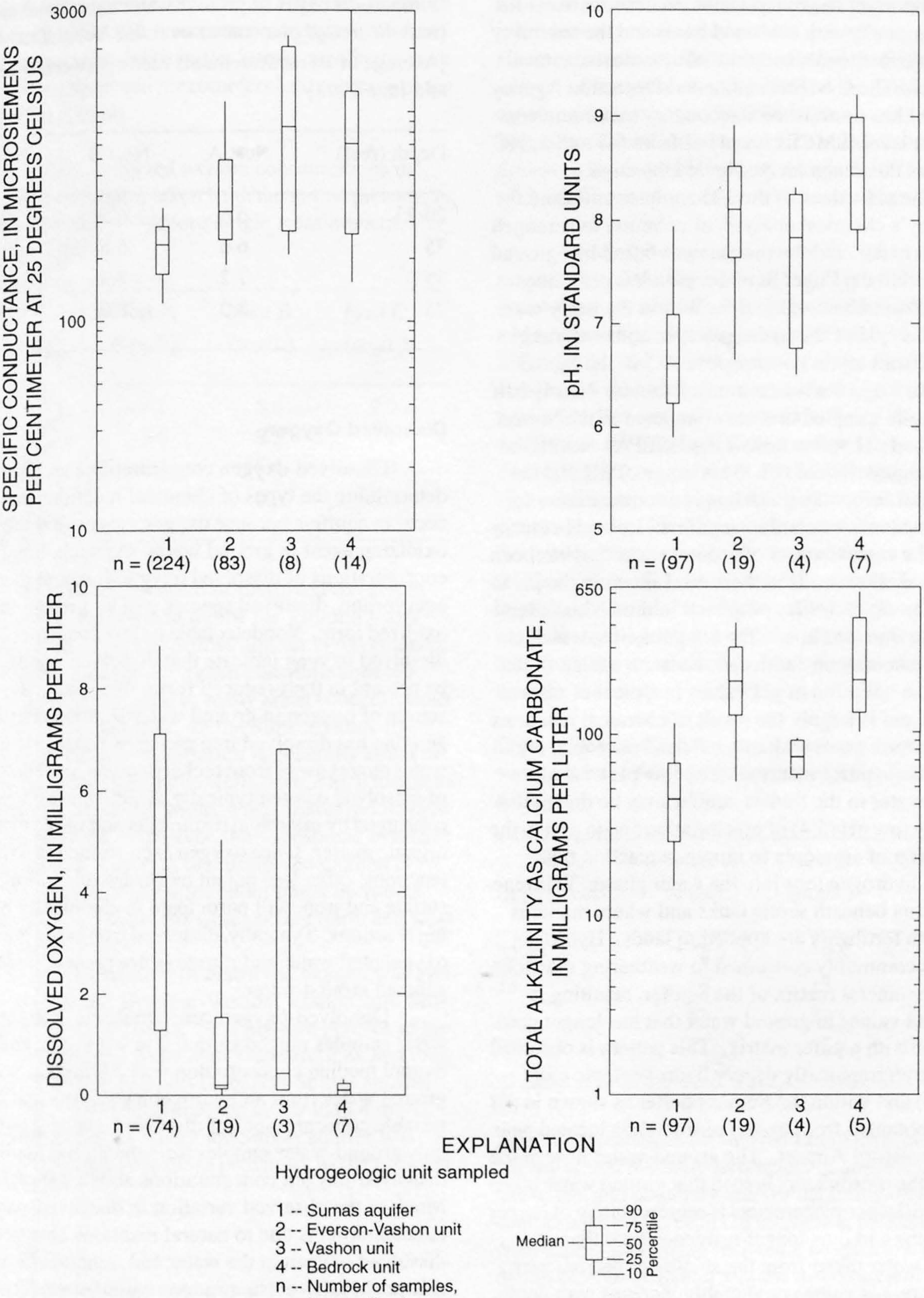


Figure 13. Distribution and median values of specific conductance, pH, and concentration of alkalinity and dissolved oxygen in ground water from four hydrogeologic units of the Lynden-Everson-Nooksack-Sumas (LENS) study area.

pH is important in ground water because it affects the dissociation of weak acids and bases and the solubility of many constituents and thus affects most chemical reactions. The U.S. Environmental Protection Agency (USEPA) has established a secondary maximum contaminant level (SMCL) for pH of from 6.5 to 8.5; HC considers this range an Aesthetic Objective.

The pH values of the 125 samples collected for this study's chemical analysis of common ions ranged from 5.6 to 9.2, and the median was 6.9. Most ground water within the Puget Sound region has pH values ranging from about 6.0 to 8.5. Within the study area, the median pH of the hydrogeologic units increased steadily from top to bottom--from 6.5 in the Sumas aquifer to 8.4 in the bedrock unit (table 6). Nearly half of the wells sampled that are completed in the Sumas aquifer had pH values below the USEPA's and HC's aesthetic guideline of 6.5. This range of pH and the proportion below the guideline is not uncommon for ground water from shallow aquifers. Low pH contributes to the corrosiveness of ground water that has been noted in shallow wells in the area. Likewise, the pH in two of the seven wells completed in the bedrock semiconfining unit was above the 8.5 guideline, which is also not uncommon for deeper bedrock wells.

The variation in pH values is typical of natural systems and is largely the result of chemical reactions of the ground water with minerals and microbial organisms in the aquifer material. The low pH of shallow ground water in the Sumas aquifer may be due to the naturally low pH (5.4) of precipitation and in part to the conversion of ammonia to nitrate, a reaction that releases hydrogen ions into the water phase. This reaction occurs beneath septic tanks and where manures and some fertilizers are applied to lands. Hydrogen ions are commonly consumed in weathering reactions with the mineral matrix of the aquifer, resulting in larger pH values in ground water that has longer contact time with aquifer matrix. This pattern is observed in the stratigraphically deeper hydrogeologic units (table 6) and within the Sumas aquifer as shown in pH values obtained from nested piezometers located near the Abbotsford Airport. The ground-water flow in the area of the piezometers is such that ground water taken from the deeper piezometers is representative of longer flow paths and thus longer residence time than is ground water taken from the shallower piezometers. Therefore, pH values predictably increase with depth, as shown below.

Comparison of pH of ground-water samples obtained from the nested piezometer near the Abbotsford Airport [Average of 10 measurements made between June 1988 and June 1992]

Depth (feet)	Nest A	Nest B	Nest C
20-25	6.6	6.5	6.4
35	6.6	6.6	6.3
55	7.2	7.3	7.3
75	8.0	8.0	8.0

Dissolved Oxygen

Dissolved-oxygen concentrations are useful in determining the types of chemical reactions that can occur in aquifers because oxygen is typically the initial oxidizing agent in ground water. As such, large concentrations of dissolved oxygen indicate that, at equilibrium, dissolved species will be present in their oxidized form. Nondetectable or low concentrations of dissolved oxygen indicate that dissolved species may be present in their reduced form. Normally, the only source of oxygen in ground water is atmospheric oxygen that has dissolved into recharge water. As ground water moves away from recharge areas, concentrations of dissolved oxygen typically diminish as oxygen is consumed by microbial respiration and the oxidation of organic matter. Once oxygen is consumed in oxidizing reactions, other less potent oxidizers, such as nitrate sulfate and iron, will participate in chemically oxidizing reactions. Typically, dissolved iron is not present in oxygenated water and nitrate is not present in deoxygenated ground water.

Dissolved-oxygen concentrations in ground-water samples ranged from 0.0 to 9.8 mg/L, and the overall median concentration was 2.8 mg/L. Some ground water from all hydrogeologic units had nondetectable concentrations of dissolved oxygen; however, only ground-water samples from the Sumas aquifer had dissolved-oxygen concentrations above 7.0 mg/L. Much of the observed variation in dissolved-oxygen concentration is due to natural reactions between dissolved oxygen in the water and minerals or organic matter. Median concentrations varied considerably by units, the largest being in the Sumas aquifer (4.3 mg/L) and smallest in the bedrock unit (0.1 mg/L), as shown in figure 13. Like pH, concentrations of dissolved oxygen decrease with depth in the Sumas aquifer, as seen in data from the nested piezometers located south of the Abbotsford Airport.

Comparison of dissolved oxygen concentrations in ground-water samples taken from the nested piezometer near the Abbotsford Airport; single measurement, December 1991

Depth (feet)	Nest A (mg/L)	Nest B (mg/L)	Nest C (mg/L)
20-25	8.1	8.8	9.0
35	7.6	8.5	9.2
55	6.0	6.4	5.0
75	1.0	0.2	0.8

The areal distribution of dissolved oxygen in ground water is shown in figure 14. Ground water throughout much of the Sumas aquifer is oxygenated, meaning that dissolved-oxygen concentrations are larger than 1.0 mg/L and in many areas concentrations are larger than 4.0 mg/L. In the Sumas Valley the dissolved-oxygen concentration is generally small or absent. The lack of suitable wells from which to obtain samples limited the locations where dissolved oxygen could be measured; however, the widespread evidence of iron staining indicates that dissolved oxygen is absent in ground water throughout much of Sumas Valley. Similar conditions were present north and west of Lynden.

The concentration of dissolved oxygen was generally small in the Everson-Vashon, Vashon, and bedrock hydrogeologic units. Seventy-five percent of the samples from these wells had concentrations less than 1 mg/L. The four samples from non-Sumas aquifer wells, which had concentrations larger than 4 mg/L, were all in locations where the Sumas aquifer was directly overlying or in close proximity to the sampled well.

Alkalinity

Alkalinity is the capacity of water to react with and neutralize acids. Generally in natural water this capacity is the result of several individual constituents within the water. In most ground water, bicarbonate is the most prominent alkalinity species; however, other ions such as carbonate, ammonia, phosphate, and some silicates can also contribute to alkalinity. For example, several of the ground-water samples from the Sumas aquifer that had large alkalinities also contained large concentrations of ammonia, which normally was below detection levels in this hydrogeologic unit. These samples were from observation wells near manure storage lagoons.

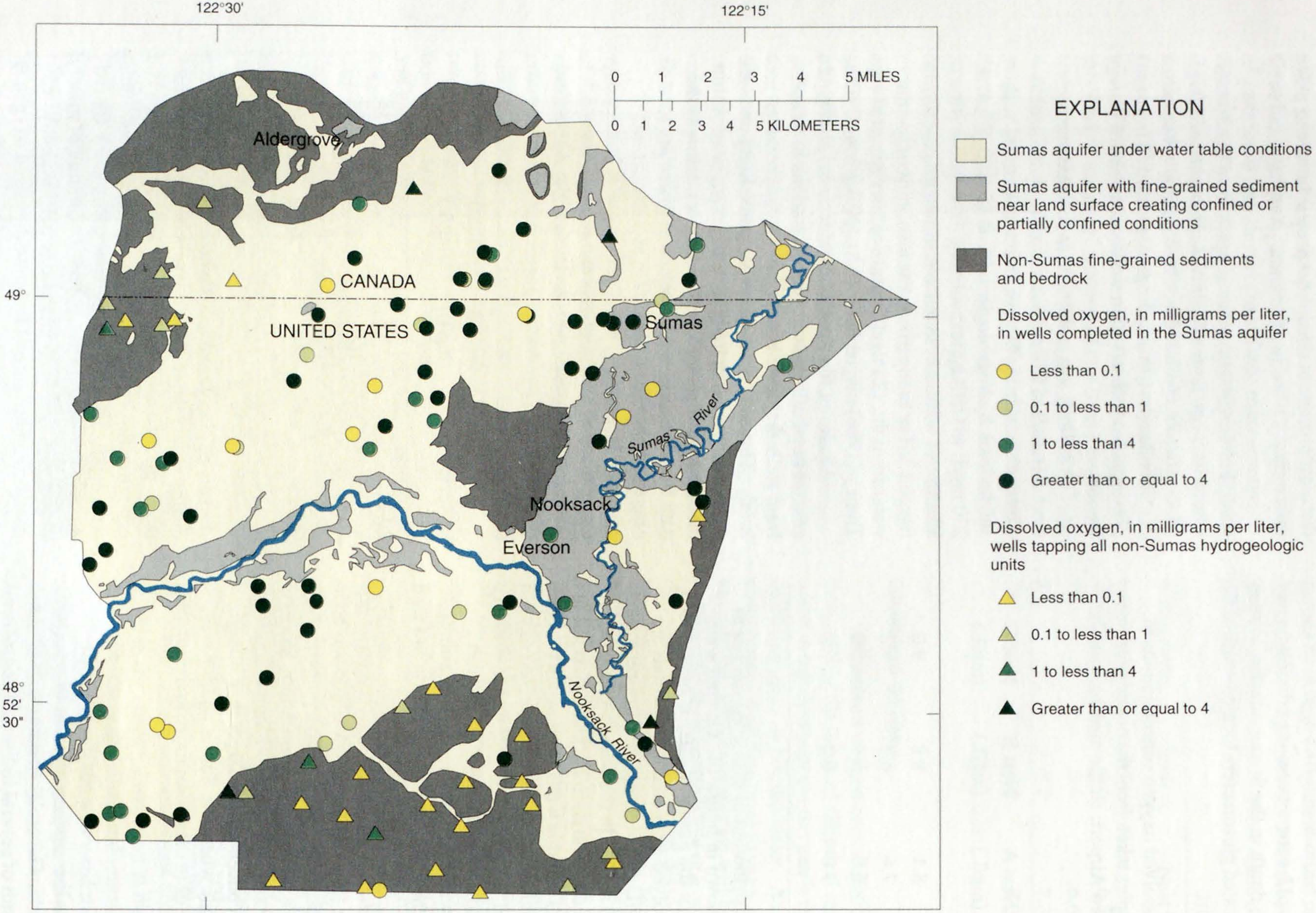
Alkalinity concentrations in the study area ranged from 9 to 610 mg/L as $CaCO_3$, with median concentrations in the Sumas, Everson-Vashon, Vashon, and bedrock hydrogeologic units of 45, 190, 75, and 230 mg/L as $CaCO_3$, respectively. The distribution of alkalinities within these units is shown graphically in figure 13. For comparison, the alkalinity in ground water from the 12 Puget Sound counties sampled by Turney (1986) ranged from 49 to 220 mg/L as $CaCO_3$.

Alkalinity, like specific conductance, displayed a general trend of increasing concentrations in samples from wells that were deeper and had lower water levels. This same relation between alkalinity and well depth is observed in multiple wells completed within the same hydrogeologic unit, as shown below in the data from the three sets of nested piezometers located near the Abbotsford Airport.

Comparison of alkalinity concentrations in ground water from the nested piezometer near the Abbotsford Airport

Depth (feet)	Nest A (mg/L)	Nest B (mg/L)	Nest C (mg/L)
20-25	8.7	9.8	18
35	14	13	24
55	53	51	53
75	71	65	66

A likely explanation for this pattern of changing water quality is that the increased levels of specific conductance, pH, and alkalinity and the declining oxygen concentrations are the results of increasing residence times with depth. Increasing residence times allow for oxidation of organic matter and the dissolution of mineral phases resulting in an increase in pH, alkalinity, and specific conductance. Declining dissolved oxygen is also consistent with the longer residence times, as



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 14. Areal distribution of dissolved oxygen concentrations in ground water in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

ground water is further removed from the atmospheric source of oxygen and is consumed by reactions with the mineral phases and organic material.

Major Dissolved Chemical Species

Generally over 95 percent of all the dissolved matter in ground water is made up of 8 to 10 individual chemical species that are commonly referred to as the major ions. Positively charged ions, referred to as cations, typically include calcium, magnesium, sodium, and potassium. Negatively charged ions, referred to as anions, typically include bicarbonate, chloride, sulfate, fluoride, and in some ground water, including many from the study area, nitrate. Silica, which is uncharged, is included in discussions of major ions because it is a major component of dissolved solids in ground water. Other constituents, such as carbonate and fluoride, or metals, such as iron and manganese, are also common components of dissolved solids, but are rarely found in large enough concentrations to make a significant difference.

The total concentration of all of the chemical species dissolved in the water is referred to as the total dissolved-solids concentration. Dissolved-solids concentrations ranged from 53 to 5,630 mg/L, with a median concentration of 161 mg/L. The median dissolved-solids concentration in the Sumas aquifer was 147 mg/L, and there was a general increase in median dissolved-solids concentrations in the stratigraphically deeper hydrogeologic units. For example, the median dissolved-solids concentration in the bedrock unit was 567 mg/L. Some of this variation is undoubtedly due to increased residence time of water in the lower units, but some is likely due to the different types of aquifer material, some of which appear to contain some remnant seawater. Water that has been in the ground for a longer time generally has had the opportunity to dissolve more minerals than water with a shorter residence time.

The characteristic variability in concentration and distribution of the major ions in water samples can be schematically represented by the shape and size of a Stiff diagram. Stiff diagrams have been plotted for wells along two of the hydrogeologic cross sections (see fig. 15) to illustrate characteristic difference in the major ion composition of ground water from the LENS study area. Highly mineralized water from deep in the Everson-Vashon unit and the bedrock unit can be seen as the large Stiff diagrams with large sodium and chloride components. Concentrations in ground water from the Sumas aquifer are smaller and are typified by calcium, bicarbonate, and nitrate components. Water samples from bedrock wells typically have large sodium and bicarbonate components. Ground-water from wells in the Sumas River Valley is distinctive because of its large magnesium concentrations. Section I-I' (fig. 15) also shows Stiff diagrams from two of the nested sets of piezometers located near the Abbotsford Airport, which show both decreasing nitrate concentrations with depth and an increasing overall amount of dissolved material in the deeper ground water. Section A-A' (fig. 15) shows changes in major ion composition in the Sumas aquifer between areas of the outwash plain north of Lynden and wells from the Sumas Valley, the latter of which were found to have proportionately larger magnesium concentrations. Also shown on section A-A' are differences in the composition of major ions from wells completed in the Everson-Vashon unit in the upland areas along the northwest margin of the study area.

Major Cations

The distribution of the concentrations of major cations (calcium, magnesium, sodium, and potassium) observed in ground water from the four hydrogeologic units is shown in the boxplot diagram in figure 16. Ground water in the study area shows noticeable differences in the concentration of the major cations among the four hydrogeologic units. In contrast to the pattern described for specific conductance where total dissolved solids was found to increase in deeper, less permeable units, the concentrations of calcium and magnesium tend to decline (fig. 16) in the deeper units. However, the concentrations of sodium increase significantly in the deeper units and offset the decline of the other cations. The median sodium concentration in the Sumas aquifer was about 6 mg/L, and 75 percent of the samples were below 8.7 mg/L. Median sodium concentrations in the Everson-Vashon, Vashon, and bedrock units were 98 mg/L, 190 mg/L, and 220 mg/L, respectively. Concentrations of sodium in ground-water samples from the Everson-Vashon, Vashon, and bedrock units were large compared to the USEPA and HC aesthetic guideline of 200 mg/L for individuals on salt-restricted diets. Four of the five samples from the bedrock unit exceeded this drinking water guideline. The concentration of potassium was generally small in all hydrogeologic units.

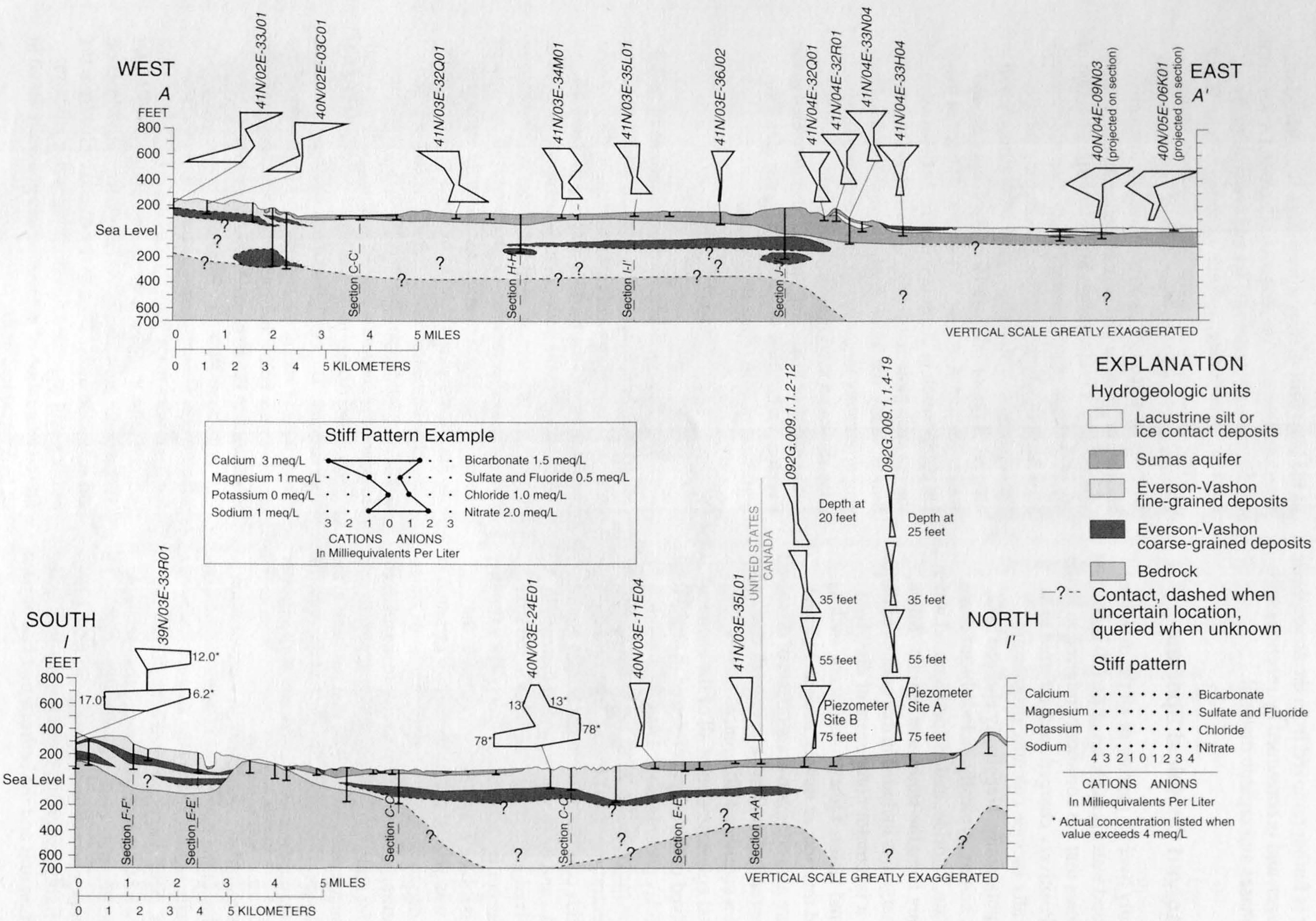


Figure 15. Stiff diagrams showing distribution of major ion chemistry in wells along hydrogeologic sections *A-A'* and *I-I'*. See plate 2 for location of hydrogeologic sections.

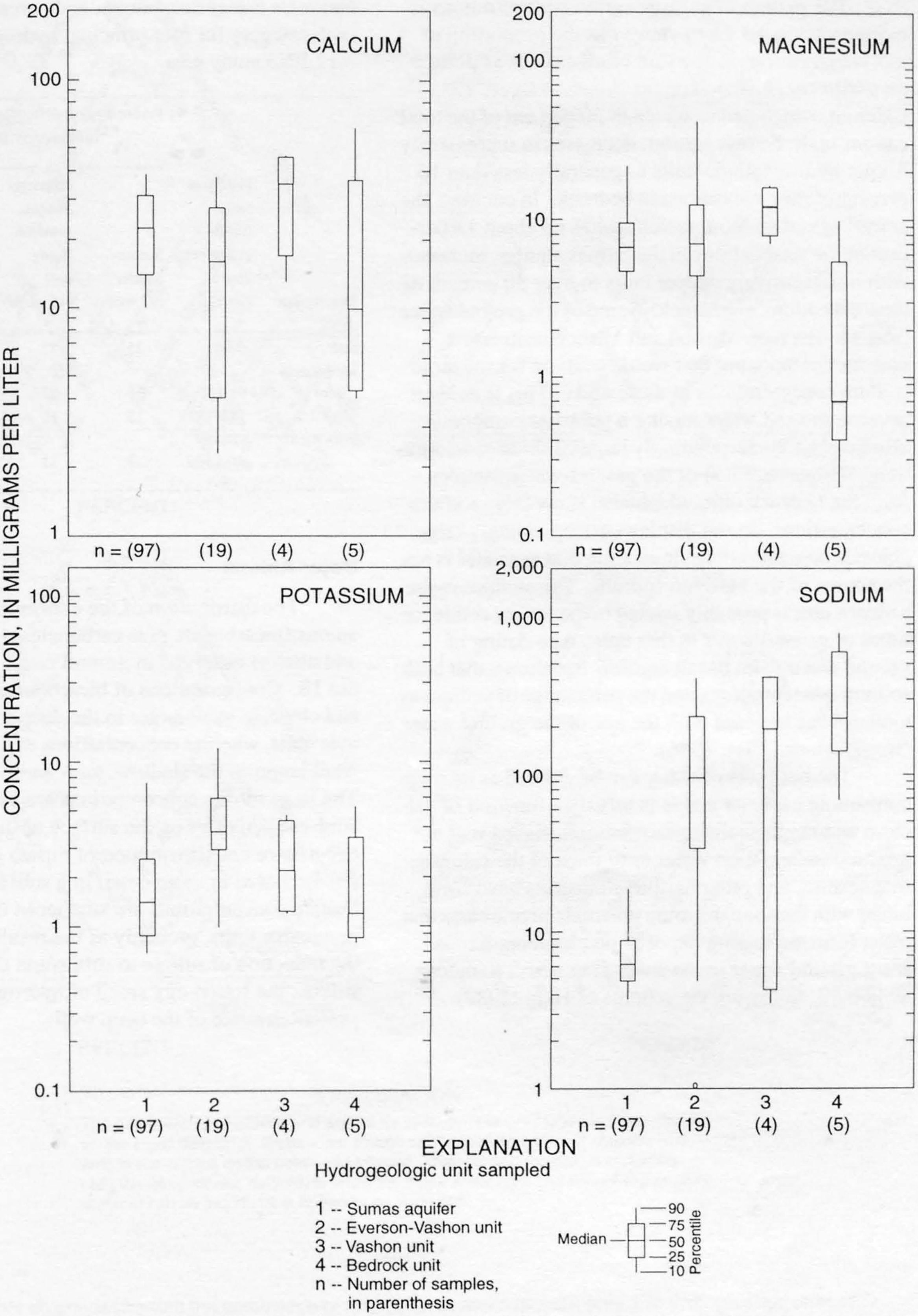


Figure 16. Distribution of concentrations of cations in milligrams per liter in ground water from four hydrogeologic units in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

The pattern of shifting cation concentrations is more pronounced when viewed as the proportion of individual cations to the sum of all cations as plotted on a trilinear (Piper) diagram shown in figure 17. Calcium, which makes up about 50 percent of the total cations in the Sumas aquifer, decreases in successively deeper hydrogeologic units to generally less than 10 percent of the total cations in bedrock. In contrast, the percentage of sodium, which makes up about 13 percent of the total cations in the Sumas aquifer, increases within successively deeper units to over 90 percent of the total cations in bedrock. Some of the ground water from the Everson-Vashon and Vashon units has a seawater component that would account for the large sodium concentrations in these units. This is evident because ground water having a seawater component also displays correspondingly large chloride concentrations. However, most of the ground-water samples from the bedrock unit, which also show large sodium concentrations, do not display correspondingly large chloride concentrations, indicating that seawater is not the source of the elevated sodium. The sodium in the bedrock unit is probably related to the longer residence times of ground water in that unit. Age-dating of ground water from basalt aquifers has shown that both sodium concentrations and the percentage of sodium to total cations increase with the age of the ground water (Bortleson and Cox, 1986).

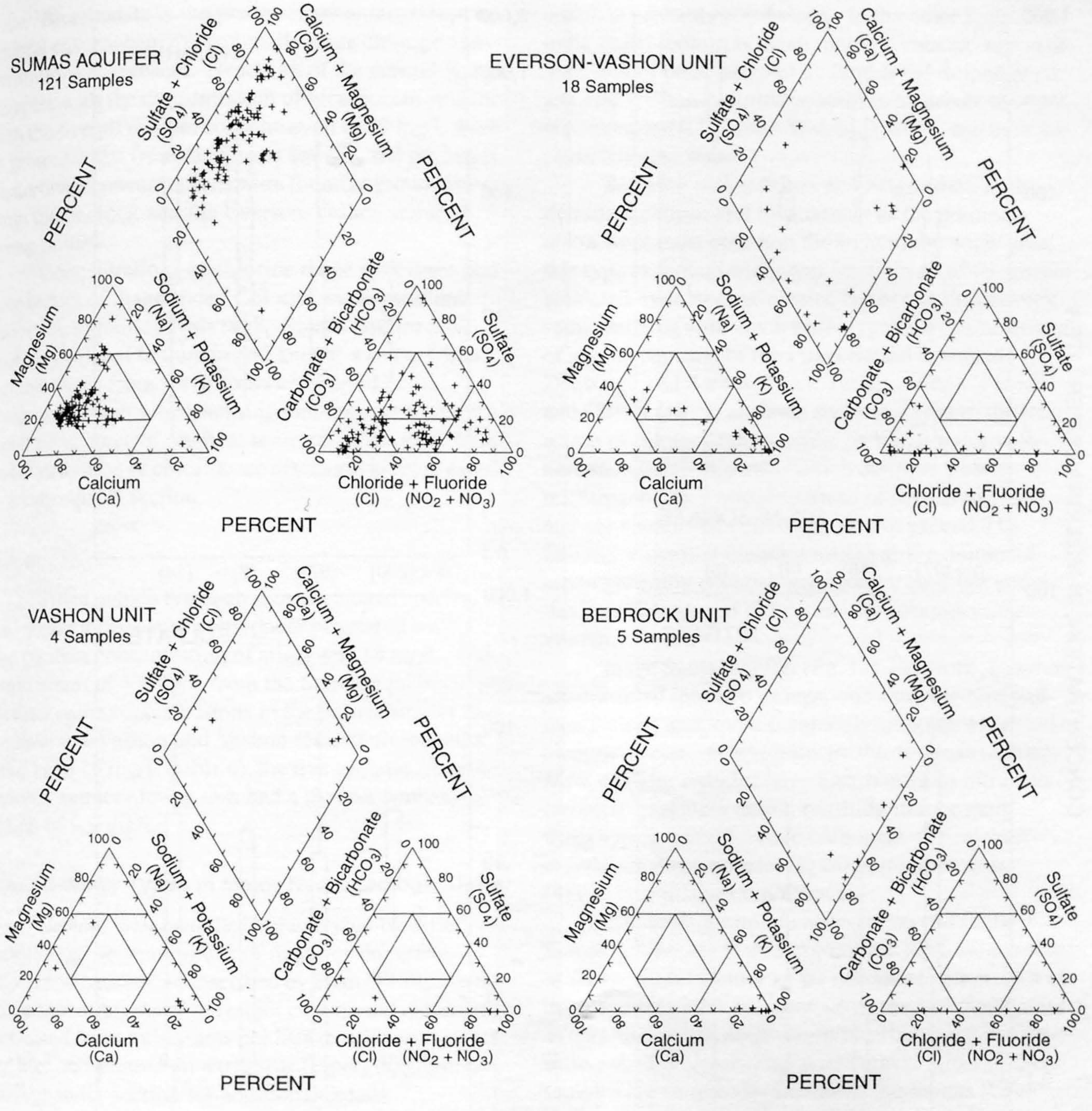
The hardness of water can be defined as its soap-consuming capacity and is primarily a function of calcium and magnesium concentrations. Soaps will not produce suds in hard water until most of the calcium, magnesium, and other hardness minerals have combined with the soap, forming insoluble precipitates that often form encrusting deposits on plumbing fixtures. Most ground water in the study area is soft to moderately hard, following the scheme of Hem (1989):

Hardness categories, ranges, and percentage of wells in each category for four principal hydrogeologic units in the LENS study area

		Percentage of wells from each hydrogeologic unit in each hardness class			
Description	Hardness range (milligrams per liter of $CaCO_3$)	Sumas aquifer (97 wells)	Everson-Vashon semiconfining unit (19 wells)	Vashon semiconfining unit (4 wells)	Bedrock semiconfining unit (5 wells)
Soft	0-60	25	37	0	80
Moderately hard	61-120	55	37	50	0
Hard	121-180	13	16	50	0
Very hard	Greater than 180	7	11	0	20

Major Anions

The distribution of the concentrations of major anions (bicarbonate plus carbonate, chloride, sulfate, and nitrate) observed in ground water is shown in figure 18. Concentrations of bicarbonate plus carbonate and chloride were larger in the deeper and less permeable units, whereas concentrations of nitrate and sulfate were larger in the shallow, more permeable aquifer. The large nitrate concentrations are associated with land-use activities on the surface of the aquifer; the occurrence and distribution of nitrate in ground water are discussed in more detail in a subsequent section. Sulfate concentrations are smaller in the deeper, less permeable units, probably as the result of dilution or the reduction of sulfate to sulfite and then to hydrogen sulfide; the rotten-egg smell of hydrogen sulfide was present in some of the deep wells.



EXPLANATION

The percentages of cations and anions for each sample are plotted in three places on the Piper diagrams. Cations are plotted on the left hand trilinear diagram and anions are plotted on the right hand trilinear. Their plotting location is projected onto the quadralinear diagram to show the major water type. Additional explanatory material can be found in the Appendix on page 126.

Figure 17. Piper diagrams showing the percentage of major ions in water samples from four hydrogeologic units in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

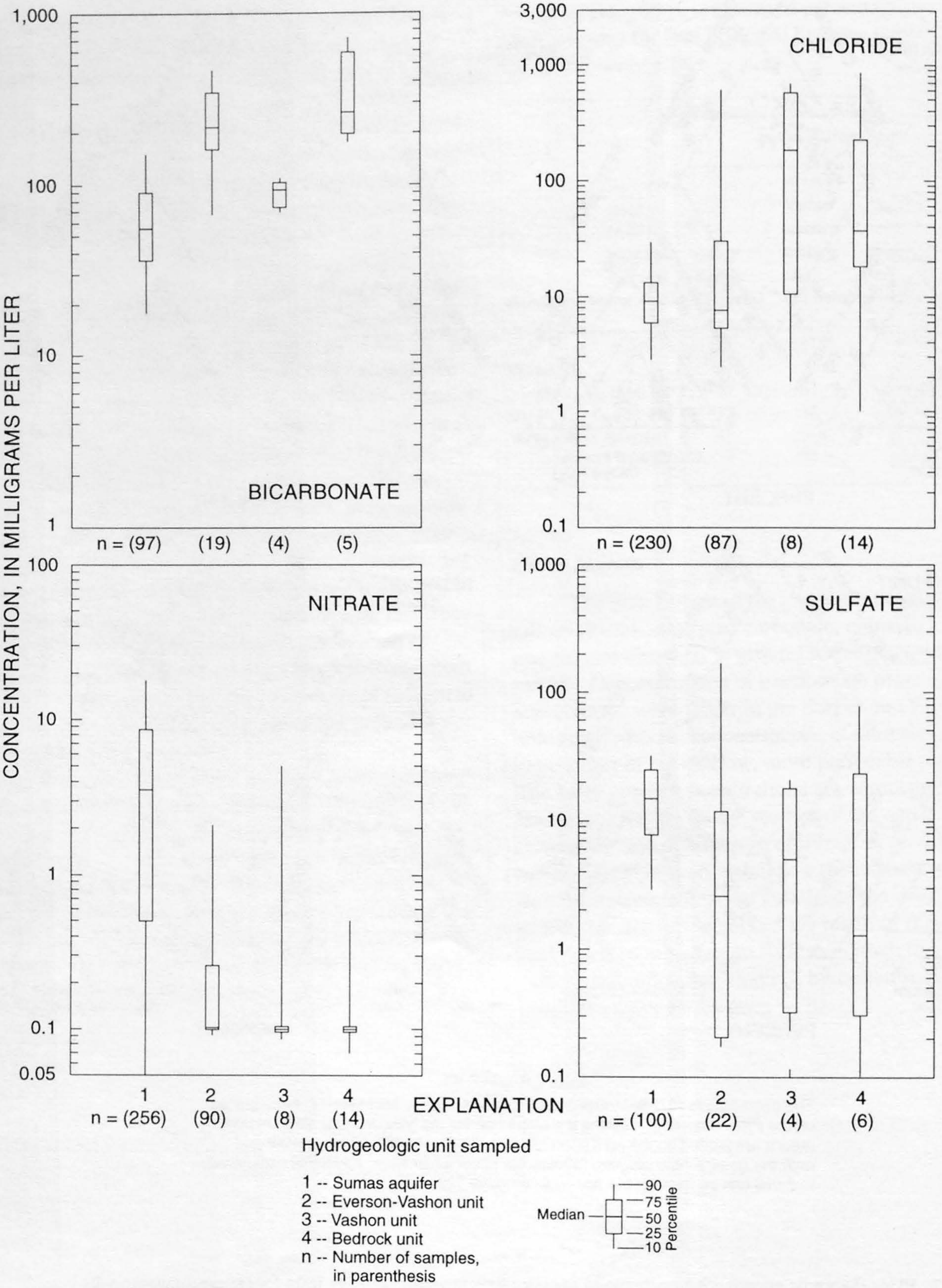


Figure 18. Distribution of concentrations of anions in milligrams per liter in ground water from four hydrogeologic units in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

Bicarbonate is the predominant anion except in several cases where exceptionally large chloride concentrations are present. Nearly all of the ground-water samples with the concentration of bicarbonate smaller than the overall median concentration of 79 mg/L were in ground water from the Sumas aquifer, and the larger bicarbonate concentrations were found in ground water from the bedrock and the Everson-Vashon semiconfining units.

Concentrations of chloride range over three and four orders of magnitude. Chloride concentrations above background levels in the Sumas aquifer are probably related to human and animal wastes, while ground water from some wells completed in the Everson-Vashon semiconfining unit appears to show a small percentage of remnant seawater. The occurrence and distribution of chloride are discussed in more detail in a subsequent section.

Silica

Silica, which is a neutral or uncharged species, is also a major dissolved component of ground water. The median concentration of silica was 18 mg/L, with a maximum of 53 mg/L from the Sumas aquifer. Median silica concentrations in the Sumas aquifer and the Everson-Vashon and Vashon semiconfining units were 17 to 19 mg/L (table 6), the five samples from the bedrock semiconfining unit had a median concentration of 9.9 mg/L.

Ground-Water Types in Major Hydrogeologic Units

Ground water can be characterized by differences in the concentrations of major or dominant anions and cations, as described by Hem (1989). To do this, concentrations of the major cations and anions are converted from milligrams per liter to milliequivalents per liter and plotted on a trilinear (Piper) diagram; see the Appendix section for additional details.

For this study, all samples with complete major ion analysis were plotted on one trilinear diagram for each hydrogeologic unit (fig. 17); this allowed differences between units to be easily seen, as well as allowing trends and anomalies to be more easily discerned. Significant differences are apparent in the general patterns of cations, anions, and water types observed in different hydrogeologic units. In the Sumas aquifer, calcium and magnesium are the predominant cations, while sodium is predominant in only one sample, which is probably anomalous. In the other hydrogeologic units, sodium is much more prominent, and in at least half of these samples sodium is the dominant cation, and sodium-chloride or sodium bicarbonate water is present in the Everson-Vashon, Vashon, and bedrock semiconfining units.

Samples with calcium and magnesium as the dominant cations and bicarbonate as the dominant anion were most common throughout the study area; this type of ground water was found in all of the unconsolidated hydrogeologic units, but not in the bedrock semiconfining unit. Such water types are characteristic of glacial deposits of the Puget Sound Lowlands (Van Denburgh and Santos, 1965; Turney, 1986). Freeze and Cherry (1979) attribute this water type to the interaction of dilute, slightly acidic recharge water with aluminosilicate minerals, which dissolve slowly, resulting in small concentrations of dissolved solids and pH values that commonly do not exceed 7.0. Ground water that includes nitrate as the dominant anion generally occurs where nearby land-use activities have introduced nitrate into the ground-water system.

In the Sumas aquifer (fig. 17), the plots of cations are clustered into two groups, one showing no dominant cations and, more commonly, another where calcium or calcium-magnesium are the dominant cations. Most of these samples have bicarbonate or nitrate as the complementary anion, resulting in four main water types: (1) calcium/bicarbonate, (2) calcium-magnesium/bicarbonate, (3) calcium/nitrate, and (4) calcium-magnesium/nitrate.

The other group of cations observed in the Sumas aquifer are from samples that have magnesium or magnesium-calcium as the dominant cation. All of these samples have bicarbonate as the complementary anion and result in magnesium/bicarbonate and magnesium-calcium/bicarbonate water types. Most of these samples are from wells located in the Sumas River Valley. The larger magnesium concentrations in the Sumas Valley are likely the result of differences in the mineralogy of the sediments making up the aquifer material. Sediments in the Sumas Valley are composed primarily of basaltic and andesitic clasts derived from Mt. Baker (Cameron, 1989). The Mt. Baker area above the Sumas and Nooksack Valleys is also known to include areas of peridotite and dunite, rocks that contain substantial amounts of olivine, an iron-magnesium mineral that is easily weathered. Olivine is also more prominent in volcanic rocks like basalts and andesite than in granitic or metamorphic rocks, which make up most of the Sumas outwash (Armstrong, 1981). Consequently, ground water from different locations in the Sumas aquifer may be distinguished by this chemical difference.

The characteristic ground-water types from the Everson-Vashon and Vashon units (see fig. 17) show considerably more variation than ground water from the Sumas aquifer. In general, cations varied between calcium and sodium while anions varied between bicarbonate and chloride. Calcium-bicarbonate water similar to the Sumas aquifer were often found in wells completed in the Everson-Vashon and Vashon units and whose depths were less than 100 feet. In deeper wells, the predominant cation shifted toward magnesium in two cases, but mostly the predominant cation shifted toward sodium, resulting in largely sodium-bicarbonate water at depth. Sodium-chloride water was also common in the deepest wells, and this water probably reflect the presence of remnant seawater trapped in the aquifer during previous glaciation. The possibility of remnant seawater is discussed in more detail in a subsequent section on chloride in ground water.

In the bedrock semiconfining unit, which is composed of nonmarine sandstone, three of four well water samples had a sodium-bicarbonate water type; the remaining well had a sodium-chloride water type.

Ground-water samples containing nitrate as a dominant anion or magnesium as a dominant cation is limited to the Sumas aquifer. Ground water that has chloride as the dominant anion can be from either the Everson-Vashon, Vashon or Bedrock semiconfining units. Sodium is a dominant cation in all bedrock wells and in some Everson-Vashon and Vashon samples.

Nitrate and Other Nitrogen Compounds

Nitrogen is present throughout the natural environment and may undergo a variety of biologically mediated transformations of one form to another. The most common form of nitrogen found in ground water of the United Sates is nitrate, which is highly soluble and moves easily within ground water. Other forms of nitrogen commonly found in ground water include ammonia, organic nitrogen, and nitrite. Additional information on nitrogen forms and transformations is provided in the Appendix section at the end of this report.

The presence of nitrate in ground water is important because large concentrations of nitrate in drinking water are toxic to some humans and animals. The health effects and implications of nitrate and nitrate toxicity have been reviewed by the National Research Council (1978). Of widest concern is the consumption of drinking water with concentrations of nitrate above 10 mg/L by infants less than 3 months of age and other sensitive individuals. Consumption of such drinking water may lead to methemoglobinemia, a condition that deprives the body of oxygen by interfering with the blood's ability to carry oxygen. As a precaution, the USEPA and Health Canada, as well as state and provincial health agencies, have established a maximum contaminant level (MCL) for drinking water of 10 mg/L nitrate as nitrogen in public drinking water. The presence of nitrate in ground water is also of concern because in many instances where pesticides have been detected, the concentrations of nitrate have generally been elevated well above natural background levels. Thus, the presence of elevated nitrate concentrations in ground water substantially increases the likelihood of detecting measurable concentrations of pesticides.

Nitrate was the most common form of nitrogen found in ground water of the study area, and 15 percent of the wells sampled had concentrations of nitrate that equalled or exceeded the primary drinking water MCL of 10 mg/L. Ammonia and organic nitrogen were present in generally small concentrations in some ground water; exceptions were noted near source areas such as manure lagoons. Nitrite, which is chemically unstable in an oxygenated environment, was occasionally found in deeper ground water of the study area.

The statistical distributions of nitrate, ammonia, and organic nitrogen in ground water of the study area are shown in general on figure 19. These plots represent concentrations of 568 samples collected from 368 wells between March 1990 and December 1992. Nitrate concentrations are plotted on plate 4; most are from single samples collected during the well inventory period, March 1990 to August 1990. If two or more samples were collected from the same well, such as the monthly observation wells, the concentrations plotted on figure 19 and plate 4 are the arithmetic mean of the individual samples. Data from multiple samples for all nitrogen species measured in ground-water samples are shown in appendix table 8.

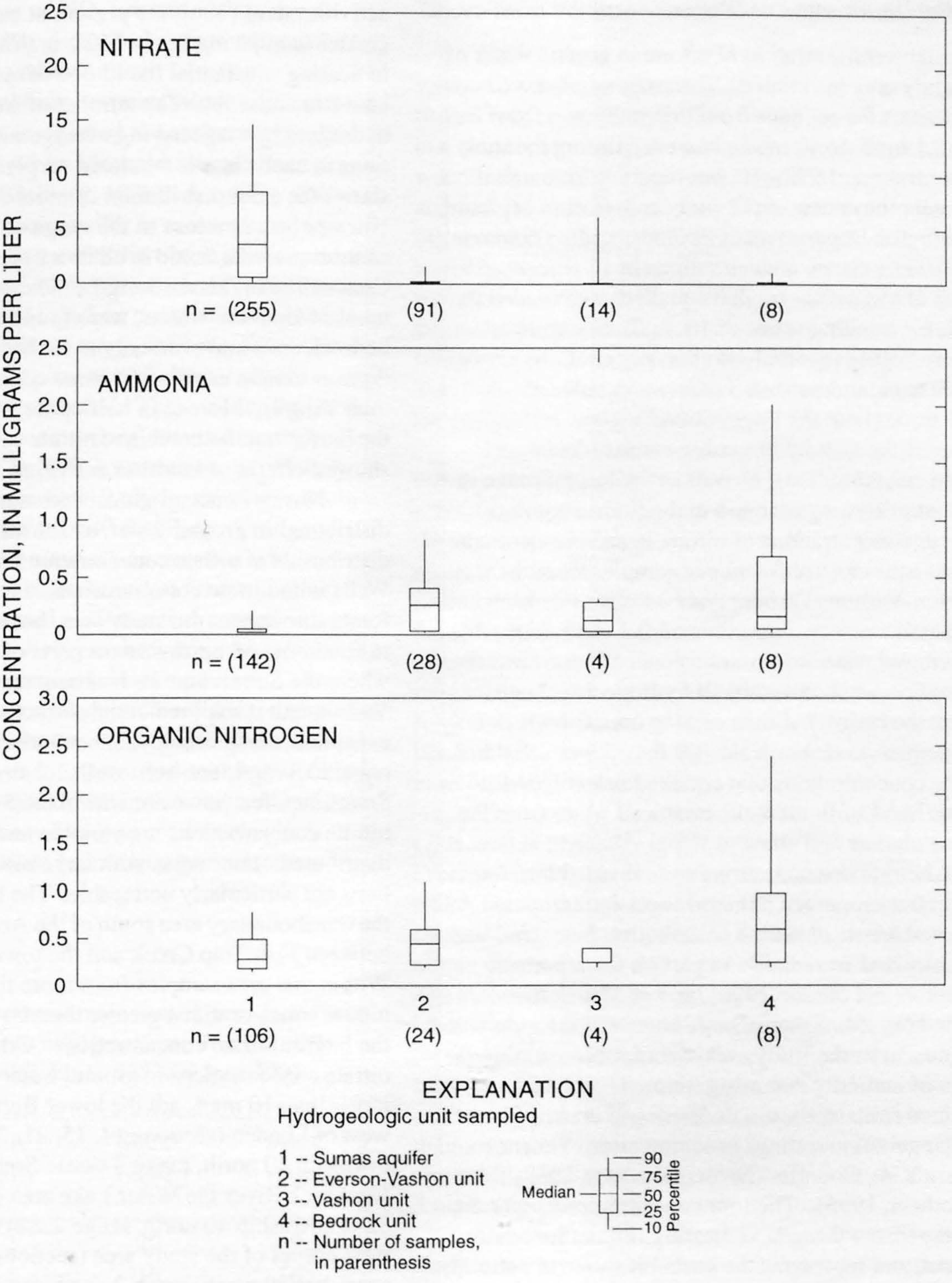


Figure 19. Distribution of concentrations of nitrate, ammonia and organic nitrogen by hydrogeologic unit in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

Spatial Distribution of Nitrate

The concentration of nitrate in ground water of the study area is variable. The range of observed concentrations for samples from this study was from less than 0.1 mg/L to 43 mg/L; however, during the study a concentration of 99 mg/L was reported from a shallow well near the center of the study area (Denis Erickson, Washington Department of Ecology, written commun., 1993). The nitrate concentrations in 15 percent (55 wells) of the wells sampled equalled or exceeded the MCL for drinking water of 10 mg/L. By comparison, Turney (1986) reported nitrate concentrations exceeding 10 mg/L in less than 3 percent of wells sampled in 1981 throughout the Puget Sound region.

Of the four hydrogeologic units, the largest nitrate concentrations, as well as the largest range in concentrations, were found in the Sumas aquifer. Median concentrations of nitrate in samples from the Sumas aquifer were 3.8 mg/L; samples from the Everson-Vashon, Vashon, and bedrock units each had median nitrate concentrations of 0.1 mg/L (see table 6). Ground water with nitrate concentrations less than 0.1 mg/L was observed in all hydrogeologic units except the bedrock semiconfining unit, for which only six samples were available. Of the 55 wells that had nitrate concentrations that equalled or exceeded 10 mg/L, 54 of those wells produced water from the Sumas aquifer.

Nitrate concentrations were divided into four concentration ranges. These ranges differentiated expected levels of nitrate contribution from land-use activities and were based in part on the reports of Hamilton and others (1993), and of Madison and Brunett (1985). Because large undeveloped areas were not present in the study area, data for determining the range of naturally occurring nitrate levels were obtained from studies in undeveloped areas with similar geologic settings in southwestern Thurston and eastern King Counties (Drost and others, 1998; Turney and others, 1995). The four concentration ranges are: (1) less than 1.0 mg/L, indicating little or no nitrate present, and represents the probable range of naturally occurring nitrate concentrations in ground water with no significant contribution of nitrate from land-use sources; (2) 1.0 to 2.9 mg/L, the transitional range between natural concentrations and concentrations showing probable land-use influences; (3) 3.0 to 9.9 mg/L, nitrate present at concentrations indicating substantial likelihood of contribution from land-use activities; and (4) nitrate present at concentrations greater than 10 mg/L, the MCL in drinking water, also indicating substantial likelihood of contribution from land-use activities. The number of wells from each hydrogeologic unit having average nitrate concentrations in each class is tabulated on plate 4, which also shows the areal distribution of nitrate concentrations. Nitrate concentrations in the range of background concentrations were found in all four hydrogeologic units. Concentrations above 3 mg/L, indicating a large likelihood of land-use effects, were found in all but the bedrock unit; however, only in the Sumas aquifer were there extensive areas with nitrate concentrations larger than 3 mg/L. More than half of the wells sampled in the Sumas aquifer contained nitrate concentrations that showed effects of land-use activities.

Nitrate concentrations were not uniformly distributed in ground water, as shown by the areal distribution of nitrate concentrations shown on plate 4. Wells with nitrate concentrations less than 3 mg/L are found throughout the study area, but are concentrated in southern and northwestern parts of the study area where the Sumas aquifer is absent and the Everson-Vashon unit is exposed at the surface. Almost without exception, samples with concentrations greater than or equal to 3 mg/L are from wells located within the Sumas aquifer; however, within the Sumas aquifer, nitrate concentrations are variable and are unevenly distributed. Four areas with large nitrate concentrations are particularly noticeable. The largest of these is the transboundary area south of the Abbotsford Airport between Fish Trap Creek and the town of Sumas. Within this area samples from more than 25 wells had nitrate concentrations greater than 10 mg/L, including the largest nitrate concentrations. Other areas where nitrate concentrations in ground water were commonly larger than 10 mg/L are the lower Bertrand Creek area west of Lynden (sections 14, 15, 21, 22, and 23 of township 40 north, range 3 east). South of the Nooksack River the Wiser Lake area (sections 31 and 32 of township 40 north, range 2 east) and the southwest corner of the study area (sections 24 and 25 of township 39 north, range 2 east) also had nitrate concentrations that were predominantly larger than 3 mg/L. The area east of Lynden near sections 17 and 18 of township 40 north, range 3 east, had nitrate concentrations that generally were between 3 and 10 mg/L, with samples from several wells having concentrations greater than 10 mg/L. This is the same area sampled for EDB by Black and Veatch (1986).

Large concentrations of NO_3 are noticeably absent from the Sumas Valley area, the Everson area, and the area northwest of Lynden.

An inverse relation between nitrate concentration and well depth is reported to be a general feature of shallow aquifers where elevated nitrate concentrations are common (Halberg, 1989). A similar pattern was noted in the Sumas aquifer in areas where large nitrate concentrations greater than 10 mg/L are prevalent. However, when all the nitrate data for the Sumas aquifer are considered together, the relation is absent or much less pronounced, in large part because areas where nitrates are not present have low concentrations throughout the vertical profile. Thus, it is common to find small nitrate concentrations, less than 1 mg/L, at all depths, whereas large concentrations, particularly concentrations that exceed 10 mg/L, are almost exclusively from wells less than 40 feet deep. This general pattern of decreasing nitrate concentration with increasing depth can be seen in data (shown below) from three sets of nested piezometers installed near the Abbotsford Airport. As these data show, the relation is not perfect and is expected to vary with time. The distribution of nitrate with depth is related to the presence of a source of nitrates at the land surface, vertical ground-water flow, and the presence or absence of clay or silt layers that retard downward movement and can create localized zones of anoxic conditions where denitrification of nitrate to nitrogen gas can occur.

Average nitrate concentration in nested piezometer near Abbotsford Airport, in milligrams per liter from 10 measurements between June 1988 and June 1993

Depth (feet)	Site A (mg/L)	Site B (mg/L)	Site C (mg/L)
20 to 25	4.2	20	9.5
35	4.4	19	16
55	5.0	9	8.2
75	6.3	3.3	2.5

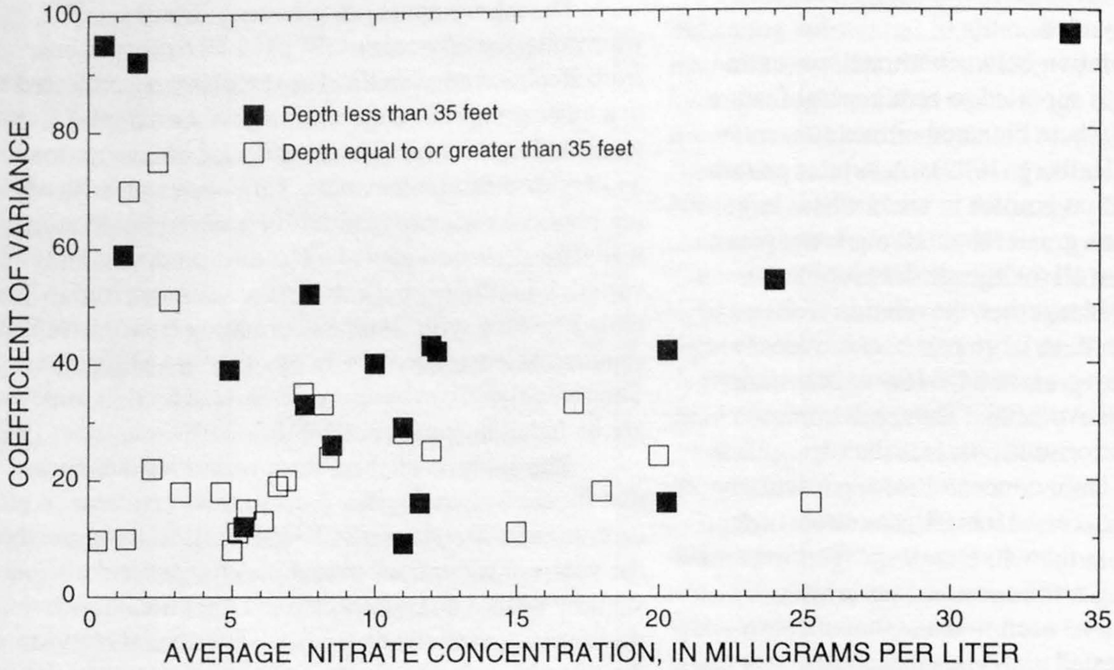
Short-Term Variation in Nitrate Concentrations

During the course of this study, water samples were collected approximately 10 to 12 times per year from 25 observation wells. The samples were collected in a manner similar to the reconnaissance samples and were analyzed for nitrates and chloride concentrations and for specific conductance. Time-series plots showing seasonal variation of nitrate concentrations in these wells are shown on plate 4. The data on the monthly variation in nitrate concentration are summarized in table 11, along with similar information from 15 wells sampled at least twice yearly by other investigators. The monthly observation data collected by this study are included in appendix table 1.

The analysis of short-term variations indicates that for the Sumas aquifer, the variation in nitrate concentration is often large; and depending on the time of the year, concentrations in many wells, particularly shallow wells, can be expected to either increase or decrease substantially over a period of several months. As a result, there is a substantial chance that a single sample from a well with elevated nitrate concentrations may represent the nitrate concentration in the aquifer for only a short period of time and that the concentration of nitrate in that well may be significantly different in as little as 3 to 6 months.

The range of short-term variation in nitrate concentration is generally larger in wells that have larger average nitrate concentrations, as shown in figure 20, which shows the relations between average nitrate concentration and the standard deviation, and average nitrate concentration and the coefficient of variance. The standard deviation is an expression of the variability of the individual nitrate concentrations around the mean concentration, and the plot shows that as the mean concentration increases, the standard deviation, or variability about the mean, also increases. However, the range of variation expressed by the coefficient of variance is similar at most concentration levels above 3 mg/L (fig. 20).

Concentrations of nitrate in ground water in the study area vary with time and show generally consistent patterns in some but not all hydrogeologic units. Variations were greatest in the Sumas aquifer. Nitrate concentrations varied by less than 3 mg/L in 24 percent of the Sumas wells and in nearly all wells from other hydrogeologic units where multiple samples had been collected. In wells that are completed in the Sumas aquifer, seasonal variations in nitrate concentration exceeded 5 mg/L in 62 percent of the wells, and


(a) Well *40N/03E-05M05*

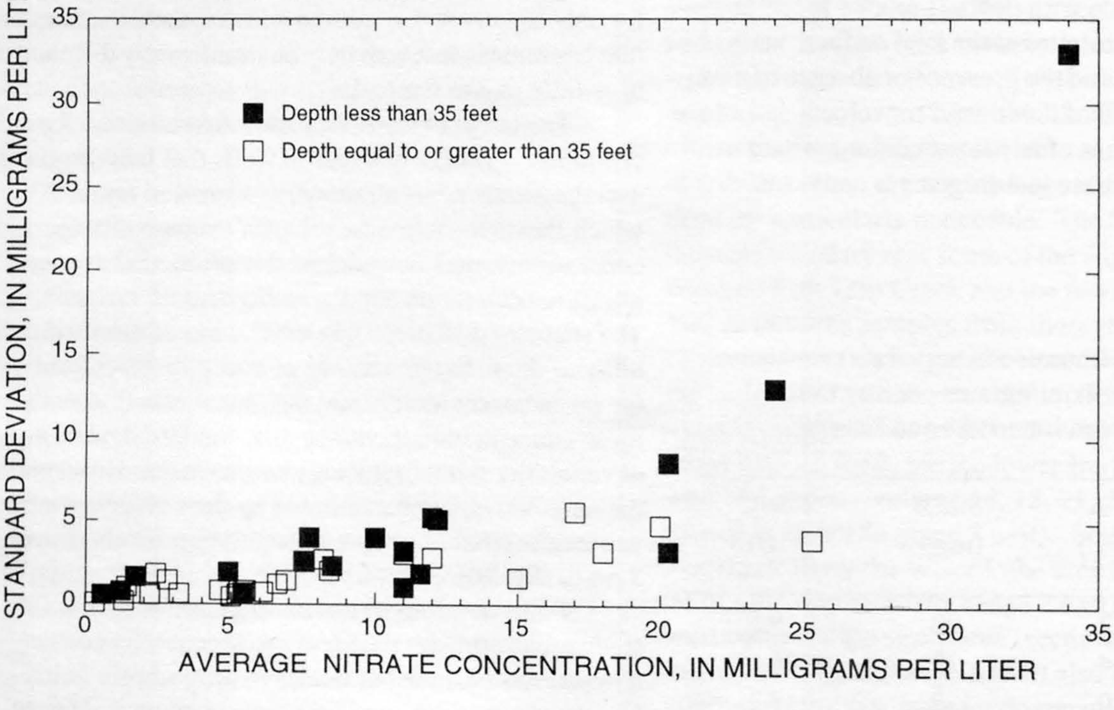

(b) Well *40N/03E-05M05*

Figure 20. Variability of nitrate concentrations in Sumas aquifer showing (a) average nitrate concentration and coefficient of variance and (b) average nitrate concentration and standard deviation.

exceeded 10 mg/L in 36 percent of the wells. The largest seasonal variability was observed from a concurrent study of the Sumas aquifer, which reported 99 mg/L from a shallow piezometer (well 40N/03E-05M05) in a grassland pasture that received regular applications of dairy manure (Denis Erickson, Washington Department of Ecology, written commun., 1993).

Within the shallow water table of the Sumas aquifer, there appears to be a pattern of larger nitrate concentrations in the winter and early spring, which then decline in late spring and summer; however, that pattern of variation in nitrate concentrations was not observed in all wells. In the time-series plots of nitrate concentrations for shallow (less than 40 ft) wells in the water-table part of the Sumas aquifer that are shown on plate 4, nitrate concentrations increased between October and January in 7 of 11 cases and then decreased between April and August in 4 of the wells. Another example of this pattern is seen in the data from Erickson (1991) for the 12-foot piezometer 40N/03E-05M05, which is shown in figure 21. This piezometer is screened at the water table and located in a field where dairy manures were reportedly applied approximately every 30 days. This well was sampled 18 times between February 1990 and April 1993, with 8 samplings occurring during 1990. During this period, nitrate concentrations from 2.5 to 99 mg/L were observed, with highs of 99, 37, and 91 mg/L during January 1991, April 1992, and April 1993, respectively; low concentrations of 2.9, 21, and 29 mg/L were observed in June 1990, August 1991, and July 1992. Samples obtained during the fall and winter of 1990 and 1992 show rapidly increasing nitrate concentrations. The concentrations observed in the summer of 1991 and spring of 1992 are not inconsistent with the possibility that a large concentration, similar to the 99 and 91 mg/L observed during other winter periods, may have been present at some time during the fall or winter of 1991-1992.

The period of rapidly rising nitrate concentrations observed in well 40N/03E-05M05 coincides with the period of rising water table. As was discussed in the section on water-level fluctuations, the seasonal variation in shallow ground-water levels is correlated to the period of winter rains, when deep percolation and most ground-water recharge occur. Two processes related to this cycle explain much of the large variation in nitrate concentration. The rising water table may intersect a portion of the unsaturated zone in which nitrates have accumulated from the nitrification of organic matter during the previous low water-level period. Moreover, the major recharge event for the Sumas aquifer is seasonal, occurring in the fall and winter, probably causing nitrates in the unsaturated zone to be carried down to the water table with the fall-winter recharge event.

The similarity in the variation of the concentration of chloride (fig. 21) suggests that seasonal recharge has the larger influence on short-term temporal variation because concentrations of nitrate and chloride in animal manures are well correlated, whereas chloride is not a prominent component of soil organic matter and large chloride concentrations would not be expected to correlate with large concentrations of nitrate from the nitrification of soil organic matter. Thus, unless there is extensive irrigation during the summer months in excess of the cumulative soil moisture deficit of 15 inches (table 5), water probably does not percolate completely through the soil and into the ground-water system. Nitrate may be moved deeper into the soil profile during summer rains or irrigation, but unless the entire soil column is saturated, most of the nitrate likely will not move below the unsaturated zone. As a result, in the fall, the first pulse of water to completely pass through the soil profile and into the shallow ground-water system will carry a large load of dissolved nitrate with it, resulting in larger nitrate concentrations near the water table at this time.

Although the first pulse of recharge water to reach the water table in the fall may carry a large load of nitrate, subsequent recharge pulses may not encounter as much nitrate available for leaching within the soil profile. The varying concentrations of nitrate in recharge water will therefore lead to varying concentrations in the ground water. As ground water moves along its flow path, mixing and dispersion will occur. Thus for wells at greater distances from the recharge location, such as the Sumas City Municipal wells and most Sumas wells located in the Sumas Valley, the variability in nitrate concentration will be much smaller.

If the seasonal recharge explanation is correct, nitrate concentrations in shallow ground water fluctuate in the short term largely because of variability in the rate that nitrate is introduced into the ground water. Other factors such as the rate of ground-water flow and the rate of biochemical reactions also can cause nitrate concentrations to fluctuate; however, in the study area these factors may be less important. During the fall, the temperature in parts of the soil profile is still warm enough that nitrifying bacteria can continue to convert

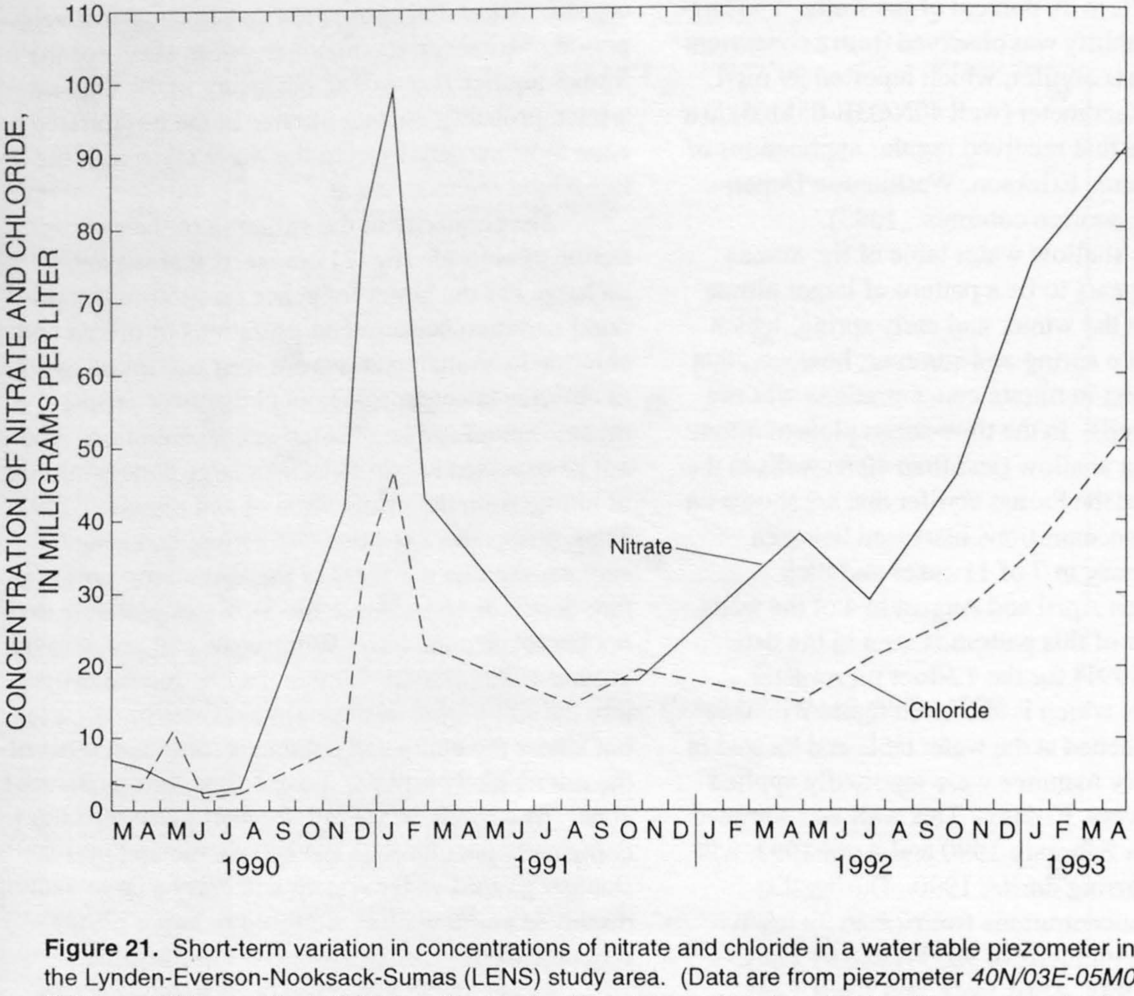


Figure 21. Short-term variation in concentrations of nitrate and chloride in a water table piezometer in the Lynden-Everson-Nooksack-Sumas (LENS) study area. (Data are from piezometer *40N/03E-05M05*, Erickson, 1991, and Denis Erickson, Washington Department of Ecology,1994, written communication.)

ammonia and organic nitrogen to nitrate. However, the use of nitrate by plants is declining during this time as most perennial plants become dormant and winter crops, if present, may not be well established. The result is that during the fall there may be significant quantities of nitrate in the soil profile, and because they are not used by plants, they will be available to be leached to the ground water by the winter recharge event.

Less variability in nitrate concentrations may occur in shallow wells affected by recharge from septic tanks and dairy lagoons because these sources generally are more constant throughout the year and should generate recharge to the ground-water system on a year-round basis. Some variability will still be present because of the seasonality of precipitation and possible temperature cycles that may affect the bacterial community.

As expected, the seasonal variability in nitrate concentrations in the Everson-Vashon unit and the Vashon unit was generally small. In three wells, the nitrate concentrations never exceeded the analytical detection limit of 0.1 mg/L. Two wells in the Everson-Vashon unit yielded ground water with detectable nitrate concentrations that averaged 1.3 and 6.9 mg/L. Nitrate concentrations in the first well varied from 1.1 to 1.4 mg/L, with a coefficient of variance of 9.9 percent, and in the second varied from 5.0 to 10.0 mg/L, with a coefficient of variance of 20 percent (see table 11).

Long-Term Variation in Nitrate Concentrations

Data used to assess long-term (3 years or more) variations in nitrate concentrations included historical data for 21 sampling sites where repetitive samples have been collected and monitoring data for wells with more than 3 years of record. Because of the large degree of short-term variations in nitrate concentrations, long-term trends are difficult to assess without extensive time series data.

Long-term variability in nitrate concentration in ground water is demonstrated in data from the 21 wells in the Bertrand Creek area that were sampled in mid-August of 1988 (Erickson, 1992) and again in mid-August of 1991 for this study (table 12). Eleven wells showed larger concentrations in the second sampling, and 10 wells had smaller concentrations in the second sampling. The overall median nitrate concentration rose from 5.0 mg/L in 1988 to 6.7 mg/L in 1991; however, the variability observed in the change in concentration from one sampling to the next is so large that the change in median concentrations is not statistically different when evaluated using the nonparametric matched-pair sign test (Helsel and Hirsch, 1992).

Previous studies that included areal surveys of nitrate concentrations in ground water in the study area include those by Obbert (1973), Kwong (1986), Kohut and others (1989), Erickson (1991), and Liebscher and others (1992). The studies by Kwong, Kohut and others, and Liebscher and others are confined to the Canadian part of the study area. All of those studies conclude that nitrate concentrations in ground water are increasing in the Canadian part of the study area, which is also the area where large nitrate concentrations were most prevalent. Obbert (1973), who conducted a survey of nitrate concentrations in ground water in western Whatcom County, collected 31 of 45 ground-water samples from wells within the present study area. The median concentration of all of Obbert's ground-water nitrate data was 1.25 mg/L, while the median nitrate concentration from Obbert's sites located within the LENS area was 2.8 mg/L. This compares similarly to a median nitrate concentration of 3.8 mg/L in samples from wells completed in the Sumas aquifer. The distribution of the sample data from these two studies, shown in figure 22, shows similar median values (less than 1 mg/L difference); however, the more recent data includes larger maximum and 75 percentile values. The sample populations of the two studies are not identical, and there were seasonal differences in the time that samples were collected; thus, it is difficult to assess whether the data actually represent a change in nitrate concentrations in ground water or are artifacts of the differences in the sample populations.

The long-term trend in nitrate concentrations in ground water from individual wells varies, with the LENS study area containing areas of both increasing and decreasing nitrate concentrations, and thus showing no consistent overall pattern. Data available for this study show about the same number of cases of increasing and decreasing nitrate concentrations. Time-series plots of nitrate concentrations from 18 wells and 1 spring all of which have had data gathered for a period of 3 years or longer, are shown in figure 23. The majority of these wells are near the Abbotsford Airport and the town of Sumas. Of the 18 wells shown in figure 23, there are examples which show increasing, decreasing, and essentially unchanged nitrate

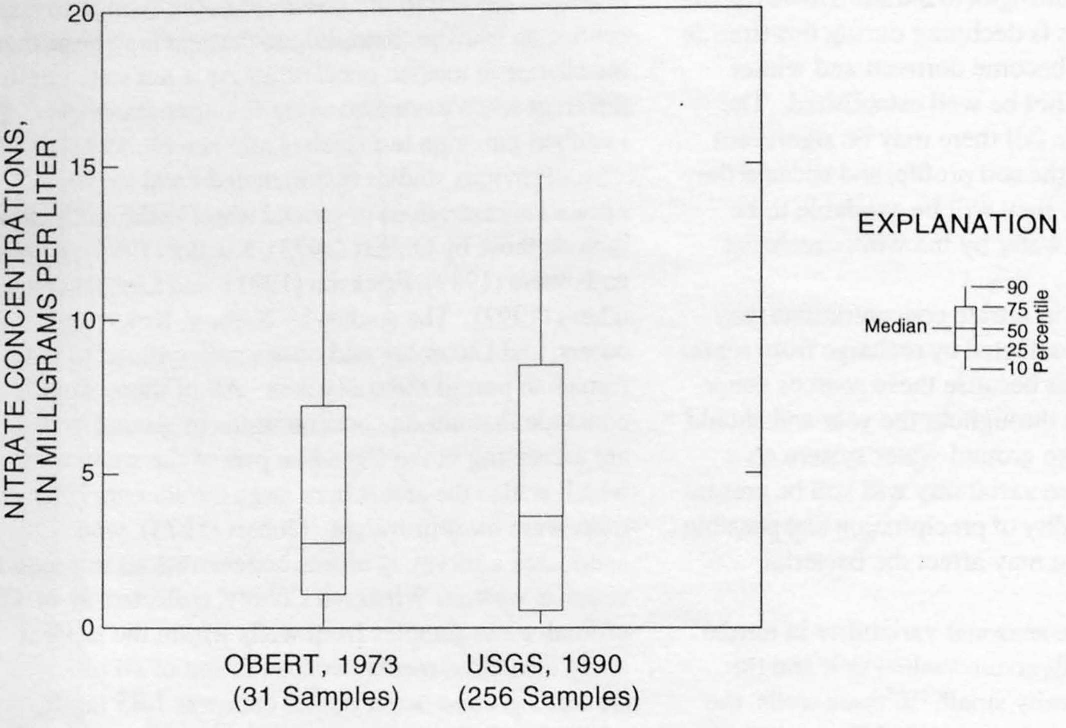


Figure 22. Comparison of median nitrate concentrations in ground water in the Lynden-Everson-Nooksack-Sumas (LENS) study area in 1972 (Obbert, 1973) and in 1990 (for this study).

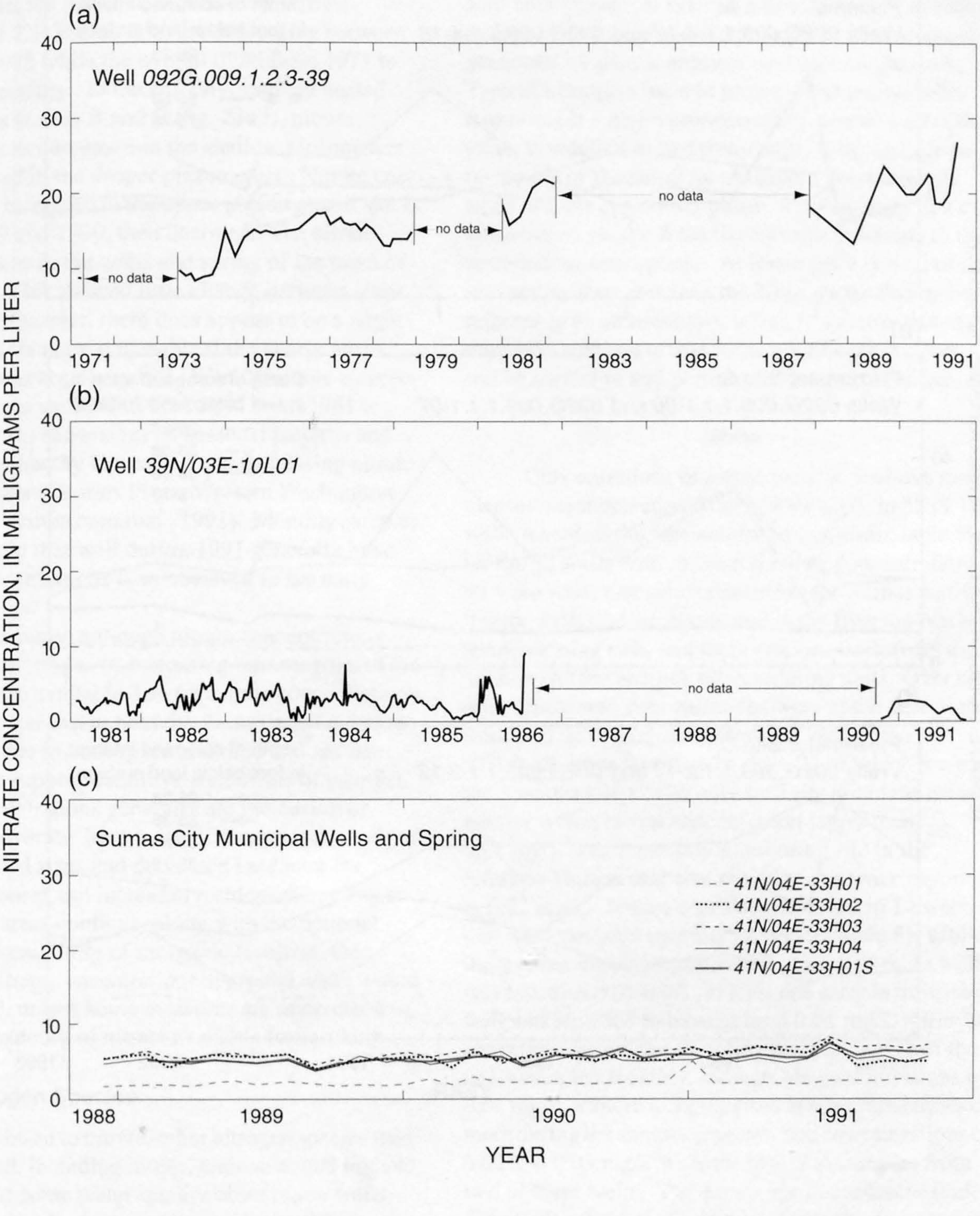


Figure 23. Long-term variability of nitrate concentrations at (a) well 092G.009.1.2.3-39, (b) well 39N/03E-10L01, (c) Sumas City wells and spring, (d) piezometer site A, (e) piezometer site B, and (f) piezometer site C.

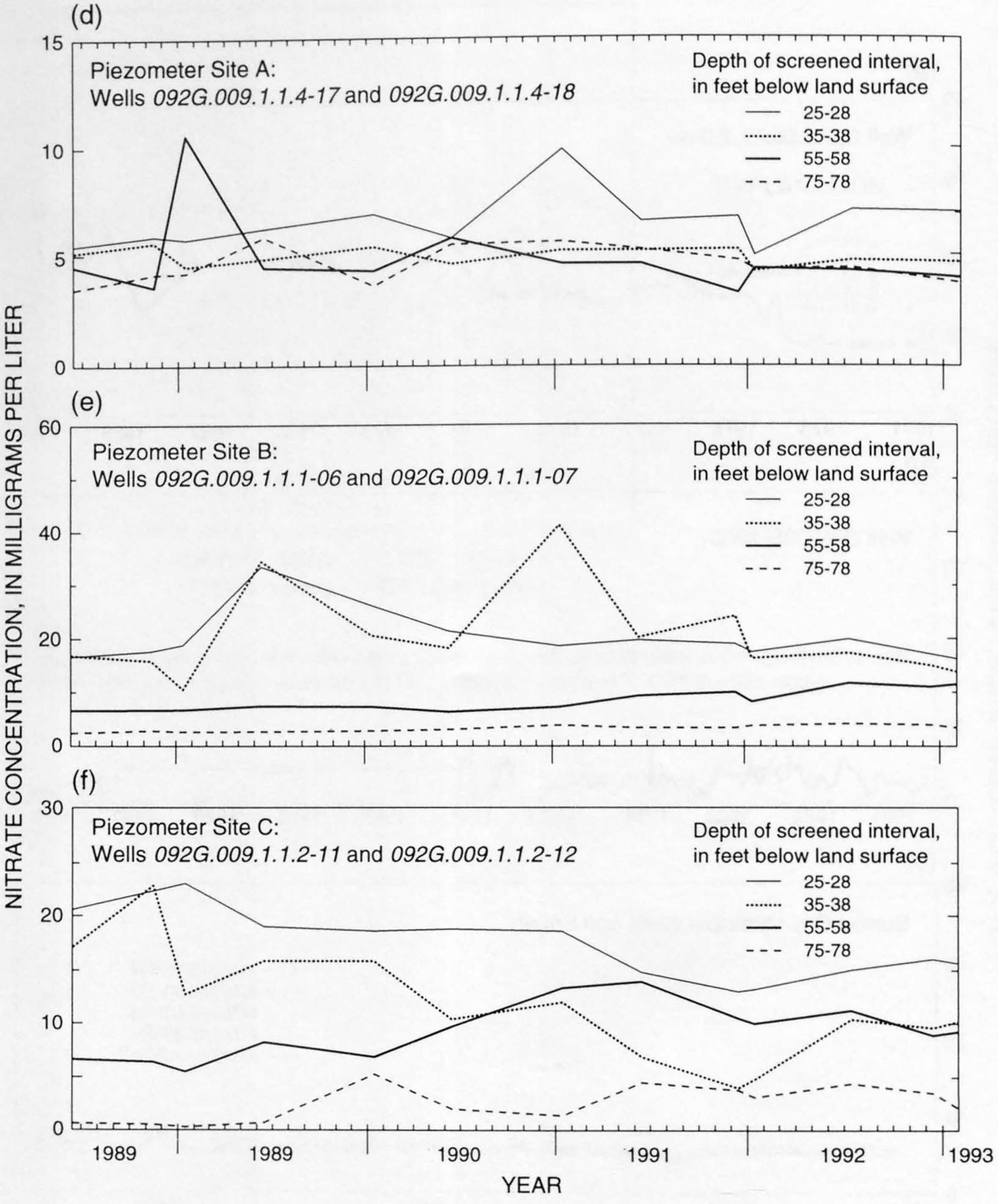


Figure 23. continued.

concentrations. Some wells show periods of a non-seasonal reversal in the trend of nitrate concentrations. For example, the nitrate concentrations in well 092G.009.1.2.3-39 (fig. 23a) are decreasing between 1976 and 1978 while the overall trend from 1971 to 1991 is increasing. In the BC Environment nested piezometers at sites B and C (fig. 23e,f), nitrate concentrations decreased in the shallow piezometers and increased in the deeper piezometers. Nitrate concentrations increased in the upper piezometer at site B during 1989 and 1990, then declined. The nitrate concentrations in the wells and spring of the town of Sumas (fig. 23c) showed little change between 1989 and 1993. However, there does appear to be a slight increase that is more noticeable if the yearly mean concentrations are compared. Weekly nitrate samples collected from well 39N/03E-10L01 from 1981 to 1986 (fig. 23b) show signs of seasonal patterns and periods of generally increasing and decreasing nitrate concentrations (Charles Flora, Western Washington University, written commun., 1991). Monthly samples obtained from that well during 1991 generally have smaller concentrations than observed in the early 1980's.

In summary, although nitrate concentrations have been reported to be increasing in some parts of the study area, the available data for nitrate concentrations in ground water throughout the Sumas aquifer are highly variable in both space and time and are not sufficient to support definitive statements of whether nitrate concentrations generally are increasing or decreasing over the long term. If the general trends of increased herd sizes and decreased land base for manure disposal and increased residential housing in unsewered areas continue, along with the national trend of increased use of inorganic fertilizer, then increased nitrate concentrations in ground water would be expected, unless some measures are undertaken to reduce the amount of nitrate available for leaching.

Other Nitrogen Species

In addition to nitrate, other nitrogen species were also sampled, including nitrite, ammonia, and organic nitrogen. At some water-quality observation wells, bimonthly samples included the analysis of nitrite, ammonia, and organic nitrogen. Data for all nitrogen species are tabulated in appendix table 8.

Nitrite is an intermediate nitrogen species, but generally it is not found in significant concentrations in shallow ground water because it is unstable in the presence of dissolved oxygen. Ammonia and organic nitrogen are the predominant forms of nitrogen associated with biological systems. Organic nitrogen refers to the numerous nitrogen-containing organic molecules generated by plants, animals, and microorganisms. Typical examples include proteins and amino acids. Ammonia is a major component of animal wastes that exists in solution in two states depending, in large part, on the pH of the solution. At higher pH, ammonia tends to exist in the NH_3 phase, which is a gas that can volatilize or escape from the aqueous solutions to the surrounding atmosphere. At lower pH's typical of natural water, ammonia is in the NH_4^+ phase (commonly referred to as ammonium), which is a cation that may remain in solution in that form, but like other cations it can be sorbed to soil particles and mineral surfaces.

Nitrite

Concentrations of nitrite were at or above the measurement detection limit of 0.01 mg/L in 53 of 187 wells where nitrite was measured (appendix table 8). Of the 53 wells with measured nitrite concentrations, 42 were wells that are completed in the Sumas aquifer, 9 were wells that are completed in the Everson-Vashon semiconfining unit, and there was one each from the Vashon and the bedrock semiconfining units. Over half of the measured concentrations were at the detection limit of 0.01 mg/L; concentrations larger than 0.01 mg/L were found at 26 sites, 25 of which were in the Sumas aquifer. The only well site not in the Sumas aquifer with a nitrite concentration larger than 0.01 mg/L was a monthly monitoring site in the Everson-Vashon unit where nitrite was twice reported at 0.02 mg/L. Nitrite was also measured in 14 wells that were sampled monthly (appendix table 8). While the median nitrite concentration in each of these wells was less than 0.01 mg/L, at least one sample from each well was reported to have at least 0.01 mg/L nitrite at some time during the sampling period. In five of the wells sampled monthly, measurable concentrations of 0.01 mg/L or more were reported at least three times or more during the sampling period, and concentrations of 0.02 and 0.03 mg/L were measured in samples from two of these wells. The larger nitrite concentrations, from 0.09 to 0.66 mg/L, were found in the deeper parts of the Sumas aquifer or in ground-water discharge areas. The persistence of nitrite concentrations in ground water from deeper wells and their variation with well depth is shown in data from the nested piezometers near the Abbotsford Airport.

Concentration of nitrite in ground water from nested piezometer near the Abbotsford Airport--average of 11 measurements between June 1988 and July 1993

Depth (feet)	Nest A (mg/L)	Nest B (mg/L)	Nest C (mg/L)
20-25	<0.01	<0.01	<0.01
35	<0.01	<0.01	<0.01
55	<0.01	<0.01	<0.01
75	0.69	0.21	0.04

The presence of nitrite in deeper ground water may indicate that biological denitrification is occurring in parts of the Sumas aquifer. Nitrite is seldom present in most shallow ground water, in part because it is chemically unstable in oxygenated water. However, nitrite is an intermediate product in the microbial denitrification and may accumulate in a denitrifying system where oxygen is absent or present at very low concentrations (Firestone, 1982). Thus the presence of nitrite in ground water having less than 1 mg/L dissolved oxygen may indicate the occurrence of denitrification. Although nitrification is another microbial process that produces nitrite, nitrification is restricted to well oxygenated systems where nitrite typically is rapidly converted to nitrate (National Research Council, 1978). The occurrence of denitrification is important in ground-water systems where nitrate is present because denitrification is the only process other than dilution or utilization by plants that can result in a substantial reduction of nitrates in ground water.

Several additional lines of evidence also suggest that denitrification may be occurring in some of the deeper parts of the Sumas aquifer. Nitrous oxide, which is present in the atmosphere at concentrations ranging from 5 to 20 μg/L, is also a product of microbial denitrification. Three dissolved-gas samples were collected at the nested piezometers for analysis of nitrous oxide. Two samples from the 75-foot-deep piezometers at sites B and C where dissolved-oxygen concentrations were less than 1 mg/L were found to have nitrous oxide concentrations of 170 and 340 μg/L. The third sample, collected from the 35-foot-deep piezometer at nest C, which had a dissolved-oxygen concentration of 9.0 mg/L, also contained 8.8 μg/L nitrous oxide. Excess nitrogen was also reported from a gas sample collected from the well at the Nooksack Valley High School (40N/04E-09N01) leading to an estimate of denitrification on the order of 10 mg/L (Eurybiades Busenberg, U.S. Geological Survey, written commun., 1992). Other evidence of denitrification is that the microbial process tends to enrich the nitrogen-15 isotope ratios of the nitrate remaining in the ground water--nitrogen-15 isotopes from the deeper piezometers near the Abbotsford Airport were found to be enriched compared to shallow samples collected nearer the water table (Wassenaar, 1994). Lastly, denitrifying bacteria were identified in ground-water samples from the deeper piezometers (Rodney Zimmerman, BC Environment, written commun., 1992). These data provide multiple lines of evidence suggesting that denitrification is occurring and as such is reducing nitrate concentrations in some parts of the Sumas aquifer. Similar conditions also occur in parts of the Sumas aquifer in the Sumas River Valley and may occur at other locations in the Sumas aquifer.

Wassenaar (1994) concluded that denitrification was not widespread in the Sumas aquifer near Abbotsford Airport; however, his data were largely collected from the shallow wells in the recharge areas of the Sumas aquifer and thus do not adequately represent conditions throughout the entire aquifer, particularly the deeper zones or areas where ground water discharges. Nitrate concentrations in the discharge and deeper zones were typically much smaller than median concentrations for the entire aquifer, plate 4, and may be the result of either denitrification or dilution.

Ammonia

Ammonia, like nitrate, has natural and human sources. Ammonia, a major component of animal waste, is the predominant form of nitrogen in barnyard manures and septic tank waste water; and as noted by Feth (1966), ammonia is the most prominent form of nitrogen in rainwater. Anhydrous ammonia is also a common form of inorganic nitrogen fertilization. Ammonia is stable in ground-water systems that have oxidation-reduction conditions that are reducing, a common feature of which is the absence or low concentrations of dissolved oxygen.

The distribution of ammonia concentrations in the four hydrogeologic units is shown in figure 19, along with other forms of nitrogen. The concentrations of ammonia in all 182 ground-water samples analyzed for ammonia ranged from less than 0.01 mg/L to 63 mg/L, with a median concentration of 0.02 mg/L. However, the three largest concentrations, 34, 43, and

63 mg/L, were from samples obtained from the piezometers installed adjacent to manure storage lagoons; the next largest concentration was 2.2 mg/L. In the Sumas aquifer, 90 percent of sampled wells had ammonia concentrations below 0.1 mg/L. Concentrations between 0.1 and 2.5 mg/L were all found in Sumas aquifer wells in which measurements indicated that dissolved oxygen was either absent or present only at low concentrations. These were generally found in either the Sumas River Valley or areas west and northwest of Lynden where extensive subsurface drainage has been installed.

Concentrations of ammonium and nitrate were inversely related; hence the spatial distribution of ammonium shows a general pattern opposite that of the distribution of nitrate. This is largely because nitrate is the dominant nitrogen species under aerobic or oxygenated conditions, and ammonium is the dominant species under anaerobic or deoxygenated conditions.

Organic Nitrogen

Concentrations of organic nitrogen in ground water ranged from 0.2 mg/L to 4.0 mg/L, with a median of 0.6 mg/L. Organic nitrogen refers to nitrogen-containing organic compounds typically associated with biological material such as proteins and amino acids. The distribution of organic nitrogen concentrations in the four hydrogeologic units is shown in figure 19. Median concentrations were largest, 0.6 mg/L, in samples from wells completed in bedrock semiconfining unit. Continental sandstones that make up this unit contain large coal deposits that are likely the source of the organic nitrogen and ammonia found in the ground water. Drillers' logs often report that peat, wood, or organic material has been encountered during drilling in the Everson-Vashon material. While peat deposits are common on the surface of the Sumas aquifer, wells in the Sumas aquifer that contain large concentrations of organic nitrogen do not appear to be related to these areas.

In parts of the Sumas aquifer, the concentration of organic nitrogen is generally correlated to the concentration of nitrate; however, the wells showing the largest concentration of organic nitrogen were piezometers located downgradient of dairy lagoons where the chemical environment is reducing and thus incompatible with the presence of nitrate. In the Sumas aquifer, over which land application of barnyard manures is common, larger concentrations of organic nitrogen were often found in wells that were screened closer to the land surface. Concentrations of organic nitrogen found in the nests of piezometers near the Abbotsford Airport are shown below. The presence of organic nitrogen in ground water generally indicates the presence of organic wastes or sewage (Hem, 1989).

Concentrations of organic nitrogen from piezometer nests near the Abbotsford Airport

	Organic nitrogen concentrations, in milligrams per liter		
Depth (feet)	Nest A	Nest B	Nest C
20-25	0.08	0.13	0.10
35	0.09	0.11	0.12
55	0.08	<0.04	0.09
75	<0.04	0.10	0.10

Septage-Related Compounds

Concentrations of boron, organic carbon, and methylene blue active substances (MBAS) in ground water were measured to assist in the identification of ground water that might be influenced by leachate from septic systems. Similar analyses in other areas of western Washington have shown a good relation between MBAS and nitrate concentrations in residential areas (Drost and others, 1998). Boron and MBAS, which are present as detergent residues in household wastewater, have been identified in septage-contaminated ground water (LeBlanc, 1984). Large concentrations of organic carbon may suggest the presence of several types of organic compounds, including those from septic systems and organic compounds such as solvents, oils, and greases. Large concentrations of organic carbon in ground water may also be associated with decaying organic matter. Most of the samples for these constituents were collected near residential areas overlying the Sumas aquifer, where contamination of ground water from septic systems is more likely. Some samples, however, were also collected from the other hydrogeologic units to determine natural variations. The discussion in this section of the text is limited largely to the comparison of concentrations found in the different hydrogeologic units and to areal distribution. These compounds and their relation to nitrates in ground water of the Sumas aquifer are also discussed in a later section devoted to the evaluation of the sources of nitrates in ground water.

Boron

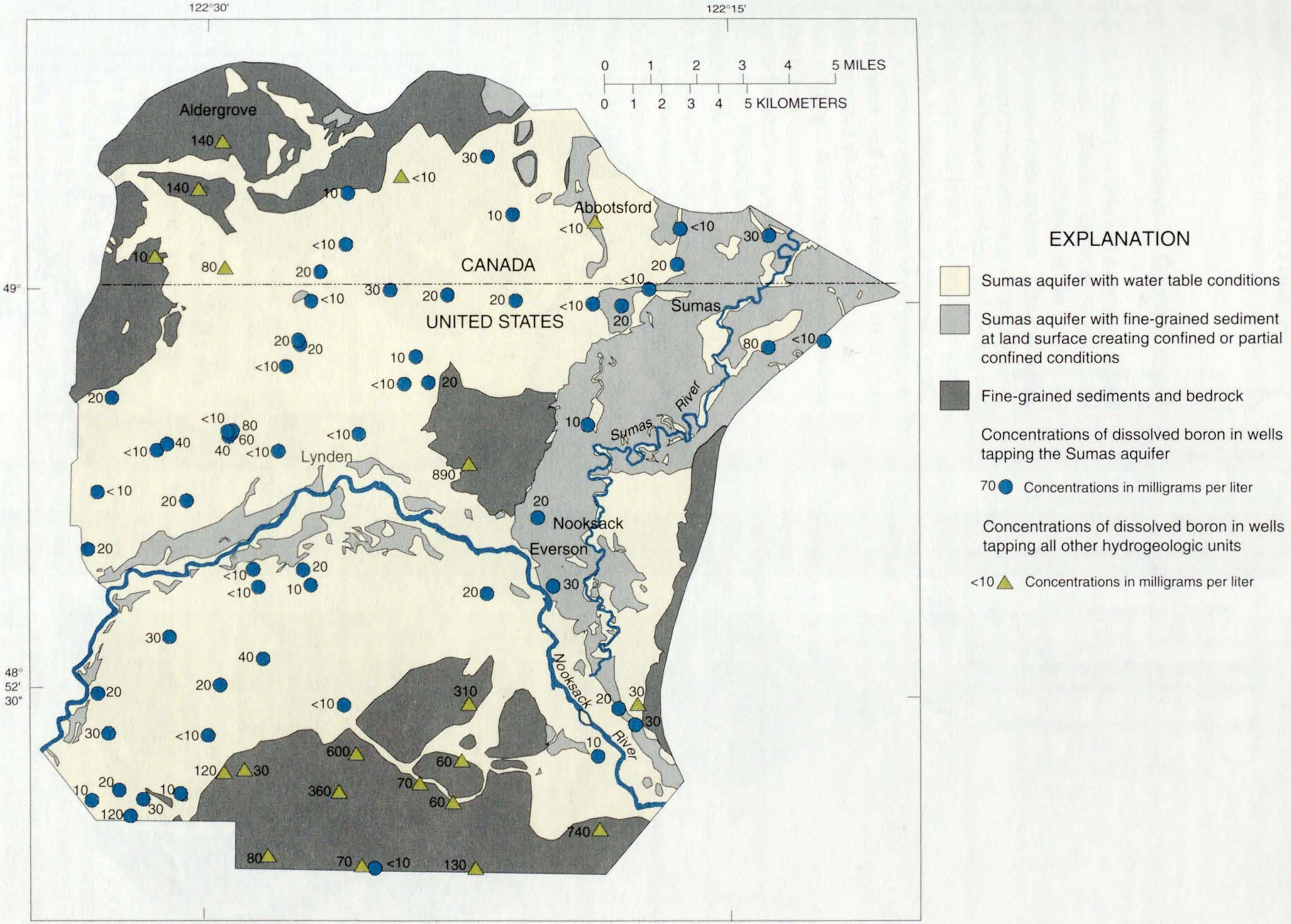
The concentration of boron in ground water was determined in samples from 79 wells that ranged from below the detection limit of 10 µg/L to 860 µg/L. Ground water in the Sumas aquifer generally displayed small boron concentrations, with a median concentration of 20 µg/L, while concentrations in the other units were noticeably larger--median concentrations of 120, 30, and 60 µg/L in the Everson-Vashon, Vashon, and bedrock hydrogeologic units, respectively (table 6). The large concentrations in the older units are probably attributable to natural conditions rather than to any land-use activities. Natural concentrations of boron in ground water in excess of 100 µg/L are not uncommon (Hem, 1989), and the boron concentration of seawater is typically 4.6 mg/L. The largest concentration of boron in ground water was 860 µg/L, observed in well 40N/03E-24E01, which is completed in the Everson-Vashon hydrogeologic unit. This well also produces water with large chloride and bromide concentrations, indicating the presence of seawater--a boron concentration of 860 µg/L is roughly 18 percent of the concentration found in seawater. All but one of the boron concentrations above 100 µg/L occur in the older units and may also contain relict seawater. The one well completed in the Sumas aquifer having a boron concentration over 100 µg/L is located in an area surrounded by septic systems, which are probably the local source of the boron. Ground-water samples from the Sumas aquifer that had boron concentrations between 50 and 100 µg/L were from areas generally associated with dairy farming. The areal distribution of boron concentrations is shown in figure 24. Most samples with concentrations above 100 µg/L were from wells in the older units and may be similar to 40N/03E-24E01, where there is other water-quality evidence of a component of relict seawater in the sample.

Dissolved Organic Carbon

Concentrations of dissolved organic carbon (DOC) were typically below 2.0 mg/L, the median concentration being 0.7 mg/L (table 6), which is comparable to the median concentration for DOC of 0.7 mg/L for ground water throughout the United States (Leenheer and others, 1974; Thurman, 1985). Only two ground-water samples were obtained from the bedrock unit for DOC analysis. While the concentrations of these two samples, 1.0 and 1.4 mg/L, were larger than the median concentration found in the overlying hydrogeologic units, the small sample size precludes much interpretation; however, the source of the carbon in these samples may be coal present in the sedimentary bedrock. The two largest DOC concentrations (26 and 39 mg/L) were found in piezometers associated with monitoring seepage from manure lagoons. Several of the other 11 samples with DOC concentrations larger than 2.0 mg/L were from areas where the surrounding land use included manure applications. Of the 13 samples that contained DOC concentrations greater than 2 mg/L, dissolved-oxygen concentration data were available for 10 samples; and in all 10 cases, the dissolved-oxygen concentration was below 1 mg/L, generally 0.2 or less. This reflects the general instability of organic carbon in the presence of oxygen, where, under equilibrium conditions organic carbon will be oxidized to carbon dioxide (Pankow, 1991). This relation partially explains the higher DOC concentrations observed in the Sumas Valley area (fig. 25) and in the Everson-Vashon hydrogeologic unit, where lithologic logs generally report more instances of organic or woody material than do lithologic logs of the Sumas aquifer. In the presence of larger quantities of organic material, oxidation of organic carbon would rapidly consume dissolved oxygen in recharge water and lead to anoxic conditions that are more compatible with the presence of DOC.

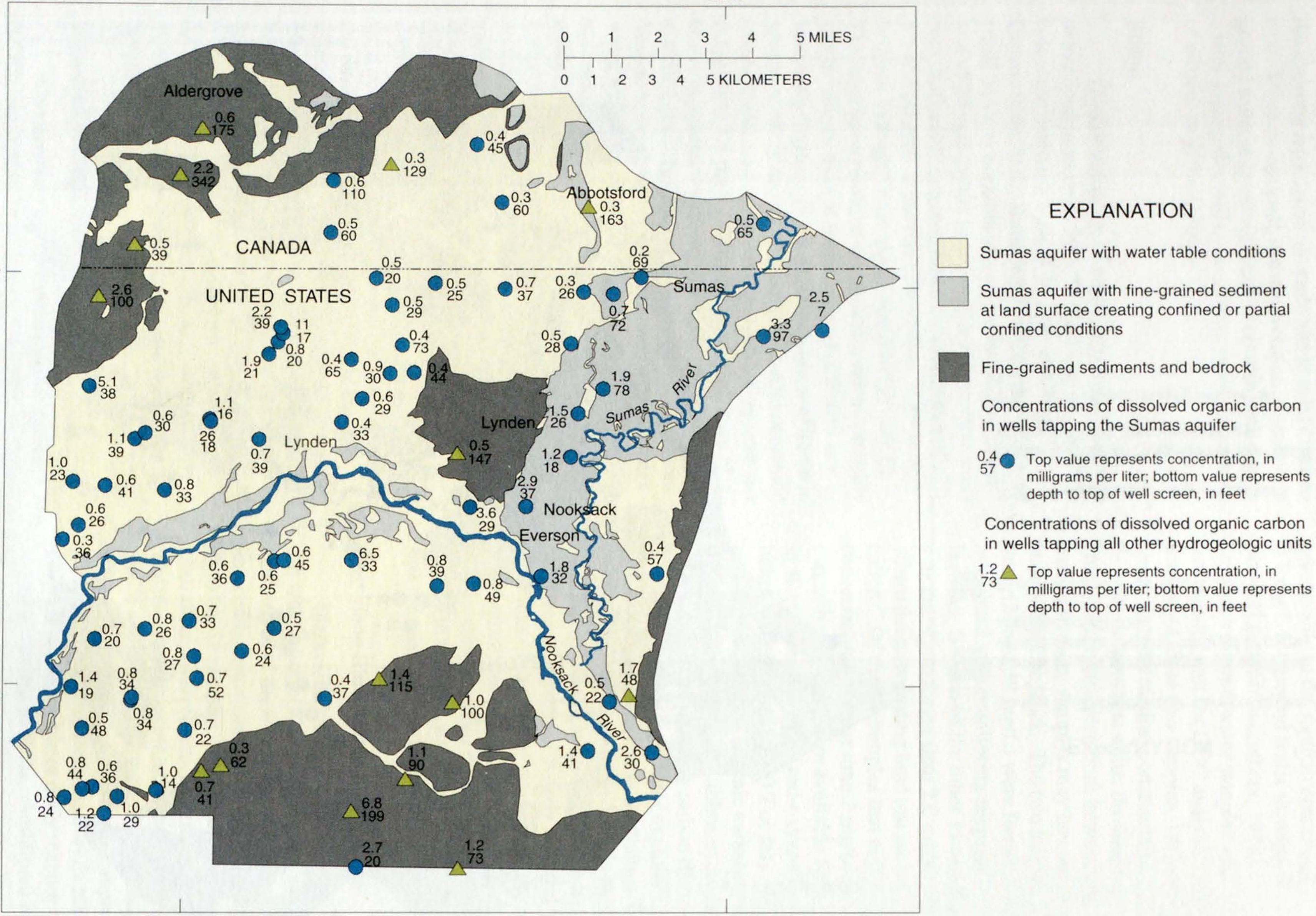
Methylene Blue Active Substances

Methylene blue active substances (MBAS) were not widely present in ground-water samples from the study area; of the 67 samples analyzed for MBAS, detectable concentrations at or above 0.02 mg/L were found in 11 samples. Consequently, the median concentration observed was less than the detection limit. The maximum concentration measured was 0.09 mg/L, which was found in two piezometers adjacent to a manure lagoon. The majority of samples with detectable concentrations were from wells associated with land-use activities where dairy manure was either stored or applied to fields. Additional discussion



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 24. Areal distribution of dissolved boron concentrations in ground water in the Lynden-Everson-Nooksack-Sumas (LENS) study area.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 25. Areal distribution of dissolved organic carbon concentrations in ground water in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

concerning MBAS can be found in a later section of this report on the evaluation of sources of nitrate in the Sumas aquifer.

Chloride Concentrations in Ground Water

Chloride is highly soluble and a common constituent of natural water. Because chloride does not sorb to aquifer materials or soil particles, it can be used as a tracer in some ground-water systems. Chloride is not, however, a common constituent of geologic materials within the Fraser-Whatcom Lowland, and except for areas of relict seawater and brine solutions, the concentration of chloride in natural water is generally small. Chloride is a prominent component of domestic sewage, animal manures, and some fertilizers; all of which have been documented as sources of chloride in ground-water systems. Also irrigation using shallow ground water may increase the concentration of chloride within the shallow ground water because of evapoconcentration (Nightingale and Bianchi, 1974). Chloride imparts a definite salty taste to water at concentrations above 250 mg/L, the concentration set by the USEPA as a Secondary Maximum Contaminant level and by HC as an aesthetic objective.

Within the four hydrogeologic units, chloride concentrations varied, in part because of differences in the hydrologic and water-quality characteristics of the individual units. The concentration of chloride ranged from 0.3 to 2,800 mg/L, with a median value of 8.8 mg/L in the 344 wells sampled for this study. The largest chloride concentration (2,800 mg/L) was observed in a well completed in the Everson-Vashon unit. The largest seasonal variation of from 6.8 to 20 mg/L was from a well completed in the Sumas aquifer. The largest net change in chloride concentration was observed in the observation well completed in the Vashon unit where the chloride concentration rose steadily from 640 to 840 mg/L from May, 1990 to October 1991. Chloride concentrations within the Sumas and Everson-Vashon units were generally smaller than concentrations in the stratigraphically deeper Vashon and bedrock units. Median chloride concentrations within the four hydrogeologic units were 8.8 mg/L in the Sumas aquifer, 7.7 mg/L in the Everson-Vashon unit, 182 mg/L in the Vashon unit, and 37 mg/L in the bedrock unit. For comparison, the range of median chloride concentration observed in 12 Puget Sound counties was from 1.8 to 86 mg/L (Turney, 1986), however, several of these counties include areas where seawater intrusion has affected chloride concentrations.

The areal distribution of chloride in ground water in the study area is shown on plate 5 along with time series and cumulative frequency distribution plots of chloride concentrations. The time series plots are of chloride data collected repeatedly (generally monthly) at observation wells throughout the study area. The cumulative frequency distribution plots show the range and distribution of chloride concentrations within individual hydrogeologic units.

The observed chloride concentrations were divided into four ranges of concentrations: (1) background concentrations, and (2) slightly, (3) moderately, and (4) significantly elevated concentrations. Because there were few undeveloped areas within the study area, the estimated range of background chloride concentrations in the Sumas aquifer (0.5 to 4 mg/L) is based on data from undeveloped areas of Thurston and east King Counties that have similar hydrogeologic environments. This range is similar to the range determined by Gilliom and Patmont (1982) for a shallow glacial aquifer in the Puget Sound region. The estimated range of background chloride concentrations in the lower permeable units, the Everson-Vashon, Vashon, and bedrock units, is from 0 to 7 mg/L and was based primarily on the cumulative frequency distribution of chloride in the Everson-Vashon unit, for which there were many more samples than for the other semiconfining units. The larger range of background chloride concentrations in the Everson-Vashon unit may be due, in part, to the lower permeabilities and longer ground-water residence times but also may be due to the different geologic materials and presence of more clay particles in these units. Chloride concentrations above background levels and below 25 mg/L were considered slightly elevated, while concentrations between 25 mg/L and 250 mg/L were considered moderately elevated. The percentage of wells sampled with chloride concentrations larger than 25 mg/L in the Sumas aquifer, the Everson-Vashon unit, and the Vashon and bedrock units was 9, 26, 62, and 57, respectively. Chloride concentrations above 250 mg/L, the USEPA and HC drinking water guideline, were considered significantly elevated and were found in 12 wells (3.5 percent). The distribution of chloride concentrations in the four concentration groups is tabulated on plate 5. Seventy-five percent (260) of the wells sampled showed chloride concentrations larger than the range of background concentrations.

Sumas Aquifer

Chloride concentrations in 231 wells completed in the Sumas aquifer ranged from 0.3 to 210 mg/L, with a median concentration of 8.8 mg/L. Eighty-four percent of the wells sampled had chloride concentrations larger than the range of background concentrations found in glacial outwash deposits. The chloride concentration in the majority of wells sampled (74 percent) fell within the range of slightly elevated chloride concentrations. The spatial distribution of chloride in the Sumas aquifer (plate 5) indicates that slightly elevated chloride concentrations occur throughout most of the aquifer. In general, ground water that contains background levels of chloride has small values of specific conductance, indicating low levels of dissolved material, and also contained background levels of nitrates. These wells were found throughout most of the study area. Nine percent (21 wells) of the wells completed in the Sumas aquifer had moderately elevated chloride concentrations between 25 and 250 mg/L; about half (9) of these wells are located in the area south and west of the town of Everson, while the remainder (12 wells) generally were spread out throughout the rest of the extent of the Sumas aquifer. The cause of the moderately elevated levels of chloride in ground water from these nine wells near the town of Everson is not known. None of the 231 wells completed in the Sumas aquifer had what is considered significantly elevated chloride concentrations greater than 250 mg/L. Median depths of sampled wells completed in the Sumas aquifer within the three chloride concentration classes were between 29 and 37 feet, with no noticeable variation associated with depth. Likewise, consistent variation of chloride concentrations with depth was not observed in the three sets of piezometers located near the Abbotsford Airport.

Depths and chloride concentrations in ground water from the nested piezometers near the Abbotsford Airport; average of 12 measurements between June 1988 and July 1993

Depth (feet)	Nest A (mg/L)	Nest B (mg/L)	Nest C (mg/L)
20-25	2.8	9.9	6.8
35	2.4	8.8	9.9
55	2.2	5.0	5.5
75	5.2	5.1	6.0

Everson-Vashon Semiconfining Unit

Chloride concentrations in 91 wells completed in the Everson-Vashon unit ranged from 0.8 to 2,800 mg/L, with a median concentration of 7.9 mg/L. Nearly half of the wells in the Everson-Vashon unit had chloride concentrations within the range of natural background concentrations. No definite areal pattern was apparent in the distribution of chloride concentrations in the Everson-Vashon unit, however, chloride concentrations in this unit tended to increase with depth. The median depth of Everson-Vashon wells that had chloride concentrations in the range of background was 96 feet, while median depths of wells with chloride concentrations in the slightly, moderately, and significantly elevated ranges were 134, 116, and 219 feet, respectively. Monthly chloride concentrations in the Everson-Vashon wells monitored between August 1990 and September 1991 showed fairly uniform concentrations varying by less than 3 mg/L (plate 5).

Vashon and Bedrock Semiconfining Units

Chloride concentrations were larger in the Vashon and bedrock semiconfining units, where more than half of the sampled wells had chloride concentrations in the moderately or significantly elevated concentration ranges. In the nine wells completed in the Vashon semiconfining unit, which is located along the eastern margin of the study area (plate 5), one well had moderately elevated chloride concentrations, while four had significantly elevated chloride concentrations. One Vashon well had a chloride concentration in the range of background concentrations. In the one Vashon well monitored repeatedly between May 1990 and October 1991, chloride concentrations rose steadily from 640 to 840 mg/L. In the wells completed in the bedrock unit, six wells had chloride concentrations in the moderately elevated range, and two had chloride levels in the significantly elevated range, while both the background and slightly elevated chloride concentrations were found in three wells apiece. The median depth of sampled wells classified by concentration category varied from 12 feet for wells with background concentrations, to 131 feet for the wells that had significantly elevated chlorides. The chloride concentration in the one bedrock well that was monitored repeatedly was consistent; 13 of the 14 samples had 52 mg/L chloride, while the remaining sample was reported to have 56 mg/L chloride.

Potential Sources of Chloride in Ground Water

Within the Puget Sound area, elevated chloride concentrations occurring near the coast line are typically attributed to seawater intrusion, while large chloride concentrations found further inland have been attributed to older marine sediments (Van Denburgh and Santos, 1965) or remnant seawater. The LENS study area is outside of the range of potential seawater intrusion. However, the older bedrock within the study area is a nonmarine sedimentary unit that, during the last glacial episode, was partially submerged beneath seawater.

The chloride in ground water within the study area is derived largely from three sources: (1) chloride in precipitation that recharges the entire ground-water system; (2) land-use activities such as septic tank effluent, spreading and handling of barnyard manures, or application of chloride containing fertilizers; and (3) remnant seawater trapped within hydrogeologic units during earlier geologic times. There is no evidence that the Sumas aquifer was ever inundated by seawater; however, the aquifer is generally exposed at the surface and highly permeable, which would lead to relatively rapid flushing of any seawater that might have been present. The Everson unit was deposited in a marine environment, and older nonmarine sediments, like the Vashon outwash and bedrock unit, were inundated by seawater when the area submerged during glacial episodes as recent as 11,000 to 13,000 years ago (Easterbrook, 1973).

Ground water and hydrocarbon exploration activities within the study area have reported large concentrations of chloride in deep ground water. These large chloride concentrations generally are attributed to seawater. Bromide, a conservative water-quality constituent, is generally present in large amounts in seawater, relative to uncontaminated ground water. Consequently, in ground water that contains a substantial fraction of seawater, the concentrations of chloride and bromide will be elevated, and the ratio of bromide to chloride should remain comparable to that of seawater. However, it should be noted that bromide also can be present in ground water as the result of some land-use activities. The largest single commercial use of bromide is as the gasoline additive ethylene dibromide (Hem, 1989); however, the use of ethylene dibromide in parts of the study area as a soil fumigant is also well documented.

The concentrations of bromide and chloride in ground-water samples from the LENS study area are plotted in figure 26a, along with the present day bromide-chloride concentration in seawater and a line showing how seawater concentrations would vary upon dilution. Bromide and chloride concentrations in ground water of the LENS study area plot along the seawater dilution line, indicating that many of the samples, particularly those with large chloride concentrations, may contain substantial fractions of seawater. Two samples had large bromide concentrations but had relatively small chloride concentrations and plotted well away from the seawater dilution line. The sample from well 40N/02E-23D01 is from an area where EDB is reported to have been applied as a soil fumigant (Black and Veatch, 1986); the other well, 40N/03E-31P03, is located where residential housing is the predominant land use. The bromide present in these two samples is likely the result of land-use activities.

When plotted on a cumulative frequency diagram, bromide concentrations in ground-water samples from the study area show a sharp break between 0.04 to 0.06 mg/L (fig. 26b). Bromide concentrations below this break are interpreted to have little or no seawater component, while samples with greater than 0.06 mg/L of bromide and proportionally large chloride concentrations probably contain varying, but significant quantities of seawater. Samples from wells completed in the Everson-Vashon and bedrock units make up most of the points on the upper curve of the frequency distribution plot. Bromide concentrations between 0.04 and 0.06 mg/L correspond to chloride concentrations of 15 to 25 mg/L and indicate that ground water with chloride concentrations above this level may include a small but substantial component of seawater; ground water with 2 percent seawater would exceed the drinking water guideline for chloride. Therefore, small but significant quantities of remnant seawater trapped during the last glacial episode are believed to be the source of chloride in most ground water with concentrations larger than 25 mg/L.

Large concentrations of chloride or "salty water" have been reported in deeper ground water throughout the study area, the locations and altitudes of which are plotted on figure 27. The widespread occurrence of large chloride concentrations indicates that it is unlikely that large sustainable quantities of potable water (chloride concentrations less than 250 mg/L) will be found in or below the Everson-Vashon unit. While some samples from all hydrogeologic units had small

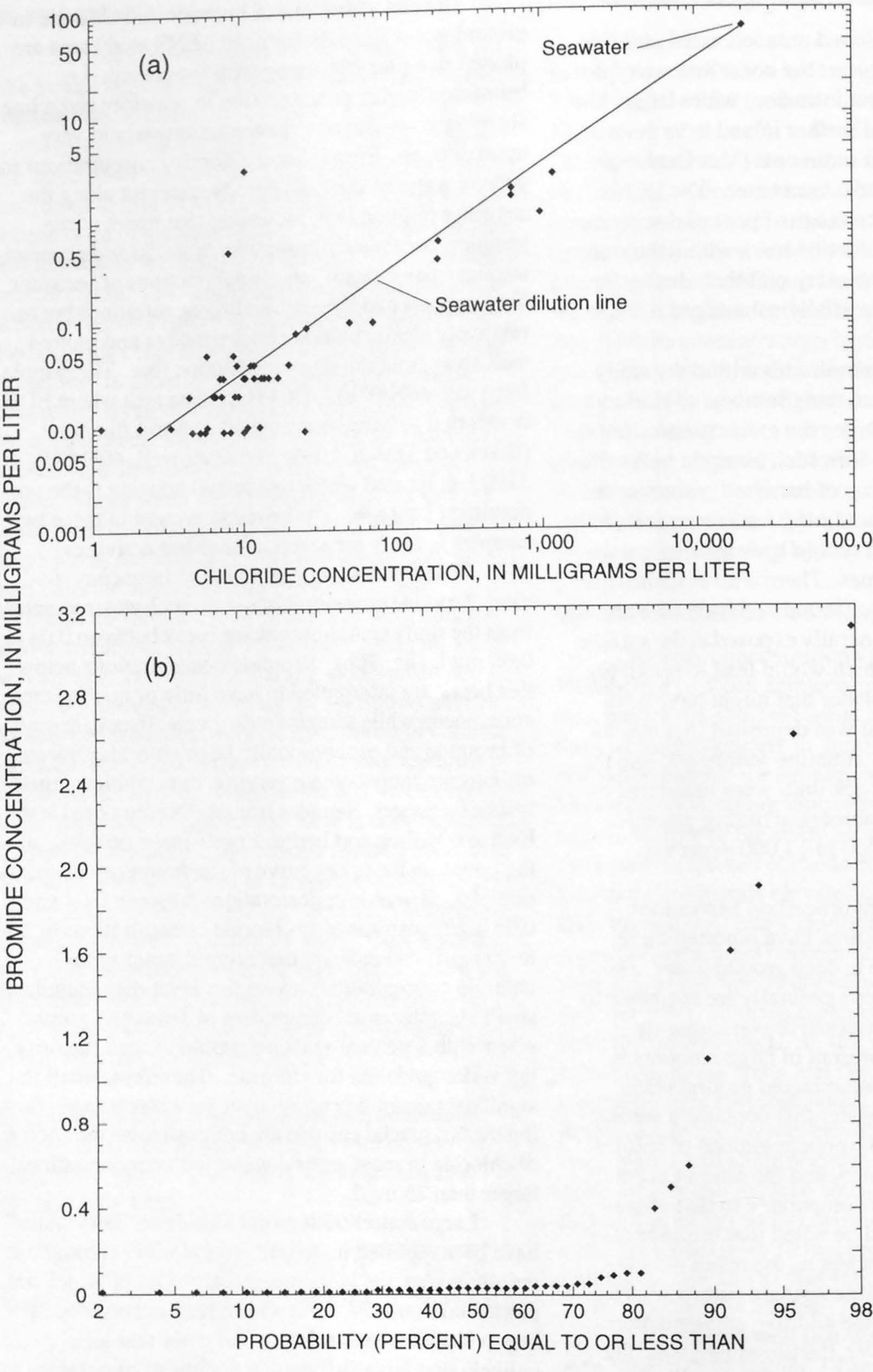
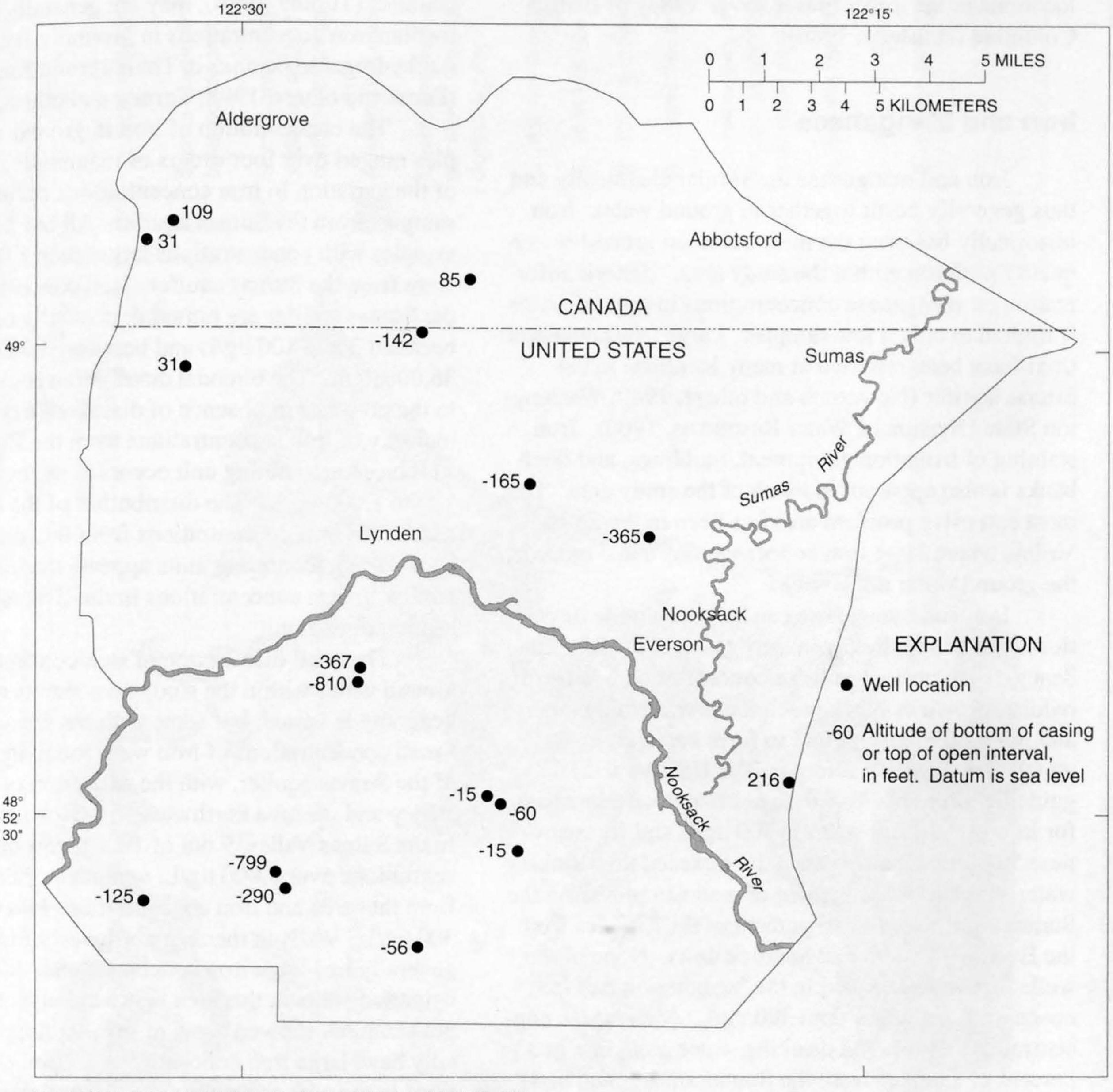


Figure 26. Plots of (a) bromide and chloride concentrations in ground water from aquifers in the Lynden-Everson-Nooksack-Sumas (LENS) study area and in seawater; and (b) normal probability of dissolved bromide concentrations in ground water from aquifers in the LENS study area.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 27. Locations of wells in the Lynden-Everson-Nooksack-Sumas (LENS) study area with concentrations of chloride greater than 250 milligrams per liter or described as "salty water" by well driller.

bromide and chloride concentrations, larger chloride concentrations characteristic of seawater were found predominantly in the stratigraphically lower hydrogeologic units. Large chloride concentrations have been reported in ground-water samples from hydrogeologic units equivalent to the Everson-Vashon in many locations in the lower Fraser River Valley of British Columbia (Halstead, 1986).

Iron and Manganese

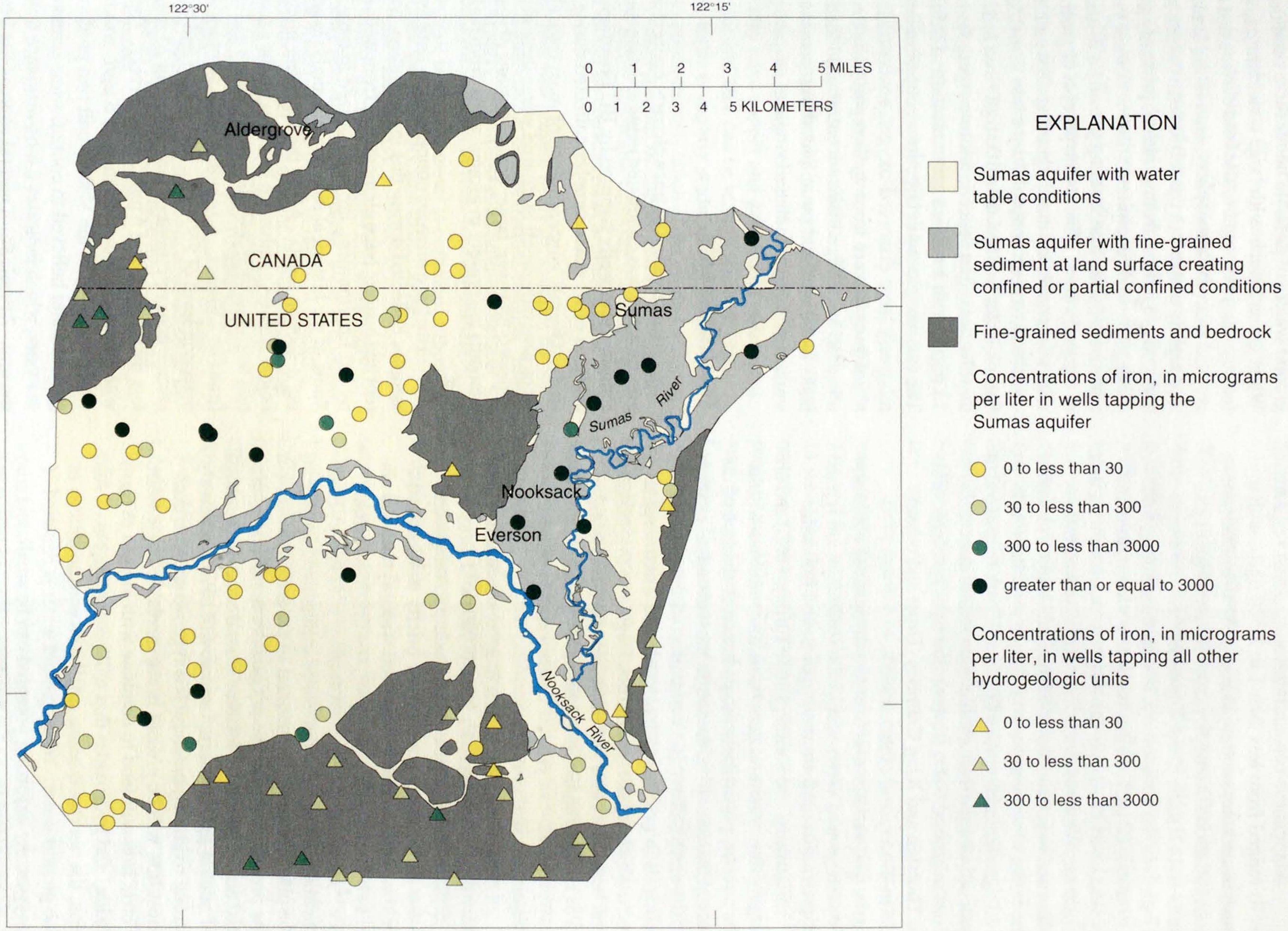
Iron and manganese are similar chemically and thus generally occur together in ground water. Iron historically has been the most common ground-water-quality problem within the study area. Historic information on manganese concentrations in ground water is limited to only a few samples. Large iron concentrations have been reported at many locations in the Sumas aquifer (Newcomb and others, 1949; Washington State Division of Water Resources, 1960). Iron staining of irrigation equipment, buildings, and ditch banks is also apparent in much of the study area. The most extensive problem area has been in the Sumas Valley, where large iron concentrations make much of the ground water nonpotable.

Iron and manganese can be undesirable impurities in water supplies, primarily because of their tendency, when present in large concentrations, to form reddish-brown or black precipitates that stain laundry and plumbing fixtures, and to form bacterial mats, which can clog well screens. The USEPA and HC guideline primarily based on aesthetic considerations for iron in drinking water is 300 μg/L and for manganese 50 μg/L. Iron concentrations exceed this drinking water standard in 22 percent of well samples from the Sumas aquifer and in 20 percent of the samples from the Everson-Vashon and bedrock units. None of the wells that were sampled in the Vashon unit had iron concentrations larger than 300 μg/L. Manganese concentrations exceed the drinking water guideline in 33 percent of samples from the Sumas aquifer and in 47 percent of samples from the Everson-Vashon unit. One of four samples from the Vashon and two of five samples from the bedrock unit exceeded the drinking water guideline.

Iron concentrations measured in 152 wells in the study area ranged from less than 3 μg/L to 36,000 μg/L, with a median concentration of 30 μg/L. Median iron concentrations in samples from the four principal hydrogeologic units were: 26 μg/L in the Sumas aquifer (118 sites), 80 μg/L in the Everson-Vashon unit (25 sites), 54 μg/L in the Vashon unit (4 sites), and 48 μg/L in the bedrock unit (5 sites). While median iron concentrations observed in ground water in the LENS area are within the range of median concentrations reported for the 12 Puget Sound counties (Turney, 1986), they are generally larger than median iron concentrations in ground water from similar hydrogeologic units in Thurston and King Counties (Drost and others, 1998; Turney and others, 1995).

The concentration of iron in ground-water samples ranged over four orders of magnitude, with most of the variation in iron concentrations occurring in samples from the Sumas aquifer. All but 1 of the 25 samples with concentrations larger than 1,000 μg/L were from the Sumas aquifer. Iron concentrations in the Sumas aquifer are bimodal, generally occurring between 3 and 100 μg/L and between 3,000 and 36,000 μg/L. The bimodal distribution is likely related to the presence or absence of dissolved oxygen. The majority of iron concentrations from the Everson-Vashon semiconfining unit occurs in the range of from 100 to 1,000 μg/L. The distribution of the limited number of iron concentrations from the Vashon and bedrock semiconfining units appears to cover ranges similar to iron concentrations in the Everson-Vashon semiconfining unit.

The areal distribution of iron concentrations in ground water within the study area shown in figure 28 generally is varied, but some patterns are apparent. Small concentrations of iron were found in most areas of the Sumas aquifer, with the exception of the Sumas Valley and the area northwest of the town of Lynden. In the Sumas Valley, 9 out of 10 samples had iron concentrations over 3,000 μg/L, and none of the samples from this area had iron concentrations less than 300 μg/L. Wells in the area northwest of Lynden also generally had large iron concentrations. Many of the irrigation wells in this area that were inventoried, but not sampled, showed signs of iron staining and reportedly have large iron concentrations. Iron concentrations in the area around the Abbotsford Airport generally were less than 30 μg/L. Little vertical variation was observed in the iron concentrations from the nested piezometers located near the airport. Iron concentrations in the Everson-Vashon unit located south of the Nooksack River were generally between 30 and 300 μg/L.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975
and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

Figure 28. Areal distribution of iron concentration in ground water in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

Manganese concentrations measured in 125 wells ranged from less than 1 to 3,500 μg/L, with a median concentration of 12 μg/L. Median manganese concentrations in samples from the hydrogeologic units were 8 μg/L in the Sumas aquifer (96 sites), 17 μg/L in the Everson-Vashon semiconfining unit (19 sites), 20 μg/L in the Vashon semiconfining unit (4 sites), and 13 μg/L in the bedrock semiconfining unit (5 sites). While median manganese concentrations observed in ground water of the LENS area are within the range of median concentrations reported for the 12 Puget Sound counties (Turney, 1986), they are also generally larger than median manganese concentrations in ground water from similar hydrogeologic units in Thurston and King Counties (Drost and others, 1998; Turney and others, 1995).

The variations of iron and manganese concentrations in ground water within the study area are typical of ground water from the Puget Sound Lowlands (Van Denberg and Santos, 1965; Turney, 1986) and are largely due to natural geochemical conditions within the aquifer, particularly the presence or absence of dissolved oxygen. Iron, the fourth most abundant element in the earth's crust, is a component of many accessory minerals in granites and volcanic and metamorphic rock, which are the type of rock fragments that make up much of the Sumas glacial sediments (Armstrong, 1981). These sediments, being geologically young and unweathered, can provide a ready source of iron for dissolution into ground water.

The chemistry of iron in ground water has been described extensively by Hem (1989) and Drever (1982), some aspects of which relate to the ground water of the study area and are briefly summarized below. Iron can exist in ground-water systems as one of two interchangeable forms, the divalent ferrous (Fe^{+2}) form or the trivalent ferric (Fe^{+3}) form. The chemical form and behavior of iron depend largely on the pH and oxidizing potential of the ground water, but the presence of dissolved organic material and microbial activity is also a factor. Ground water in the range of neutral pH, between 5 and 9, will have a relatively strong oxidizing potential if oxygen is present; thus most iron will be present in the insoluble ferric form. Ferric iron will tend to combine with oxygen to form oxides and hydroxides that will precipitate out of solution, the net result being small iron concentrations in the ground water. When ground water is depleted of oxygen, the oxidizing potential can be small, and iron may be present in the ferrous form. Ferrous iron is soluble and stable, and large ferrous iron concentrations in ground water are possible under these conditions. When ground water with large concentrations of ferrous iron is brought to the land surface and reoxygenated from the atmosphere, iron in the ferrous form will rapidly convert to the ferric form (which is insoluble) and precipitate from solution, primarily as an oxide. The iron precipitate adheres to most surfaces and results in the iron staining prevalent in many parts of the study area. Ninety-one percent of ground water with iron concentrations larger than 200 μg/L had dissolved-oxygen concentrations less than 0.5 mg/L. Samples that had less than 100 μg/L iron had dissolved-oxygen concentrations ranging from 0 to 13 mg/L, with a median concentration of 5.5 mg/L. The two samples with large iron concentrations and relatively large dissolved-oxygen concentrations of about 3 mg/L were from wells reported by the well owner to have large iron concentrations. Small air leaks in the well and pump plumbing were the likely sources of oxygen in these samples.

Trace Elements

An evaluation of trace element concentrations in ground water was conducted using existing data for 22 samples from wells sampled by BC Environment and analyses of 23 water samples collected during this study. Overall, concentrations of most trace elements were generally small in ground water from glacial deposits; however, larger concentrations of some trace elements are present in ground water from the bedrock unit.

The trace element concentration data for water samples collected during this investigation, plus current and historic trace element data from wells sampled by BC Environment, are summarized in table 13. Some of the historical data contain analyses with varying detection levels. All of the reporting limits are below USEPA's reference levels, with the exception of two historical analyses for arsenic, which had reporting limits of 250 μg/L. Excluding the 2 samples with a detection level of 250 μg/L, the median and maximum arsenic concentrations of the remaining 25 samples are less than 1 μg/L and 6 μg/L, respectively. The sample with the arsenic concentration of 6 μg/L was from a well completed in the Vashon unit that produces ground water believed to contain some remnant seawater, which indicates a long residence time within the unit. Arsenic from natural sources has been reported in ground water from older glacial deposits in east King County at median concentrations of 6 and 12 µg/L in ground water (Turney and others, 1995); therefore, it is possible that the arsenic present in this well water is also from natural sources.

Barium was one of the most common trace elements found in ground-water samples collected for this study. In 30 samples, barium concentrations ranged from 4 to 1,100 µg/L, with a median concentration of 12 µg/L. Barium is present naturally, and the larger concentrations were generally found in deep wells that pump ground water with long residence times. Samples from wells within the bedrock unit had concentrations between 43 and 1,100 µg/L, and well 40N/4E-09N03, which is in the confined part of the Sumas aquifer, had a sample with a barium concentration of 390 µg/L.

Zinc and copper were present in most samples, and the concentrations were variable. The presence of these trace elements in small concentrations is not surprising because many wells sampled were domestic wells that may have copper and galvanized pipes from which copper and zinc can be readily leached, especially if the water is slightly acidic or low in dissolved-solids concentrations, as is much of the ground water in this area. Concentrations of copper and zinc were all significantly below applicable drinking water reference levels and should be considered as artifacts of the well plumbing.

Strontium was present in all six samples for which it was analyzed at concentrations ranging from 120 to 1,700 µg/L. Strontium is a common replacement element for calcium in rock-forming minerals, and its presence in ground water is common, although concentrations are generally less than 200 µg/L (Skougstad and Horr, 1963).

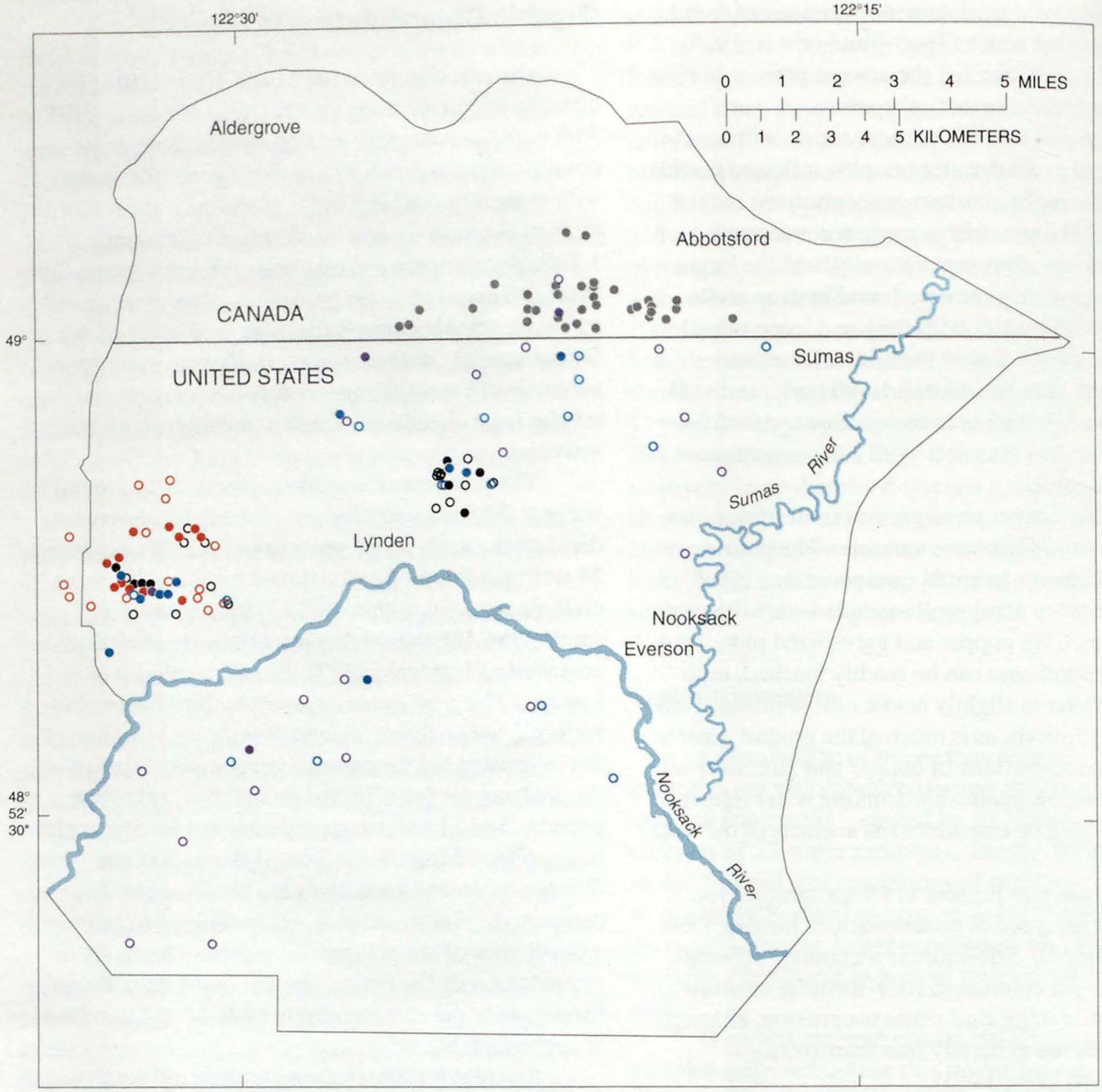
The remaining trace elements that were analyzed for were rarely present and, if present, were at concentrations that were not significant in terms of drinking water standards. Silver was present in nine samples at concentrations of from 1 to 2 µg/L. Molybdenum was detected in three samples between 10 and 40 µg/L. Cadmium, lead, and lithium were detected in two samples, and chromium and selenium were detected in only one sample. Vanadium, cobalt, and beryllium were not detected.

Organic Compounds

Organic chemicals have been detected in at least 60 wells within the study area between 1984 and 1993. Although the concentrations of most organic compounds found in ground water were generally small with respect to drinking water guidelines, concentrations of the most commonly detected compounds, 1,2-dichloropropane and ethylene dibromide, generally exceeded drinking water guidelines. The presence of synthetic organic compounds in ground water of the Sumas aquifer confirms the aquifer's vulnerability to contamination and showed clearly that parts of the aquifer have already been contaminated by land-use activities.

The presence of organic compounds in ground water of the Sumas aquifer was evaluated from existing data and the analyses of water samples collected from 24 wells for this study. Existing data generally focus on three subareas within the LENS study area: (1) south of the Abbotsford Airport; (2) the Bertrand Creek area west of Lynden; and (3) the area northeast of Lynden. These areas are apparent by the cluster of wells plotted on figure 29, which shows the location of the wells sampled for organic compounds. Most of the analyses are for a limited group of organic compounds. The 24 water samples collected for this study were collected from wells located throughout the Sumas aquifer and were analyzed for 63 organic compounds. These samples were collected to provide a broad view of the presence of organic chemicals in ground water of the Sumas aquifer, and data collected for this study are summarized in table 14 and itemized in appendix table 7.

Samples for this study were analyzed for selected compounds from 3 classes of organic chemicals, including 41 volatile organic compounds, 12 triazine or nitrogen-containing herbicides, and 10 carbamate insecticides or metabolites. The volatile organic compounds include the soil fumigant 1,2-dibromoethane, commonly referred to as ethylene dibromide or EDB, 1,2-dichloropropane, (1,2-DCP), 1,3-dichloropropene (*cis-* and *trans-*), and 1,2-dibromo-3-chloropropane.



Base and hydrology from U.S. Geological Survey digital data, 1:100,000, 1975 and Canadian Department of Energy, Mines and Resources, 1:50,000, 1977, 1980.

EXPLANATION

Location of well sampled, agency, year(s) sampled, and reference

Solid circle indicates detectable concentrations of pesticide or volatile organic compounds; open circle indicates concentrations below analytical detection limits. Locations of nondetectable samples not available for data from Environment Canada

- ● U.S. Geological Survey, 1990-1991, present investigation
- ● Washington Department of Ecology, 1988, Erickson and Norton, 1990
- ● Washington Department of Health, 1993, Stephen Hulsman, written communication
- ● Environment Canada, 1984-1990, Liebscher and others, 1992
- ● Department of Ecology, 1984, Black and Veatch, 1986

Figure 29. Locations of wells sampled for pesticides and volatile organic compounds in the Lynden-Everson-Nooksack-Sumas (LENS) study area.

Of the 24 wells for which samples were collected, organic compounds were detected in ground water from 4 wells. A total of six compounds were detected, four volatile organics, including EDB and 1,2-DCP, one carbamate insecticide, oxamyl, and one triazine herbicide, atrazine. The concentrations of these six compounds within ground water from the four wells are shown below.

Concentrations of organic compounds detected in ground water from four wells in the LENS study area

[<, less than]

Well number	Concentrations of organic compounds detected, in micrograms per liter					
	EDB 1,2-dibromoethane	1,2-DCP 1,2-dichloropropane	1,3-dichloropropane	1,2,3-trichloropropane	Oxamyl	Atrazine
39N/02E-01P02	<0.2	1.6	<0.2	<0.2	<0.5	<0.1
	<0.2	2.8	<0.2	<0.2	<0.5	<0.1
40N/02E-27B01	0.3	5.6	0.2	1.4	<0.5	<0.1
	0.3	5.6	0.2	1.2	<0.5	<0.1
092G.009.1.1.4-18-20	<0.2	<0.2	<0.2	<0.2	0.5	<0.1
41N/03E-32Q01	<0.2	<0.2	<0.2	<0.2	<0.5	0.1

Organic compounds have been detected in at least 60 wells sampled in either concurrent or previous studies (table 15 and fig. 29). Several of these studies focus on the presence of EDB in ground water of two areas near Lynden, and EDB has been detected in at least eight different wells within these areas. When Erickson and Norton (1990) sampled 27 wells within the subarea west of Lynden for the presence of more than 40 different organic compounds used in agricultural application, they detected five organic compounds, including nine occurrences of 1,2-DCP, two occurrences each of EDB and prometon, and single occurrences of carbofuran and dibromochloropropane. EC has been sampling ground water from the Sumas aquifer, referred to as the Abbotsford aquifer in British Columbia, for the presence of pesticides since 1984. Through 1990, EC found 11 different organic compounds in at least 30 different wells. The most commonly found compounds were 1,2-DCP in 27 wells, atrazine in 11 wells, dinoseb in 9 wells, and simizine and diazinon in 7 wells each (Liebscher and others, 1992). A concurrent study by Washinton State Department of Health sampled 26 wells in the LENS study area for 23 organic compounds in June 1993 and again after the winter rains. The most commonly found compounds were EDB, 1,2-DCP, atrazine and 1,2,3 trichloropropane, and in general, concentrations were slightly larger in samples collected after the winter rains (Stephen Hulsman, Washington State Department of Health, written commun., April 26, 1994).

Most of the organic compounds found (table 15) are pesticides associated with commercial agricultural activity; however, some compounds, including diazinon and prometon, are also associated with products sold for home use. Several of the detected compounds, including EDB, dinoseb, and alachlor, are not currently registered for use as pesticides in either the United States or Canada. EDB is known to remain in soils for up to 19 years following applications as a soil fumigant (Steinberg and others, 1987). The presence of these compounds, particularly EDB, in recent ground-water samples is likely due to historical use. EDB concentrations in two wells near Lynden generally decreased from April 1984 to September 1988, (Sweet-Edwards/EMCON, 1989) also suggesting an historical source.

Water-Quality Characteristics of Major Hydrogeologic Units

Although the preceding discussion has described a ground-water system with highly variable water-quality characteristics, some generalities can summarize the more typical water-quality characteristics of ground water within the study area. A more detailed discussion on factors affecting regional ground-water quality is presented by Runnells (1993).

Ground water within the study area originates largely as precipitation. Although the chemistry of rain water is dilute, common water-quality constituents found in ground water within the study area are present in smaller concentrations in precipitation samples collected within the Puget Sound region and adjoining area (National Atmospheric Deposition Program, 1991; Laird and others, 1986) (table 16). Irrigation is believed to make up a small fraction of the recharge water in the study area; however, because the source of most irrigation water is ground water or streamflow derived from ground-water base flow, the concentrations of constituents in irrigation water are larger.

Table 16. Average concentration of major ions and yearly depositional rates at three locations in western Washington
[mg/L, milligrams per liter; kg/ha, kilograms per hectare]

	Hoh Ranger Station 1980-1992		LeGrand 1984-1992		Marblemount 1984-1992	
Water-quality constituent	Concentration in mg/L	Deposition in lb/acre (kg/ha)	Concentration in mg/L	Deposition in lb/acre (kg/ha)	Concentration in mg/L	Deposition in lb/acre (kg/ha)
Calcium	0.04	1.2 (1.3)	0.04	0.4 (0.4)	0.03	0.5 (0.6)
Magnesium	0.06	1.9 (2.1)	0.04	0.3 (0.3)	0.03	0.4 (0.5)
Potassium	0.02	0.7 (0.8)	0.02	0.2 (0.2)	0.01	0.2 (0.2)
Sodium	0.55	15 (17)	0.28	2.0 (2.3)	0.14	2.4 (2.7)
Ammonia	0.01	0.4 (0.5)	0.04	0.4 (0.4)	0.03	0.5 (0.6)
Nitrate	0.08	2.3 (2.6)	0.33	2.5 (2.8)	0.30	5.3 (5.9)
Chloride	0.99	28 (32)	0.49	0.8 (0.9)	0.26	4.5 (5)
Sulfate	0.30	8.5 (9.5)	0.57	36 (4)	0.37	6.3 (7.1)

Sumas Aquifer

Ground water from the Sumas aquifer is typically calcium or magnesium bicarbonate, with varying amounts of nitrate and chloride replacing the bicarbonate as the dominant anion. This ground water is also generally dilute, slightly acidic with low alkalinity, and typically well oxygenated, although there are localized areas where dissolved oxygen is absent or present at low concentrations. Throughout the aquifer, chloride concentrations are above background levels, suggesting that effects of land-use activities are widespread. The presence of synthetic organic compounds demonstrates that this aquifer is vulnerable to contamination and has in fact been contaminated in several locations. While elevated nitrate concentrations are not found throughout the entire aquifer, they are found in nearly every area where nitrate is chemically stable. The source of nitrate in ground water of the Sumas aquifer is believed to be land-use activities. In areas where nitrate is not present, dissolved oxygen is also typically not present; in most of these areas, the concentrations of iron and manganese are typically so large that they preclude the use of the ground water for domestic or municipal supplies.

Everson-Vashon and Vashon Semiconfining Units

Ground-water quality in the Everson-Vashon and Vashon semiconfining units is highly variable without a characteristic water type. This ground water contains more dissolved matter than found in the Sumas aquifer and has a higher specific conductance, typically between 300 to 700 microSiemens per centimeter (µS/cm), with higher pH, between 7.5 and 8.5, and a larger alkalinity, 100 to 200 mg/L. Nitrate concentrations are generally low, with many in the range of background concentrations, indicating that land-use impact on the water quality in these hydrogeologic units is not widespread. Seven percent of wells in these units showed signs of water-quality degradation from land-use activities, and only one well had a nitrate concentration equal to or greater than the MCL of 10 mg/L. Dissolved-oxygen concentrations are typically low, less than or equal to 1 mg/L. Large concentrations of iron, manganese, and chloride are common at many locations in these hydrogeologic units; these large concentrations are the result of natural occurrences in the hydrogeologic deposits.

Bedrock Semiconfining Unit

The ground-water type for samples from the bedrock semiconfining unit was either sodium-bicarbonate or sodium-chloride. This ground water had a larger concentration of dissolved constituents having the highest pHs and alkalinity, and specific conductance, while also having low concentrations of dissolved oxygen. These conditions indicate ground water from this unit likely has had longer residence time within the ground-water system.

EVALUATION OF SOURCES OF NITRATE IN GROUND WATER OF THE STUDY AREA

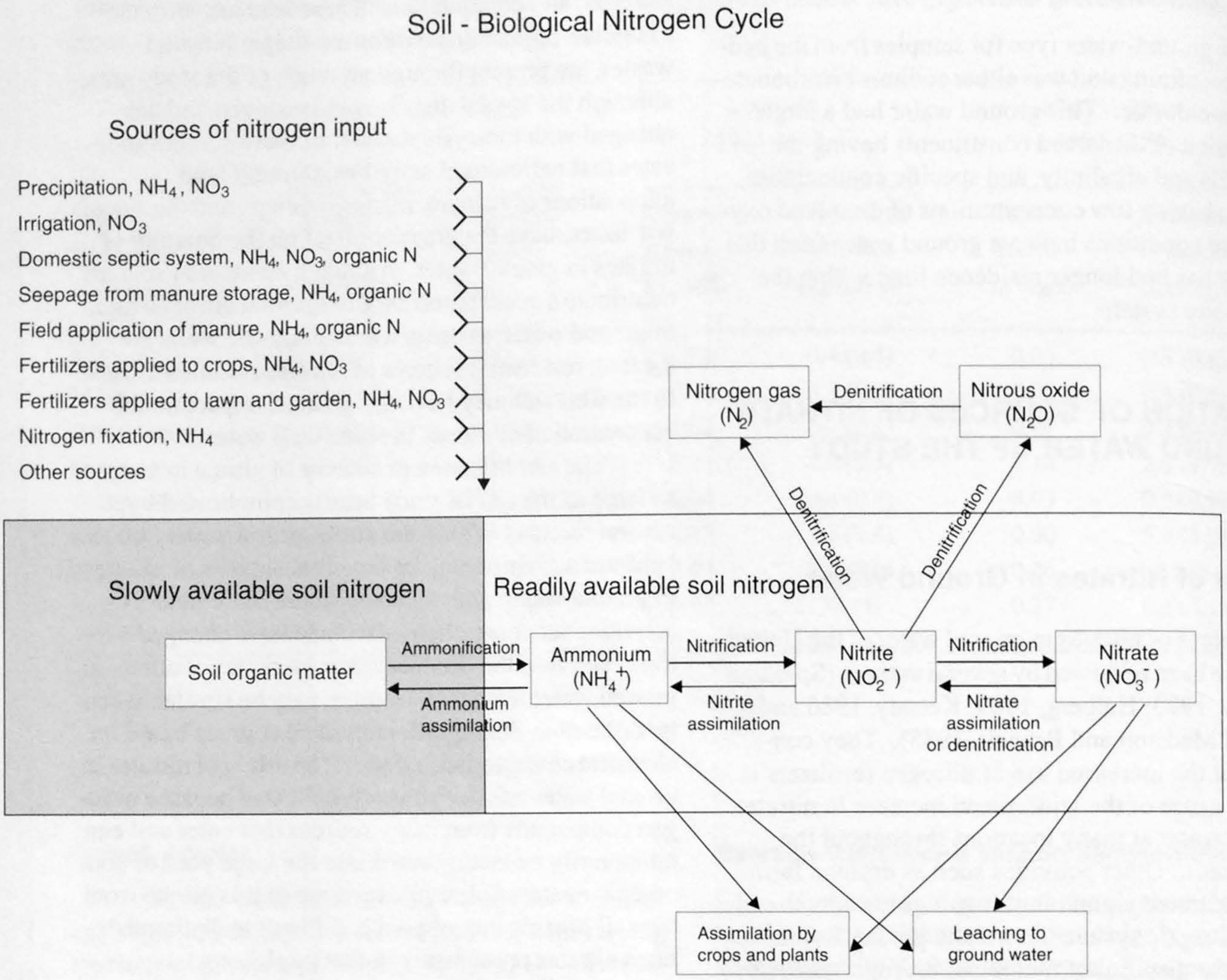
Sources of Nitrates in Ground Water

Sources of nitrates in ground water of the United States have been reviewed by several authors (Spalding and Exner, 1993; Halberg, 1989; Keeney, 1986 and 1989; and Madison and Brunett, 1985). They concluded that the increased use of nitrogen fertilizers is the major cause of the widespread increase in nitrates in ground water at many locations throughout the United States. Other activities such as dryland farming, concentrated animal farming, high-density use of residential septic systems, lawn and garden fertilization, and the disposal of municipal biosolid wastes by land application can also be major sources of nitrates in ground water in some regions. Geologic deposits and soil organic matter can be important natural sources of nitrogen in some areas. Initial deforestation and cultivation of land areas may release nitrogen from soil organic matter or peat (Keeney and Bremner, 1964; Kreitler and Jones, 1975; Boyce and others, 1976; Reinhorn and Avnimelech, 1974; and Allison, 1955), which can be transported to ground water. Also affecting more limited areas is the installation of artificial drainage systems that lower the level of ground water and allow peat and soil organic matter to be oxidized and thus making nitrates available for leaching (Avnimelech, 1971, Grootjans and others, 1986).

Potential sources of nitrate in ground water of the LENS study area include dairy and poultry manure; residential septic systems; fertilizers applied to croplands, lawns, and gardens; irrigation with ground water containing nitrates; land disposal of municipal biosolid wastes; and naturally occurring nitrogen in soils, peat material, and precipitation. These sources, with the exception of land disposal of municipal biosolid wastes, are present throughout much of the study area, although the spatial distribution is uneven and has changed with time. Evaluation of these sources indicates that agricultural activities, through land applications of manure, manure storage, and the use of fertilizers, have the greatest effect on the quantity of nitrates in ground water. Although residential sources contribute a small percentage to the total nitrogen input to ground water, in areas where domestic wells are located, residential sources of nitrates are often closest to the well and may have the greatest impact on the concentration of nitrate in some well water.

The identification of sources of nitrate in an area as large as the LENS study area is complicated by several factors. Within the study area, a variety of land-use activities may be potential sources of nitrates in ground water, and the areas where these land-use activities occur are often mixed and have changed over time. Because the chemical characteristics of nitrate in ground water from these sources may be similar, it can be difficult to distinguish individual sources based on chemical characteristics alone. The origin of nitrates in ground water can be further complicated because nitrogen compounds from many sources that enter soil can temporarily be incorporated into the large pool of soil organic matter. Subsequent release of this nitrate from the soil organic matter pool is difficult to distinguish from nitrates pre-existing in that pool.

Regardless of the source, the amount of nitrate that enters ground water is controlled by a complex set of hydrologic and biochemical processes that occur largely in the soil and unsaturated zone. Through a series of chemical transformations, most of which are mediated by bacteria, nitrogen can change chemical form in what is referred to as the soil nitrogen cycle (Stevenson, 1982). The basic features are shown schematically in figure 30, and more complete information on the soil nitrogen cycle is presented in Delwiche, 1970; Stevenson, 1982; and National Research Council, 1978. The soil nitrogen cycle largely controls the amount of nitrogen in the soil column that is available for leaching to ground water. Two hydrologic conditions that most affect the leaching of nitrate to ground water are (1) the availability of water to transport the nitrate and (2) the hydraulic conductivity of the soil and unsaturated zone materials that control the rate of movement of soil moisture and ground water.



Major Nitrogen Transformations

Ammonification: microbial decomposition of organic matter resulting in production of ammonia.

Nitrification: microbial oxidation of ammonia producing nitrite and nitrate.

Assimilation: incorporation into organic forms of nitrate, nitrite and ammonia into microorganisms and plant tissues.

Denitrification: microbial reduction of nitrate producing nitrous oxide or nitrogen gas.

Nitrogen fixation: microbial reduction of nitrogen gas to ammonia and organic nitrogen

Soil organic matter: microorganism and plant tissues containing nitrogen and forming a large nitrogen reservoir, which undergoes heterotrophic cycling.

Figure 30. Simplified diagram showing biologically mediated nitrogen transformations in soils, showing major processes of nitrogen addition and removal from soils in parts of the LENS study area.

Several environmental conditions within the study area are conducive to the migration of nitrates to ground water. Coarse-textured soils cover much of the study area, particularly overlying the Sumas aquifer, and have large hydraulic conductivities that permit relatively rapid percolation of water. Heavy precipitation from October to May generally is sufficient to permit yearly flushing of nitrogen through the unsaturated zone. Large quantities of nitrogen are continually being added to soils throughout the study area. Consequently, the presence of large nitrate concentrations in ground water of the Sumas aquifer is not unexpected. Nitrate concentrations in ground water of the Sumas aquifer are similar to concentrations in ground water in other parts of the United States where either extensive agricultural activities or numerous septic systems occur.

Estimates of Nitrate Loading From Individual Nitrate Sources

A qualitative estimate of the annual nitrate loading to ground water was made for part of the study area. The estimate was based on yearly amounts of nitrogen applied to soils of the study area and an estimate of the fraction of that nitrogen that is leached by percolating recharge. Estimates of the quantity of nitrate reaching the aquifer from different nitrogen sources within the study area are useful in determining the relative contribution from these sources. In spite of limitations described below, qualitative estimates of nitrate loading of ground water can provide organizational and conceptual models to gage the relative importance of different nitrate sources and components of the soil nitrogen cycle that affect the nitrogen content of ground water.

An extensive review by Legg and Meisinger (1982) of soil nitrogen budget studies indicated that while these studies have provided substantial insights into processes affecting soil nitrogen transformations, difficulties often occurred in quantifying the amount of nitrogen following each of the individual nitrogen pathways. In particular, difficulties often were encountered when distinguishing between losses due to denitrification or to leaching to ground water. Labelled nitrogen studies using different isotopes of nitrogen have been useful in quantifying soil nitrogen losses but are generally limited to small study plot areas. Nitrogen budgets that examine both inputs and outputs of nitrogen have been used with some success to examine the effects of nitrogen management on nitrate concentrations in ground water at the scale of individual farms (Hall and Risser, 1992) and to estimate the concentration of nitrate in ground water beneath croplands (Barry and others, 1993). Nitrogen budget studies on the scale of entire watersheds have been hampered by uncertainties and limited to qualitative estimates (Kohl and others, 1978, and Viets, 1978).

Because land-use data was limited for the study area in British Columbia, nitrate loading was estimated only for the Whatcom County portion of the study area. The sources of nitrate considered were limited to processes and or activities that are present throughout much of the study area and did not include potential small-scale point sources. Estimates were made of the annual loading of nitrogen from the following nitrate sources: atmospheric deposition, irrigation water, inorganic fertilizers applied to croplands, septic tanks, lawn fertilizers, seepage from manure storage lagoons, land application of manures, nitrogen from legumes, and mineralization of soil organic matter. Data used to estimate the nitrogen loading to the soil zones were physical features of the study area such as the number of acres of corn, the number of cows, and the number of people, which are tabulated in table 17. After the processes that affect each source were considered, an estimate was made of the percentage of nitrate nitrogen from that source that would be leached from the soil zone to ground water (table 18). The estimates of nitrate entering the ground water, which are subject to greater uncertainty than the estimate of nitrogen loading to the soil system, are based largely on the extensive literature of nitrogen in agricultural soils, much of which is reviewed by Stevenson (1982).

Data used in developing the estimates of nitrate loading were acquired through public records, discussions with agricultural extension agents working within the area, information from other nitrate studies, and data collected for this study. In many cases, individual data values of nitrate-loading parameters, such as concentration of nitrogen in rainwater, septic tank effluent, or manure slurry, covered a wide range of values. An attempt was made to select a value that would best represent the parameter for the entire area, or a weighted average was used. The information, procedures, and rationale used in developing the nitrate loading estimate are outlined in table 17 and described in subsequent text.

Table 17. Estimates of annual amounts of nitrogen applied and deposited in the Whatcom County portion of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada
[mg/L, milligrams per liter; N, nitrogen]

Areas

Total area of study area	144,000 acres
Subarea of study area within Whatcom County	110,000 acres
Sumas aquifer area within Whatcom County	86,000 acres
Commercially farmed area	70,000 acres
Non-commercially farmed areas	10,000 acres
Irrigated area (50 percent of commercially farmed area)	35,000 acres
Dairy farm land base in Whatcom County subarea	37,000 acres
Urban/suburban area	9,000 acres
Undeveloped/wood and brushland	21,000 acres
Cultivated residential lawns and garden	1,625 acres

Precipitation and applied irrigation water

Precipitation	41 inches over 110,000 acres	376,000 acre-feet
Less 15 percent for direct runoff		56,000 acre-feet
Precipitation that infiltrates soil		320,000 acre-feet
Irrigation	12 inches over 35,000 acres	35,000 acre-feet

Nitrogen in wet deposition

The concentration of nitrogen in precipitation is the sum of the precipitation-weighted mean of nitrate and ammonia. Estimate is the average of samples collected for National Atmospheric Deposition Program 1989-1990 at Hoh Ranger Station, Le Grand, and Marblemont, Washington.

(320,000 acre-feet) (0.26 mg/L NO_3 as N) = 226,000 pounds NO_3 as N

Nitrogen in dry deposition

Regional	(110,000 acres) (1.0 pounds N per acre) = 110,000 pounds NO_3 as N
Dairy landbase	(37,000 acres) (15 pounds-N per acre) = 550,000 pounds NO_3 as N

Nitrogen in irrigation water

The concentration of nitrogen in irrigation water is the median concentration in ground water from the Sumas aquifer.

(35,000 acre-feet) (3.8 mg/L NO_3 as N) = 362,000 pounds NO_3 as N

Nitrogen mineralized from soil organic matter

(70,000 farmed acres) (195 pounds NO_3 as N per acre) = 13,600,000 pounds NO_3 as N
5 percent of total leached to ground water = 680,000 pounds NO_3 as N

Table 17. Estimates of annual amounts of nitrogen applied and deposited in the Whatcom County portion of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Application of inorganic nitrogen fertilizer

Crop	Acreage	Percent of cropland fertilized each year	Fertilizer application rate (pounds per acre)	Total nitrogen applied (pounds)
Peas	2,500	20	25	12,500
Carrots	50	100	100	5,000
Potatoes (seed)	1,000	100	70	70,000
Blueberries (mineral soil)	100	100	100	10,000
Blueberries (peat soil)	50	100	50	2,500
Raspberries	2,500	100	80	200,000
Sweet corn	300	100	125	37,500
Pasture/Hay (nondairy)	10,000	25	45	112,000
Pasture (dairy)	30,800	55	60	1,020,000
Silage/feed corn (dairy)	6,200	100	90	558,000
				2,030,000

Residential fertilizer

Population 26,000 Residential cultivated acreage estimate to be 1,625 acres to which 200 pounds per acre is applied.

(1,625 acres) (200 pounds per acre) = 325,000 pounds N

Nitrogen from septic system

Population in unincorporated portions of the LENS study area utilizing domestic septic system.

1990 Census 17,600

Per capita nitrogen loading rate to soil, 10 pounds N per person, per year.

(17,600 persons) (10 pounds N per person) = 176,000 pounds N

Thirty-two percent of nitrogen retained in soil as organic nitrogen or volatilized as ammonia.

Per capita nitrate loading rate to ground water, 6.8 pounds per year.

(6.8 pounds NO_3 as N) (17,600 persons) = 120,000 pounds NO_3 as N

Nitrogen from dairy manure storage and handling applied to field

Daily nitrogen production of manure from average dairy herd.

	Nitrogen produced (pounds per day)
150 lactating cows	94.5
30 dry cows	15.1
20 immature	8.7
	118.3

Table 17. Estimates of annual amounts of nitrogen applied and deposited in the Whatcom County portion of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

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Nitrogen from dairy manure storage and handling applied to field--continued

(308 farms) (118 pounds N per day) (365 days) = 13,300,000 pounds N per year

70 percent of annual production of nitrogen in manures is lost to volatilization and denitrification during handling and application to field. Available nitrogen to field is 0.3 of total produced.

(13,300,000 pounds) (0.3) = 3,990,000 pounds N

Nitrogen from poultry manure storage, handling, and application to fields

$$(900{,}000\ \text{broilers})\ (50\ \text{days})\ \frac{1.1\ \text{pounds N}}{1{,}000\ \text{broiler} \bullet \text{days}} = 50{,}000\ \text{pounds N}$$

50 percent of annual production of nitrogen is lost to volatalization and denitrification during handling, storage, and application to field. Available nitrogen is 0.5 of total produced.

(50,000 pounds) (0.5) = 25,000 pounds N

Nitrogen from seepage of ammonia from dairy manure lagoon

85 percent of dairies estimated to have earthen lagoons
Average surface area of lagoon 30,000 square feet (2,790 square meters)
Seepage rate ≈ 1 millimeter per day ≈ 0.365 meter per year
Ammonia concentration 7 pounds per 1,000 gallons ≈ 840 milligrams per liter
= (2,790 square meters) (0.365 meter per year) (1,000 liters per cubic meter) (840 milligrams per liter) ($2.2\text{x}10^{-6}$ pounds per milligram) = 1,880 pounds per year-dairy)

(1,880 pounds per year-dairy) (308 dairies x 0.85) = 492,000 pounds N per year

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Table 18. Estimate of annual amount of nitrogen loading to soils and nitrate entering the ground-water system in the Whatcom County portion of the study area

[--, not applicable; <, less than]

Natural processor land-use activity	Nitrogen deposited, applied, or released to soils (pounds)	Fraction of nitrogen transported to ground-water system	Nitrogen entering ground-water system as nitrate (pounds)	Percentage of total, including mineral-ization of soil organic matter	Percentage of total, excluding mineral-ization of soil organic matter
		Natural sources			
Precipitation, wet	226,000	0.50	113,000	3.2	3.9
Precipitation, dry	110,000	0.40	44,000	1.2	1.5
Legumes, (alder)	--	--	75,000	2.1	2.6
		Residential sources			
Septic tank effluent	176,000	0.68	120,000	3.4	4.2
Fertilizers, lawns, and gardens	325,000	0.25	81,200	2.3	2.8
		Agricultural sources			
Redeposition of nitrogen volatilized from manure	550,000	0.40	220,000	6.2	7.6
Irrigation	362,000	0.25	90,500	2.5	3.1
Mineralization of soil organic matter	13,600,000	0.05	680,000	19	--
Inorganic nitrogen fertilizers	2,030,000	0.25	508,000	14	18
Manure storage (lagoon leakage)	492,000	0.85	418,000	12	14
Manure applied to					
cropland, dairy	3,990,000	0.30	1,200,000	34	42
cropland, poultry	25,000	0.30	7,500	<1	<1
Legumes, (peas)	--	--	10,000	<1	<1
TOTAL	21,900,000		3,570,000		

A check of the loading estimates was calculated from the combined nitrate-loading estimate and the estimate of ground-water recharge. The resulting concentration was compared to median nitrate concentrations observed in samples of ground water. The equation used to compute the average nitrate concentration in shallow ground water is expressed as

$$\text{Concentration of nitrate} = \frac{\text{Annual load of nitrogen}}{\text{Annual volume of recharge}}$$

This relation between concentrations, nitrogen load, and recharge assumes that (1) the flux of water into the ground-water system is entirely recharge, as opposed to inflow from adjacent or deeper ground water; (2) the annual average concentrations of nitrate in ground water do not change with time (which implies that the system is in steady state); and (3) all of the nitrogen leached to ground water is in the form of nitrate or is converted to nitrate. These assumptions are largely true for the study area, although none are completely valid; nevertheless, the computations are still useful to check the loading values.

Nitrogen from Atmospheric Deposition

Nitrogen inputs to soils from atmospheric deposition are ubiquitous across the study area. Atmospheric deposition includes precipitation, or wet deposition, and dry deposition, which includes particulate fallout and sorption of gaseous materials. Nitrogen loading from precipitation was calculated from an area-weighted volume of precipitation and the precipitation-weighted mean concentration of nitrate and ammonia in precipitation. The concentration of nitrate and ammonia used for these calculations was the average concentration from the three precipitation chemistry stations located in western Washington that are operated by the National Atmospheric Deposition Program. Average concentration data and depositional rates for these stations (table 16) show that nitrogen (ammonia plus nitrate) concentrations range from 0.1 to 0.4 mg/L, with an average of 0.26 mg/L, and that annual depositional rates at the rain gage locations vary from 2.7 to 5.8 pounds per acre.

The average precipitation for the part of the study area located in Whatcom County is about 41 inches per year, which generates a volume of 376,000 acre-feet of precipitation. Using an average nitrogen concentration of 0.26 mg/L in precipitation, the gross yearly wet precipitation nitrogen input to the land surface is 266,000 pounds. Direct surface runoff from glacial outwash in the Puget Sound region is small (Dinicola, 1990 and R. Dinicola, U.S. Geological Survey, oral commun., 1994), and is estimated to remove 15 percent of the total precipitation, resulting in the deposition of 226,000 pounds of nitrogen or 2.05 pounds of nitrogen per acre. Some of the nitrogen in the precipitation that enters soil will be taken up by plants; however, in the study area, most of the nitrogen deposition associated with precipitation will occur during the winter and early spring when the plants are less active and likely to assimilate less nitrogen. Accordingly, half of the nitrogen in regional precipitation entering the soil profile is estimated to move through it and eventually reach the ground-water system. Thus about 42 percent of the total nitrogen in precipitation falling on the study area is estimated to reach ground water.

Dry deposition, which includes particulate fallout, submicron particle deposition to vegetation, water, or bare ground, and gaseous adsorption and absorption, has been shown to make a measurable contribution to nitrogen deposition in some areas (Dasch and Cadle, 1985). Because there are many avenues of dry deposition, it is difficult to measure. Sisterson (1990) estimates that regionally for western Washington, dry deposition is about 46 percent of wet deposition or about 1 pound per acre, which results in 110,000 pounds for the subarea. However, additional dry deposition is expected in areas where substantial amounts of manures are present due to volatilization of a large fraction of the ammonia in manures (Ivens and others, 1988). Sanderson and LaValle (1979) found that bulk deposition (combined wet and dry) at six farm sites in southern Ontario was 30 to 37 pounds of nitrogen per acre. In the dairy and agricultural region of southern Ontario, Barry and others (1993) estimated that dry deposition of nitrogen ranged from 5.9 to 15 pounds per acre and made up 44 to 55 percent of the bulk atmospheric nitrogen across the region. Similar rates were found by Goulding (1990) on adjacent farm lands in southern England. Barry and others (1993) suggest that nitrogen deposition on farms where large volumes of manure are susceptible to volatilization should include from 13 to 19 pounds of nitrogen per acre for dry redeposition of nitrogen resulting from manure volatilization.

Within the study area in Whatcom County, there were 308 dairies that annually generate approximately 13 million pounds of nitrogen in manure.

Approximately 70 percent of the nitrogen in manure is estimated to volatilize to the atmosphere; the portion that is redeposited is not well known. Based on the research of Sanderson and LaValle (1979) and of Goulding (1990), a minimum estimate of the redeposition of manure-volatilized nitrogen would be 15 pounds per acre, which would apply to the 37,000 acres of the dairy land base. This would result in the deposition of 550,000 pounds of nitrogen or about 6 percent of the estimated volatilized nitrogen from manure. Manure spreading is reported year round but is more frequent during the growing season. Thus a large percentage, on the order of from 30 to 50 percent, of the nitrogen in dry deposition resulting from manure volatilization may be assimilated by plants and less likely to reach the ground-water system. As such, only 40 percent of the manure based redeposition of nitrogen is estimated to reach the ground-water system as nitrate.

Nitrogen from Irrigation Water

Nitrogen loading from irrigation water was calculated from the concentration of nitrate in ground water used for irrigation and from the estimated volume of irrigation water applied to croplands. Roughly half of the area farmed in the study area, or about 35,000 acres, is irrigated. Whatcom County Conservation District's survey of on-farm irrigation indicated that 35 percent of the irrigators in the study area reported that they apply about 7 to 9 inches of irrigation water, whereas previous estimates of irrigation water use had been 18 inches (Bierlink, 1994). The recommended irrigation water use for the study area for pasture, corn, and raspberries is 13, 10, and 11 inches of irrigation water, respectively. Based on these values, a value of 12 inches of irrigation water was used to estimate nitrate loading. Because most of the irrigation water is taken from ground water, the concentration of nitrate in irrigation water used in the loading estimate is the median concentration observed in water samples collected from the Sumas aquifer, which is 3.8 mg/L. Irrigators using stream water rather than ground water are expected to have similar nitrate concentrations because much of the streamflow during irrigation season (July-September) is derived largely from discharging ground water. The resulting annual loading from irrigation water is estimated to be about 10 pounds per acre in the irrigated parts of the subarea, totaling 362,000 pounds (table 17). The percentage of nitrogen in irrigation water eventually reaching ground water is considered similar to the percentage for fertilizers, which is estimated to be 25 percent, or in other words, a loading of 90,400 pounds to the ground-water system.

Nitrogen from Septic Tanks

Because septic tanks are used for the disposal of domestic waste water throughout most of the unincorporated parts of the study area, nitrogen loading from septic tanks was calculated by estimating the number of people in the unincorporated part of the study area in Whatcom County and also estimating the per capita load of nitrate transported to ground water from septic tank effluent. The population in the unincorporated part of the study area within Whatcom County was based on the 1990 census and estimated to be 17,600 individuals (Diane Harper, Whatcom County Planning Department, written commun., 1992). The per capita total nitrogen load rate of septic systems to the soils was calculated from estimates of the per capita volume and the total nitrogen content of septic tank effluent. The estimate of the daily volume of waste water leaving septic tanks ranged from 40 to 80 gallons per person (Cantor and Knox, 1986; Porter, 1980; and Reddy and Dunn, 1984). For this study, the per capita volume used was 60 gallons per day. Measurement of the total nitrogen concentration of septic tank effluent ranged from 30 to 90 mg/L (Dudley and Stephenson, 1973; Porter, 1980; Alhajjar and others, 1987; and Cantor and Knox, 1986). The concentration of total nitrogen in septic tank effluent used in this study was 55 mg/L, which resulted in a yearly septic loading rate of 10 pounds per person or 176,000 pounds of nitrogen per year deposited to soils within the study subarea.

Ammonia generally makes up more than 75 percent of the total nitrogen in septic tank effluent, and the remaining 25 percent is largely organic nitrogen. Organic nitrogen generally is retained in the soil absorption field, while the ammonia fraction is converted to nitrate and percolates to the ground-water system. Walker and others (1973a, b) and Dudley and Stephenson (1973) concluded that in coarse-textured, well-aerated soils such as those that overlie much of Sumas aquifer, complete conversion of ammonia to nitrate is expected in the immediate vicinity of the soil absorption trench, resulting in little or no denitrification or absorption of ammonia. The result is that most of the ammonia nitrogen in the septic tank effluent is destined to enter the ground-water system and that dilution is the primary mechanism for reducing nitrate concentrations. In the estimates used for this study, 10 percent of the ammonia fraction is allowed to undergo denitrification. Thus, the septic loading to ground water was derived from septic tank loading estimates to soil (listed in table 18) being reduced by 25 percent to account for the retention of organic nitrogen in the soil zone and the remaining fraction is further reduced by 10 percent to account for possible denitrification that may occur in areas underlain with a greater amount of fine sediment. The resulting estimate of nitrate that reaches ground water was 120,000 pounds or about 68 percent of the 176,000 pounds of nitrogen added to soils. This equates to an annual per capita loading rate of 6.8 pounds.

Nitrogen from Inorganic Fertilizers

Inorganic nitrogen fertilizers are applied to many crops grown in the study area. Estimates of applied nitrogen fertilizer were made following discussions with personnel from the Natural Resources Conservation Service and the Washington State University Extension Service to determine crop acreage and fertilizer application rates. These data for 78 percent of the farmed area within the Whatcom County subarea of the study area are listed in table 17. A total of 2,030,000 pounds are estimated to be applied annually. These values may be considered low since no estimate of fertilizer application was made for about 20 percent of the farmed areas. In addition, no fertilizer application estimates were made for nurseries or golf courses, several of which are present in the area.

Studies that addressed the leaching of applied nitrogen fertilizers to ground water were included in a review by Legg and Meisinger (1982) of research examining soil nitrogen budgets. The results showed that the percentage of nitrogen applied that leached to ground water was quite variable, ranging from 0 to 102 percent. However, the typical range was from 25 to 50 percent. Factors that appear to govern the leaching of nitrogen fertilizers to ground water are the amount of inorganic nitrogen present in the soil zone, the amount of water percolating through the soil zone, the soil texture, the depth of the root zone, and the depth to the water table. In the loading estimates in table 18, 25 percent of the total amount of inorganic fertilizer applied to fertilized cropland was assumed to leach to ground water, which results in an average of 16.9 pounds per acre over 30,140 acres or 508,000 pounds for the area (table 18).

Residential fertilizer use was based on a population of 26,000 maintaining 1,625 acres of cultivated lawns and gardens. Morton and others (1988) report that home owner and commercial domestic lawn fertilizer application rates range from 110 to 260 pounds per acre. Many of the lawns in the area are well maintained. Based on this information, an application rate of 200 pounds per acre was used to estimate residential fertilizer applications. Twenty-five percent of the nitrogen applied was estimated to be transported to ground water.

Nitrogen from Livestock Manures

Large quantities of manure are generated by the numerous dairy and poultry farms located within the study area. Most manure is disposed of by spreading on cropland, where some of its nutrient value can be utilized by crops. Nitrogen in manure, which is largely in either the ammonia or the organic nitrogen form, can be lost by either volatilization, denitrification, or leaching. Ammonia is easily volatilized if not incorporated into soils and generally must be mineralized before it can be either used by plants or leached from the soil. Volatilization of ammonia is largely a physical process and will occur at a greater rate in warm or windy conditions. Mineralization of organic nitrogen to nitrate is a microbial process and is reduced but not stopped during the cooler winter periods. Nitrates, which will continue to be mineralized during this period when they cannot be utilized by crops, are subject to an increased probability of leaching. Since it is common practice for most lagoons to be emptied before winter to provide storage during the winter rainy period, there may be a large potential for any nitrates mineralized during the winter from the manure spread on fields to be leached to below the root system before crops can utilize the nutrients.

Estimates of nitrogen applied to soils of the study area from dairy manure are based on the average herd made up of 150 lactating, 30 nonlactating, and 20 immature cows and the number of dairies (308) (table 17; John Gillies, Natural Resources Conservation Service, written commun., 1993). On the basis of average nutrient production figures (U.S. Department of Agriculture, Soil Conservation Service, 1992a) a herd of this makeup will generate manure with roughly 118 pounds of nitrogen per day. Thus for the area which has 308 dairy herds, the yearly quantity of dairy-manure nitrogen produced will be 13,300,000 pounds of nitrogen. This manure was spread on approximately

37,000 acres of cropland. Nitrogen in dairy manure operations such as used in Whatcom County can be reduced by 50 to 80 percent due to volatilization and denitrification (U.S. Department of Agriculture, Soil Conservation Service, 1992a). For this study a 70 percent reduction was used; seventy percent of the 13,300,000 pounds of dairy-produced nitrogen is estimated to be lost by these processes, leaving 3,990,000 pounds (table 17) of nitrogen incorporated into the soils of croplands. While the manure is applied to cropland for its nutrient value, it is primarily applied as a method of disposal. Compared to fertilizer applied for the same purpose, more of the nitrogen in manure may be lost to leaching because the manure is applied at times when it cannot be fully utilized by crops. This is particularly true of the manure that is spread in the fall. Consequently, it is estimated that 30 percent of the nitrogen in manure applied to croplands or 1,200,000 pounds (table 18) reaches the ground-water system.

Poultry farming in Whatcom County has declined over the last 10 to 20 years. In 1990, 1.8 million broilers were raised in Whatcom County, according to the Washington Agricultural Statistics Service (1991). About half of these chickens were raised within the study area. Broilers have a life span of about 7 weeks (50 days) and produce 1.1 pounds of nitrogen per day per 1,000 broilers (U.S. Department of Agriculture, Soil Conservation Service, 1992a). The yearly quantity of nitrogen produced is about 50,000 pounds; however, volatilization and denitrification probably reduce this number by about 50 percent, leaving about 25,000 pounds added to the soil (table 17) of which 30 percent is leached to ground water for a final loading of 7,500 pounds (table 18). The percentage reaching the ground-water system is estimated to be similar to that for dairy manures.

Earthen-lined manure storage basins, commonly referred to as manure lagoons, are used in about 85 percent of the dairies in the study area to temporarily store animal waste and waste water before they are applied to cropland. Seepage from dairy lagoons has been shown to result in elevated ground-water concentrations of chloride and nitrate in studies in Wisconsin (Bickford, 1983 and Cates, 1983) and near two lagoons located in the study area (Erickson, 1991 and 1992). Lagoons are used throughout the year and are partially emptied in the fall to provide maximum storage during the rainy winter season when the potential for surface runoff is greatest. Past studies have reported that settled solids and a microbial mat form a physical barrier along the interface of the manure slurry and the walls and bottom of the lagoon structure (Roswell and others, 1985; Miller and others, 1985; Davis and others, 1973). Estimates of seepage rates from these and other studies (Reese and Loudon, 1983; DeTar, 1979; Barrington and Jutras, 1983; and Phillips and Culley, 1985) indicate that seepage rates vary from less than 0.1 mm/day (considered to be effectively sealed) up to 5 mm/day. However, even at optimum sealing, seepage rates on the order of 0.1 mm/day can be expected (Barrington and Jutras, 1983) and can result in significant quantities of nitrogen being transported to the subsurface (Culley and Phillips, 1989, and Dalen and others, 1983).

For this study, the seepage rate for lagoons is estimated to be 1 millimeter or 0.04 inches per day. The average surface area of earthen dairy lagoons in the study area is 30,000 square feet. Ammonia is the predominant form of nitrogen in lagoon seepage. Ammonia concentrations in samples collected from 25 lagoons are about 840 mg/L or about 7 pounds per 1,000 gallons (John Gillies, Natural Resources Conservation Service, written commun., 1993). The resulting estimate of nitrogen applied to soils from lagoon seepage is 492,000 pounds per year (table 17). Denitrification in the unsaturated zone is estimated to reduce this amount by 15 percent, resulting in 418,000 pounds of nitrogen entering the ground-water system (table 18).

Nitrogen from Legumes

Peas, clover, and red alder are leguminous plants common in the study area. Peas are a minor crop, covering about 2,000 acres; clover and red alder are prominent components of the extensive pasture and woodlands. Red alder stands cover about 15,000 acres. Symbiotic bacteria associated with these legumes are capable of nitrogen fixation and can contribute nitrogen to the reservoir of soil organic matter. The quantity of nitrogen added to soils varies with plant species; red alder may contribute about 50 pounds of nitrogen per acre per year, whereas clover can add in excess of 250 pounds per acre per year. However, legumes generally do not produce more nitrogen than can be used by the host plant, and most of the nitrogen is retained in the plant until the plant is significantly disturbed, such as during harvesting or deforestation activities, at which time significant quantities of nitrogen may be released (Bormann and Likens, 1981). Nitrate concentrations ranging from 0 to 40 mg/L have been found in soil solutions beneath stands of red alder (Compton and Cole, 1993; Van Miegroet and Cole, 1985), suggesting that some leaching of symbiotically fixed nitrogen to ground water does occur beneath red alder stands.

The extent to which legumes are a potential source of nitrates in ground water in the study area is not well known. Pasture lands within the study area are routinely cropped, and most of the nitrogen fixed by legumes is believed to be tied up in the harvested biomass. If the 17,000 acres of peas and alder were to contribute nitrate to the ground-water system on the order of 5 pounds per acre, the total contribution from legumes would be 85,000 pounds, which would make up roughly 2.5 percent of the total nitrate load to the ground water.

Nitrogen from Soil Organic Matter

Soil organic matter, composed of material from plants and bacteria, is a large reservoir of nitrogen within soils. Many soils in the study area are reported to contain from 3 to 9 percent soil organic matter (table 1) in the upper 6 to 12 inches of the soil profile (U.S. Department of Agriculture, 1992b). Nitrogen typically makes up about 5 percent of soil organic matter; the nitrogen content of a soil to a depth of 40 inches can range from 6,600 to 200,000 pounds per acre (Severson and Shacklette, 1988). The amount of nitrogen that would be present in the upper foot of a soil with 5 percent organic matter and bulk density of 1.1 would be about 7,400 pounds per acre.

Nitrogen released from soil organic matter via mineralization forms nitrate, which is mobile and susceptible to leaching to ground water. Conversely, nitrate can be immobilized by being incorporated into plant and bacterial biomass. Agricultural cultivation results in large initial releases of soil nitrogen through mineralization (Reinhorn and Avnimelech, 1974; Keeney and Bremner, 1964). However, following a period of initial nitrogen loss, soil nitrogen level stabilizes within 20 to 80 years, more rapidly in soils amended with manure (Stevenson, 1982). Since much of the study area was initially cultivated following deforestation in the late 1800's (Mangum and Hurst, 1907) and manure is widely applied to much of the cultivated soils, it is probable that the annual rate of mineralization of soil nitrogen in Whatcom County soil is now fairly constant.

The amount of nitrogen mineralized and immobilized is difficult to determine. The process of mineralization of soil organic nitrogen is mediated by bacteria, and the rate depends in large part on soil temperature and moisture. Mineralization is believed to be a year-round process in areas such as the Puget Sound that do not experience severe cold winters, although larger amounts of nitrogen are mineralized during warm moist summer periods. Estimates of yearly mineralization within the lower Puget Sound area and near the Fraser-Whatcom Lowland range from 150 to 240 pounds per acre per year (Dan Sullivan, Washington State University Extension, written commun., 1993, and Grant Kowalenko, Agriculture Canada, written commun., 1992). Most of the nitrate mineralized during the growing season is incorporated into plant material and soil biomass; however, if nitrate is mineralized during the winter period when plant growth is at a minimum and soil water percolation at a maximum, it may be transported to ground water.

A simplifying assumption proposed by Fried and others (1976) contends that under conditions of continued agricultural practices the rates of mineralization and immobilization should become equal and thus there would be no net contribution from soil organic matter to nitrate leached to ground water. This rationale was adopted by Barry and others (1993) in their estimate of ground-water nitrate concentrations based on whole farm nitrogen budget.

For this study, two cases have been evaluated--one in which the net mineralization is zero, as assumed by Barry and others (1993), where none of the soil nitrogen mineralized is leached to ground water and the other in which net mineralization reaching the ground-water system is 5 percent of the total nitrogen mineralized. The mineralization rate of 195 pounds of nitrogen per acre was used to estimate nitrogen loading to soils for the 70,000 acres of commercially farmed area resulting in a total of 13,600,000 pounds of nitrate-nitrogen released within the soil (table 17). Five percent of the mineralized nitrogen is presumed to be leached to ground water as 680,000 pounds of nitrate (table 18).

Estimate of Nitrogen Loading to Ground Water

Estimates of nitrate inputs to ground water from different sources are summarized in table 18. Within the subarea the total annual nitrate loading to ground water is 3.7 million pounds of nitrogen. The weighted recharge estimate for the subarea is 20.1 inches per year over 110,000 acres, which is equivalent to

184,000 acre-feet. The resulting nitrate concentration computed from the mass of nitrate entering ground water and volume of ground-water recharge is 7.4 mg/L nitrate as N; if there is no net input from the mineralization of soil organic matter, the calculated concentration is reduced to 6.0 mg/L.

The computed loading concentrations are five to six times larger than median nitrate concentrations (1.2 mg/L) observed in all samples collected in the subarea for which nitrogen loading estimates were compiled; however, those samples include many from wells that were screened in parts of the aquifer distant from recently recharged ground water or from areas where nitrate was unstable because of the surrounding geochemical environment. A more reasonable comparison might be to limit measured nitrate concentrations to shallow (depth less than 50 feet) wells in the Sumas aquifer for which the ground water was oxygenated (dissolved-oxygen concentration greater than or equal to 1 mg/L). Nitrate concentration in this group of wells covers the range from the detection limit to 43 mg/L, and has a median concentration of 6.7 mg/L. While this concentration agrees closely with the calculated concentration based on the nitrogen loading from the soil, it should not be considered confirmation of the exactness of those estimates, only that they are reasonable approximations.

These data suggest that about 18 percent of the flux of nitrogen in the soil zone ends up in the ground-water system. However, this estimate of loading is sensitive to the large component of mineralization of soil nitrogen that was estimated from uncertain data. When the mineralization figures are not included in the budget, then the nitrogen flux in the soil is 8.3 million pounds, with 2.9 million pounds leached to ground water. The estimate of nitrogen from soil mineralization makes up over 60 percent of the input to soils, but the flux of nitrogen that reaches ground water was limited to 5 percent. Clearly, additional data regarding soil mineralization rates in the Fraser-Whatcom Lowlands would improve estimates of soil nitrogen budgets in this area.

The estimates from individual sources have also been grouped into the following general categories in table 18--natural, residential, and agricultural sources. The total of natural and residential ground-water inputs of nitrates accounts for about 12 to 15 percent of the total nitrogen input. Agricultural activities, which are the predominant land use in about 75 percent of the study area and include the largest individual potential nitrate sources, account for about 85 to 88 percent of the total estimated nitrogen input to ground water. In the estimate made here, the largest single source of nitrate loading to ground water is the application of dairy manure to pastures and croplands, which is estimated to account for 34 percent of the total nitrate input; if nitrate inputs from mineralization are assumed to be zero, dairy manure applied to croplands accounts for 42 percent of the total nitrate load to ground water. Seepage from manure lagoons is estimated to contribute another 12 to 14 percent of the total nitrogen input, or about one-third of the loading resulting from land application of manure. Together, estimates of land applications and storage of dairy manures account for over half of the total input of nitrogen to ground water. Redeposition of volatilized nitrogen to land areas accounts for 6 to 8 percent, which is larger than either natural or residential sources. Residential activities, which account for about 6 percent of the land-use area, account for about 7 percent of the nitrate loading. Natural sources, which account for about 7 percent of the total nitrate loading, are largely distributed throughout the area because the largest natural nitrate source is precipitation. The area of alder woodlands, which accounts for about 13 percent of the study area, is estimated to account for only about 2 percent of the total nitrate loading.

In terms of the regional picture, the majority of nitrates found in the Sumas aquifer comes from agricultural activities. Although residential sources make up a much smaller percentage of the total nitrogen input to the subarea than agricultural sources, in areas where domestic wells are located, residential sources of nitrogen are often the closest potential nitrogen source and may have the greatest influence on nitrogen in domestic well water.

A general comparison between loading rates for residential and agricultural land use using the agricultural data and some assumed values for residential space utilization can be made. Yearly nitrate loading for the 70,000 acres of commercial agricultural areas was 3,130,000 pounds or about 45 pounds per acre. Residential loading from septic systems and lawn or garden fertilization was estimated to range from 14 to 34 pounds per acre. Even though agricultural sources contribute nearly 10 times the quantity of nitrates to ground water than do residential sources, on a per-acre basis, the rates of nitrates entering ground water from agricultural sources are typically only 1.5 to 3 times greater than residential sources.

Nitrate-Related Water-Quality Characteristics

Six water-quality constituents associated with nitrates in ground water were examined to try to determine the source of the nitrate present in ground water in the LENS study area. The six nitrate-related water-quality constituents were the ratio of stable nitrogen isotopes ($\delta^{15}N$), and the concentrations of chloride, boron, MBAS, dissolved organic carbon, and dissolved oxygen. Because of the multiplicity of nitrate sources and the nonconservative nature of some of the water-quality constituents, this approach was not able to identify the individual sources of nitrates in ground water. However, these data were able to eliminate natural nitrate as a significant source of nitrate in the Sumas aquifer and confirmed that there are a variety of sources contributing to the presence of nitrates in ground water. In addition, the constituents MBAS and boron, which are commonly associated with domestic septage sources, were found to have the largest concentrations in ground water associated with dairy manure storage and application to fields and thus could not be used to discriminate between livestock and domestic septage sources of nitrogen.

These six parameters were selected because their concentrations have been shown to vary under differing hydrologic settings where nitrates were present and, with the exception of $\delta^{15}N$, they are often included in water-quality data collections. The expected range of concentrations for these constituents was based on previous ground-water investigations in the glacial aquifers in the Puget Sound and published investigations of nitrates in ground water, and are shown in table 19, along with median concentrations measured in samples from shallow wells completed in the Sumas aquifer. Concentrations of these constituents are shown in table 20.

The ratios of stable nitrogen isotopes (referred to as $\delta^{15}N$ and reported in units of per mil using the symbol ‰, see the Appendix section for additional details) have been used in many studies to determine the source of nitrates in ground water (Kreitler and Jones, 1975; Kreitler and others, 1978; Gromly and Spalding, 1979; Spalding and others, 1982; Flipse and Bonner, 1985; and Heaton, 1986). The $\delta^{15}N$ in nitrogen-containing materials varies primarily because of isotopic fractionation in which certain chemical and biological reactions have proportionally accumulated more of the lighter isotope in the reaction product. As such, the $\delta^{15}N$ of inorganic nitrogen fertilizer typically ranges from -2 to +2‰, whereas nitrogen in plant material is typically in the range of +4 to +10‰, and animal matter ranges from +5 to +20‰.

While a number of successful studies have used $\delta^{15}N$ in identifying nitrate sources in ground water, the method is not without limitations. Bacteria-mediated transformations of nitrogen occurring in the soil, unsaturated zone, and within the aquifer leads to additional fractionation, which can significantly alter the original characteristic $\delta^{15}N$ of the source material. Flipse and Bonner (1985) found that nitrate in shallow ground water beneath a fertilized golf course has an isotopic ratio of $\delta^{15}N = 6.5$‰, which is in the range of soil organic matter. Inorganic fertilizer, which was considered to be the source of the nitrates in the ground water, had a ratio of $\delta^{15}N = -5.9$‰ indicating that there was substantial fractionation between the nitrate source and its appearance in ground water. Berndt (1990) also noted that further complications arise in situations where the nitrate in ground water is from multiple sources, which can result in a ground water $\delta^{15}N$ value intermediate between that of the source materials.

For this study, $\delta^{15}N$ was determined at 22 sites, and additional data were available for 10 of the 12 piezometers located near Abbotsford Airport (table 20). The $\delta^{15}N$ data ranged from + 1.5 to 19‰. The $\delta^{15}N$ of the measured samples covers the entire range of potential nitrogen sources and likely includes the effects of mixing from multiple sources. However, samples in which $\delta^{15}N$ was less than 4.0‰ may largely originate from inorganic fertilizers. Two samples of ground water were collected adjacent to two dairy manure lagoons where seepage from the lagoons had been shown to impact ground water; the $\delta^{15}N$ of these samples was 7.2 and 7.4‰. The $\delta^{15}N$ in poultry manure from near the Abbotsford Airport was 7.9 to 8.6‰, while $\delta^{15}N$ of inorganic fertilizer was less than 0.0‰ (Leonard Wassenaar, Environment Canada, written commun., 1994).

While it was not possible to sort out the combined effects of denitrification and mixing, it is likely that samples in which the $\delta^{15}N$ is less than 4.0‰ are largely from fertilizer sources. Five of the 32 $\delta^{15}N$ values shown in table 20 are less than 4.0‰; four of these were from pasture settings, and the other from berry or row crop areas. As shown in table 17, inorganic fertilizers are typically applied in these areas. Samples with $\delta^{15}N$ larger than 4.0‰ could be explained as either the result of mixed source material or the effects of denitrification. Evidence that denitrification is occurring is indicated by the increasing $\delta^{15}N$

Table 19. Characteristic ranges of selected water-quality constituents in ground waters containing nitrate from different sources and concentrations observed in wells in the Sumas aquifer

[Number in parentheses indicates number of wells sampled; >, greater than; < less than]

Nitrate source	Nitrogen isotopes $\delta^{15}N\text{-}NO_3^-$ (per mil)	Chloride concentration (mg/L)	Dissolved oxygen (mg/L)	Boron concentration (mg/L)	Methylene Blue Active Substances (mg/L)	Organic carbon (mg/L)
Characteristic range of water-quality constituents						
Inorganic fertilizer	-2-+2	>5	>1	<50	<0.02	<0.7
Natural peat	+2-+8	<5	<1	<50	<0.02	>0.7
Septic tanks	+5--15	>5	variable	>50	>0.02	>0.7
Barnyard manures	+5-+18	>5	variable	<50	<0.02	>0.7
Median and range of concentration of water-quality constituents from Sumas aquifer wells with differing surrounding land use (number of data points in parenthesis)						
Undeveloped	8.5 (4) 3.1-9.7	7.0 (6) 3.0-9.2	2.5 (5) 0.0-8.5	<10 (6) <10-20	<0.02 (5) <0.02-<0.02	0.7 (5) 0.2-1.4
Residential	8.0 (1)	11 (7) 4.4-14	6.8 (7) 2.2-9.0	20 (7) <10-120	<0.02 (7) <0.02-0.06	0.6 (6) 0.3-1.2
Manure lagoon	7.3 (2) 7.2-7.4	54 (4) 44-76	0.1 (4) 0.0-0.2	50 (4) 20-80	0.05 (4) <0.02-0.09	26 (4) 21-39
Pasture and grasslands	6.8 (9) 2.0-12	10 (27) 2.7-40	3.2 (26) 0.0-9.0	15 (24) <10-120	<0.02 (27) <0.02-0.04	0.9 (27) 0.3-5.1
Berry and rowcrops	7.3 (15) 1.5-19	9 (18) 2.3-17	7.6 (18) 0.2-9.2	<10 (16) <10-40	<0.02 (12) <0.02-<0.02	0.7 (5) 0.6-1.1

Table 20. Concentration of selected water-quality constituents and land use information

[P, pasture; B, berries; U, undeveloped woodlands or brushlands; L, manure lagoon; M, mixed; S, Sumas aquifer; E, Everson-Vashon hydrogeologic unit; V, Vashon hydrogeologic unit; PC, partially or completely confined condition; --, no data; <, less than]

Hydro-geo-logic unit	Local identifier	Well depth (feet)	$\delta^{15}N$ isotope ratio, per mil	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic dissolved (mg/L as C)	Methylene blue active substance (mg/L)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as FE)	Oxygen, dissolved (mg/L)	Alkalinity, lab (mg/L as $CACO_3$)	Chloride, dissolved (mg/L as CL)	Predominate land use at well site
E	092G.008.1.2.2-01	39	--	1.0	<0.0	<0.01	--	<0.02	10	5	0.3	97	--	U
E	39N/03E-01C01	49	--	0.37	<0.2	0.01	0.8	<0.02	20	54	1.2	46	54	U
E	39N/03E-36P01	73	--	<0.05	0.4	0.29	1.2	<0.02	130	100	0.1	162	11	U
S	39N/04E-20H01	41		0.7	<0.2	<0.01	1.4	<0.02	10	73	2.7	42	--	U
S	40N/03E-16K01	33	7.60	3.70	0.50	<0.010	--	<0.02	<10	50	2.5	23	7.4	U
S	40N/03E-19A01	40	--	<0.05	<0.0	0.10	--	<0.02	<10	13,000	0.0	29	10	U
S	40N/03E-31L01	50	3.10	7.20	0.50	<0.010	--	--	<10	8	8.5	29	--	U
S(PC)	41N/04E-33H04	89	9.40	5.60	0.40	0.020	--	<0.02	<10	<3	0.8	85	--	U
S(PC)	41N/04E-33N04	72	9.70	15.0	0.70	0.030	--	<0.02	20	4	--	70	10	U
S	39N/02E-13B01	52	--	0.13	0.2	0.06	0.7	<0.02	20	5,300	5.7	79	12	R
S	39N/02E-27F04	36	--	2.6	<0.2	0.01	0.6	<0.02	20	30	2.2	98	9.2	R
S	39N/02E-27Q04	22	--	5.8	0.6	<0.01	1.2	<0.02	120	4	3.2	36	13	R
S	40N/02E-33B02	36	8.00	1.80	<0.0	<0.010	0.3	<0.02	20	12	9.4	27	14	R
S	40N/03E-31P03	36	--	19	0.8	<0.01	0.6	0.06	<10	58	7.7	35	11	R
S	40N/03E-32L01	50	--	12	0.6	<0.01	0.6	<0.02	20	20	9.0	24	4.4	R/P
S	40N/03E-32Q01	25	--	2.8	<0.2	0.01	--	<0.02	10	<10	6.8	24	5.2	R/U
S	40N/02E-13J05	16	--	<0.05	50	46	25 D	<0.02	40	19,000	--	--	76 D	L
S	40N/02E-13J06	18	--	--	--	70 E	21 D	<0.02	60	3,700	--	--	44 D	L
S	40N/02E-13J07	16	7.20	<0.050	63	63.0	26	0.09	80	1,600	0.2	451	49	L
S	40N/03E-05L01	18	7.40	<0.050	35	34.0	39	0.09	20	36,000	0.2	559	58	L
S	092G.008.2.2.3-03	60	--	4.2	--	<0.01	0.5	<0.02	<10	7	4.3	56	5.8	P
E	092G.009.2.2.3-11	60	--	0.058	--	1.4	0.5	<0.02	30	34,000	0.0	17	210	P
E	092G.008.1.4.2-15	342	--	<0.05	--	0.56	2.2	<0.02	140	340	0.2	146	620	P
S(PC)	092G.008.2.4.1-18	116	5.60	8.10	--	0.010	0.6	<0.02	10	5	1.7	79	2.7	P
S(PC)	092G.009.1.1.4-17	60	11.80	16.0	--	<0.010	0.3	<0.02	10	46	5.8	50	8.5	P/B
S	39N/02E-11B01	26	--	3.3	--	0.01	0.8	<0.02	30	14	2.2	14	8.9	P
S	39N/02E-16H03	19	--	0.83	--	<0.01	1.4	<0.02	20	20	2.1	56	11	P
S	39N/02E-24C02	22	--	2.6	--	0.02	0.7	<0.02	<10	960	3.2	24	14	P
E	39N/02E-24R02	41	--	5.2	--	<0.01	0.7	<0.02	120	40	4.7	55	17	P
S	39N/02E-26H01	14	--	12	--	0.01	1.0	<0.02	10	<3	7.1	74	10	P
S	39N/04E-16Q02	33	--	3.6	--	<0.01	--	0.03	30	30	4.1	54	5.6	P,B
S	39N/04E-22L01	30	12.50	15	--	<0.01	2.6	<0.02	--	7	0.2	269	40	P
S	40N/02E-10N02	38	--	1.4	2.7	2.2	5.1	0.04	20	8,200	0.0	187	43	P

Table 20. Concentration of selected water-quality constituents and land use information--Continued

Hydro-geo-logic unit	Local identifier	Well depth (feet)	$\delta^{15}N$ isotope ratio, per mil	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic dissolved (mg/L as C)	Methylene blue active substance (mg/L)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as FE)	Oxygen, dissolved (mg/L)	Alkalinity, lab (mg/L as $CACO_3$)	Chloride, dissolved (mg/L as CL)	Predominate land use at well site
S	40N/02E-13J04	16	3.30	<0.050	0.30	0.220	1.1	<0.02	<10	24,000	0.0	34	6.0	P
S	40N/02E-26A03	33	--	13	--	<0.01	0.8	<0.02	20	28	6.8	48	11	P/B
S	40N/03E-03R02	73	--	12	--	0.02	0.4	<0.02	10	6	--	49	11	P
S	40N/03E-05M05	12	6.80	18	--	0.08	2.2	<0.02	20	58	7.0	26	15	P
S	40N/05E-06K01	7	--	<0.05	0.2	0.04	2.5	<0.02	<10	5	0.1	144	11	P
S	40N/03E-07A02	21	4.50	11.0	--	<0.010	1.9	<0.02	<10	15	4.0	18	4.9	P
S	40N/03E-09G01	65	--	<0.05	--	0.03	0.4	<0.02	--	3,800	0.0	77	--	P
S	40N/03E-10K01	30	6.50	7.60	--	0.020	0.9	<0.02	<10	27	3.4	59	12	P
S	40N/03E-11E04	44	--	1.5	--	<0.01	0.4	<0.02	20	17	6.9	37	7.9	P
S	40N/03E-25F01	29	--	1.2	--	0.41	3.6	0.03	--	--	--	--	--	P
S	40N/04E-30G01	37	--	<0.05	--	0.59	2.9	<0.02	20	5,100	--	192	28	P
S	40N/04E-31R02	34	--	0.14	--	0.19	1.8	0.02	30	5,300	2.6	167	19	P
S	41N/03E-35L01	25	10.40	21.0	--	0.180	0.5	0.02	20	46	9.0	21	9.4	P/B
S	41N/04E-32Q01	26	8.90	16.0	--	<0.010	0.3	<0.02	<10	9	7.8	53	9.1	P
S	41N/03E-34M01	20	--	20	--	<0.01	0.5	<0.02	30	32	5.4	18	9.5	P
S	092G.009.1.1.1-06-20	20	5.5K	17.K	<0.01K	<0.01K	--	<0.02	30K	<10K	8.8	8.7K	10.K	B
S	092G.009.1.1.1-06-35	35	7.3K	17.K	<0.01K	<0.01K	--	--	20K	<10K	8.5	14.K	8.4K	B
S	092G.009.1.1.1-07-55	55	14.K	6.6K	0.03K	0.03K	--	<0.02	<10K	<10K	6.4	53.K	4.5K	B
S	092G.009.1.1.1-07-75	75	--	2.3K	0.04K	0.03K	--	<0.02	<10K	<10K	0.2	71.K	4.1K	B
S	092G.009.1.1.2-11-25	25	5.4K	17.K	0.03K	0.01K	--	<0.02	20K	10K	9.0	9.8K	10.K	B
S	092G.009.1.1.2-11-35	35	7.3K	21.K	0.03K	0.02K	--	<0.02	30K	<10K	9.2	13.K	12.K	B
S	092G.009.1.1.2-12-55	55	13.K	4.9K	<0.02K	0.02K	--	<0.02	<10K	10K	5.0	51.K	4.6K	B
S	092G.009.1.1.2-12-75	75	--	0.6K	0.06K	0.02K	--	<0.02	<10K	<10K	0.8	65.K	7.9K	B
S	092G.009.1.1.4-18-25	25	14.2K	4.6K	<0.01K	<0.01K	--	--	<10K	20K	8.1	18.K	3.5K	B
S	092G.009.1.1.4-18-35	35	15.3K	3.5K	<0.01K	<0.01K	--	--	<10K	<10K	7.6	24.K	2.3K	B
S	092G.009.1.1.4-19-55	55	12.5K	5.5K	<0.01K	<0.01K	--	--	<10K	<10K	6.0	53.K	2.6K	B
S	092G.009.1.1.4-19-75	75	19.1K	5.2K	<0.01K	<0.01K	--	--	<10K	<10K	1.0	66.K	5.4K	B
S	40N/02E-14P02	39	4.20	16.0	1.4	<0.010	0.6	<0.02	40	30	8.8	21	8.9	B
S	40N/02E-21R01	23	--	20	0.8	<0.01	1.0	0.04	<10	26	7.7	9.2	17	B
S	40N/02E-23D01	30	6.90	4.00	0.40	<0.010	1.1	<0.02	<10	26	3.4	30	9.0	B
S	40N/02E-27N02	36	1.50	9.00	0.60	<0.010	0.6	<0.02	--	50	8.4	8	9.4	B
S	40N/03E-03A02	26	7.20	9.90	0.70	0.010	--	--	--	10	9.8	--	2.2	B/P

Table 20. Concentration of selected water-quality constituents and land use information--Continued

Hydro-geo-logic unit	Local identifier	Well depth (feet)	$\delta^{15}N$ isotope ratio, per mil	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic dissolved (mg/L as C)	Methylene blue active substance (mg/L)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as FE)	Oxygen, dissolved (mg/L)	Alkalinity, lab (mg/L as $CACO_3$)	Chloride, dissolved (mg/L as CL)	Predominate land use at well site
S	41N/03E-36J01	37	3.50	7.30	0.40	0.010	0.7	<0.02	20	13	6.9	15	4.0	B/P
S	092G.009.2.1.2-19	145	--	9.1	<0.0	<0.01	--	<0.02	20	<3	4.5	50	5.8	M
S	092G.009.2.1.4-26	265	--	6.9	<0.0	<0.01	--	<0.02	<10	12	2.8	94	8.1	M
E	092G.009.1.2.4-31	163	--	9.9	<0.0	<0.01	0.3	0.03	<10	22	6.4	47	10	M
S	39N/02E-22D02	48	--	<0.05	<0.2	0.03	0.5	<0.02	30	87	1.2	81	27	M
S	39N/02E-28J03	24	--	1.4	<0.2	<0.01	0.8	<0.02	10	10	12.9	44	26	M
V	39N/04E-16H01	50	--	5.0	0.4	<0.01	1.7	<0.02	30	11	6.8	69	7.8	M
S	39N/03E-07K02	24	--	19	--	<0.01	0.6	0.04	40	10	6.6	27	13	P
S	39N/03E-08C02	27	2.00	<0.100	--	<0.010	0.5	--	--	11	--	26	7.2	P
S	39N/03E-34N01	20	--	<0.05	--	0.02	2.7	<0.02	<10	93	<1	116	3.2	P/U

D Data from concurrent sample collected by Washington Department of Ecology, concentration or total whole water values (Denis Erickson, Washington Department of Ecology, written commun.).

K Data from Kohut and others, 1987.

found in the deeper piezometers which also have larger alkalinity concentrations and smaller dissolved-oxygen concentrations.

Concentrations of chloride above background concentrations of 4 mg/L indicate influences of land-use activities. Elevated concentrations of chloride in shallow ground water larger than background concentrations have been attributed to disposal of domestic sewage (Dudley and Stephenson, 1973); livestock manures (Erickson, 1991); and the applications of fertilizers to crops (Saffigna and Keeney, 1977). Except, for instance, where evapoconcentrations might occur, natural soil and peat deposits are not expected to increase the concentration of chloride in shallow ground water. As described in an earlier section of this report, the range of background concentrations of chloride in the Sumas aquifer is from 0.5 to 4 mg/L. Sixty-four of the 69 chloride analyses in table 20 are larger than 4.0 mg/L; of the five chloride concentrations less than 4.0 mg/L, only one was from an area in which the immediate area surrounding the well is undeveloped. Because nearly all the samples had elevated chloride concentrations, peat and decaying plant matter are not considered a significant source of nitrates in ground water. In addition, the areas where large nitrate concentrations were widespread were generally upgradient of the peat deposits shown in plate 2.

Boron and MBAS are present in household waste water as residues of detergents and have been used to identify septage-contaminated ground water (Le Blanc, 1984; Drost and others 1998). These two constituents were included to distinguish septic sources from livestock manures. However, the largest concentrations of these constituents were found routinely in ground water associated with either dairy lagoons, or pastures on which dairy manures were applied. Consequently, it was not possible to distinguish septic sources from livestock manures based on the concentrations of boron or MBAS in the Sumas aquifer. It is suspected that cleaning agents used to clean dairy facilities are the source for these constituents that were found associated with dairy manure storage and field applications.

Concentrations of dissolved organic carbon (DOC) may be large in ground-water systems associated with organic materials or synthetic organic compounds from various land-use activities. Organic carbon is found in animal waste as well as drainage from peat lands (Urban and others, 1989) and as such, concentrations larger than typically found in ground water (0.7 mg/L) might indicate the presence of recharge from these sources. With the exception of the four ground-water samples collected adjacent to a manure lagoon, concentrations of organic carbon were typically small, less than 2.0 mg/L. The concentrations of dissolved organic carbon in the piezometers adjacent to the manure lagoons ranged from 21-39 mg/L, while total organic carbon (TOC) from those same wells reported by Garland and Erickson (1994) was roughly an order of magnitude larger, and the TOC of a manure sample from the lagoon itself was on the order of 1,000-2,000 mg/L. Roughly half of the samples from the pasture and row crop settings contained DOC concentrations larger than 1 mg/L while only 20 percent of the samples from the undeveloped and residential areas were larger than 1.0 mg/L. Much of the DOC present in ground water of the Sumas aquifer is probably derived from livestock manures or recalcitrant soil organic matter; however, the range of concentrations is not distinct enough to be a reliable indicator of the source of nitrates in ground water.

The concentration of dissolved oxygen varied and covered similar ranges in all land-use areas, except adjacent to manure lagoons. Outside of such site-specific areas as septic tank drain fields or areas adjacent to manure lagoons, the concentration of dissolved oxygen in the shallow unconfined portions of the Sumas aquifer appears to be more a function of depth than specific land-use activity or nitrate source material. As described in a previous section on dissolved oxygen, concentrations tended to decrease with depth and length of ground-water flow path. This nonconservative property of dissolved-oxygen concentrations in ground water limits its use as an indicator of source material or area.

While the evaluation of nitrate-related water-quality constituents was not able to identify the source of nitrates in many instances, it was able to identify samples in which nitrates were largely from fertilizers. This evaluation also provided support for the estimates of nitrate loading to ground water which indicated that most of the nitrates in ground water were the result of agricultural activity. The large range in the nitrogen isotope data indicated that there were multiple nitrate sources in the LENS study area and that fertilizer nitrogen could account for about 15 percent of the samples tested, the remaining samples being a mixture of fertilizers and either animal sources or decaying plant material. Because nearly all samples contained elevated chloride concentrations, decaying plant matter was not considered a significant source. With respect to animal sources, a distinction between livestock and domestic sources was ambiguous because both boron and MBAS were present in large concentrations near both source areas. However, the DOC data did provide some indication that livestock manures were more significant than domestic sources.

SUMMARY

Ground water is an important source of domestic, municipal, and irrigation supply in a 225-square-mile agricultural area of the Fraser-Whatcom Lowland. Population growth and the increasing concerns about ground-water quality have increased the demand for additional sources of high-quality ground water, leading to the need for a regional appraisal of the ground-water system. During a U.S. Geological Survey study conducted from 1990 to 1992 in cooperation with the Whatcom County Planning Department, water-level, lithologic, and water-quality data were collected from 608 wells and were used with existing information to describe the ground-water system and its water quality.

The objectives of this study were to describe the regional hydrogeology and ground-water quality of the shallow lowland aquifers in parts of Whatcom County and British Columbia that surround the communities of Lynden, Everson, Nooksack, and Sumas and to evaluate potential sources of existing water-quality problems found in ground water in this area. Specific study objectives were to (1) define, to the extent that available data allow, the general lithology of glacial sediments within the study area; (2) delineate and characterize hydrogeologic units; (3) characterize the water quality of individual hydrogeologic units; (4) delineate the extent of existing water-quality problems; and (5) evaluate potential sources of nitrates found in ground water in the study area.

The area is underlain largely by glacial sediments that overlie Tertiary bedrock and range in thickness from 0 to 1,500 feet. Lithologic information from geologic maps and well logs was used to construct 10 lithologic sections, which were used to identify four principal hydrogeologic units: a coarse-grained glacial unit that overlies two predominantly fine-grained glacial units, which in turn overlie the bedrock unit. These units are referred to as the Sumas aquifer, the Everson-Vashon semiconfining unit, the Vashon semiconfining unit, and the bedrock semiconfining unit. Seventy-five percent of wells within the study area are finished in the Sumas aquifer, which is highly permeable and capable of supplying large quantities of water; the other units are much less permeable and supply smaller quantities of water. Estimates of the horizontal ground-water velocity in the Sumas aquifer are on the order of 2.5 feet per day. The Sumas aquifer allows more precipitation to recharge the ground-water system than do the less permeable units, but it is also much more susceptible to contamination from land-use activities. Ground water can be obtained in varying quantities and quality from all of the hydrogeologic units. Even so, all of these units are connected hydraulically, and all units contain zones of low permeability, which can create local confined conditions. A major distinction between units is the extent of the low-permeability zones. Within the Sumas aquifer, low-permeability zones are minor occurrences within an otherwise permeable unit; however, in the Everson-Vashon unit low-permeability zones make up nearly all of the unit, with only minor occurrences of more permeable zones.

The Sumas aquifer is the most productive and extensively used aquifer in the study area. This unit is composed largely of sands and gravels that were deposited as a glacial outwash plain. These outwash deposits also include local deposits of peat, silt and clay, and ice-contact tills, all of which are significantly less permeable than the sands and gravels and which affect local hydrologic conditions within the aquifer. The most extensive occurrence of the lower-permeability deposits is in the Sumas River floodplain, where the sands and gravels have been overlain by a thin layer of lacustrine and alluvial silts, creating local confined conditions. The upland area northwest of Sumas is covered by ice-contact deposits that also create confined conditions; however, this area is much less extensive than the Sumas River floodplain. Because much of the Sumas aquifer is composed of permeable sands and gravels that are exposed at land surface, the aquifer is susceptible to contamination from surface activities.

The other three hydrogeologic units are composed of much less permeable material and are not used as extensively as the Sumas aquifer as a ground-water source. The less permeable nature of these units provides them some protection from contamination from surface activities, resulting in fewer human-caused water-quality problems. However, the lower permeability has also reduced the degree of flushing of remnant seawater from these units so that salty water is found in parts of these units that have not been completely flushed by recharging precipitation.

The principal source of ground water is recharge from precipitation. In the study area precipitation ranges from 32 to 60 inches per year, and estimates of recharge range from 11 to 45 inches per year. The general movement of ground water is from recharge areas in the uplands to discharge areas at lower altitudes. The major discharge areas are along streams, though the extensive areas of artificially drained farmlands are also significant discharge areas. Seasonal water-level fluctuations in all hydrogeologic units range from 2 to 8 feet per year; averages in the Sumas unit are about 5 feet per year. Long-term water levels appear to be unchanged in the last forty years.

Ground-water samples from more than 368 wells were analyzed for concentrations of nitrate and chloride. Nitrate concentrations ranged from less than 0.1 to 43 milligrams per liter as nitrogen. Median concentrations of nitrate were 3.8 milligrams per liter in the Sumas aquifer and less than 0.1 milligram per liter in each of the other hydrogeologic units. Locally within the Sumas aquifer, anaerobic conditions precluded the presence of nitrogen as nitrate; in these areas, any nitrogen present was in the ammonia form. Nitrite and nitrous oxide were found in some ground water that was anaerobic, and indicating that denitrification is occurring in some parts of the aquifer; thus, the quantity of nitrate in ground water is being reduced locally.

In the Sumas aquifer, nitrate concentrations exceeded the primary drinking water standard of 10 milligrams per liter in more than 25 percent of the wells sampled. In the deeper hydrogeologic units, nitrate concentrations exceeded the drinking water standard in less than 2 percent of the wells sampled. The primary sources of nitrate in ground water are attributable to land-use activities, which include the storage of barnyard manures and their subsequent application to fields, the application of nitrogenous fertilizers to crops, and the use of domestic septic systems.

Nitrate concentrations in the Sumas aquifer were variable over the short-term; concentrations were generally larger in the late fall and winter and smaller during late spring and summer. Long-term trends were more difficult to discern, but concentrations appeared to be increasing. Nitrate concentrations did not vary as much over time in the fine-grained glacial and bedrock hydrogeologic units, where concentrations remained consistently at background levels in samples from most wells.

Chloride concentrations in ground water from individual wells ranged from 0.3 to 2,800 milligrams per liter. In the shallow and highly permeable Sumas aquifer, which is most vulnerable to contamination, chloride concentrations ranged from 0.2 to 210 milligrams per liter. More than 70 percent of wells sampled in the Sumas aquifer had chloride concentrations larger than the estimated range of background concentrations of from 0.5 to 4 milligrams per liter indicating widespread effects of land-use activities. In areas where nitrate concentrations were largest, chloride concentrations were typically larger, indicating that these constituents had similar sources. Within these areas, agricultural activities were much more prevalent and involved much larger quantities of nitrogen than did septic systems, so they were the likely sources of chloride also.

Many water samples from the Everson-Vashon unit had large chloride concentrations. However, these samples also had large concentrations of bromide, suggesting that this ground water was associated with seawater. Seawater is believed to have been incorporated into the Everson-Vashon and Vashon semiconfining units either at the time of their deposition or during a subsequent marine submergence. This remnant seawater has not been completely flushed from the units by post-glacial precipitation and recharge. The widespread occurrence of ground water containing remnant seawater indicates that there is little chance that large sustainable supplies of fresh water can be developed from these deeper, generally fine-grained units.

The pesticides ethylene dibromide, 1,2-dichloropropane, 1,3-dichloropropane, atrazine, and oxamyl, along with the volatile organic compound 1,2,3-trichloropropane, were detected in 4 of 24 ground-water samples collected for this study. The sampled wells, however, did not represent a random vertical distribution; only wells open to the shallow coarse-grained glacial aquifer were sampled. Within the Sumas aquifer, additional sampling by Environment Canada and the Washington State Department of Health in areas of suspected pesticide contamination has identified many additional wells with detectable pesticides or volatile organic compounds. Most of the pesticides detected in ground water are associated with commercial agriculture; however, diazinon and prometon, which were also detected, are compounds sold for home use. The presence of several of these compounds, particularly EDB, is likely related to historical use.

Sources of nitrate in ground water of the study area include farming practices; residential septic systems; fertilizers applied to croplands, lawns, and gardens; irrigation with ground water containing nitrates; and naturally occurring soil nitrogen and precipitation. On a regional basis, estimates of nitrogen loading to ground water indicate that agricultural activities, which occupy approximately 75 percent of the land area, account for about 87 percent of the nitrate loading to ground water, the remainder being about evenly divided between domestic and natural sources. Land applications of manure, the use of fertilizers, and manure storage are the farming practices that contribute the greatest quantity of nitrates in ground water. Agricultural activities also affect the storage and release of nitrogen in soil organic matter, which can also be a substantial source of nitrate in ground water. Residential sources are estimated to contribute only 6 percent of the total nitrogen input to the ground water of the study area; however, this often occurs near areas where domestic wells are located. Thus, potential residential sources of nitrates are often the closest to some wells and may have the greatest impact on the concentration of nitrates in well water. Even though agricultural sources contribute much larger quantities of nitrates to ground water than do residential sources, on a per-acre basis, the rates of nitrates entering ground water from agricultural sources are roughly 1.5 to 3 times greater than residential sources.

Evaluation of nitrate-related water-quality characteristics did not enable identification of individual sources of nitrate in ground water; however, it did indicate that inorganic fertilizers were the source of nitrate in at least 15 percent of the samples analyzed. In addition, the combined results of this evaluation were consistent with ground-water nitrate-loading estimates that indicated that nitrates in ground water were the result of multiple sources and that farming practices were the greatest source of nitrates to ground water.

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APPENDIX

APPENDIX

Computation of Hydraulic Conductance from Specific Capacity Data

Estimations of the horizontal hydraulic conductivity for each hydrogeologic unit were made using specific-capacity data. Only data from those wells that had the most complete and reliable set of specific-capacity information (discharge rate, drawdown, long-term test, well-construction data, and geologic log) were used. Of the 608 wells inventoried, 219 had such information. Two different sets of equations were used, depending on how the well was finished. For wells that had a screened, perforated, or open-hole interval, the modified Theis equation (Ferris and others, 1962) was first used to estimate transmissivity values. This equation is

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

where

S = storage coefficient, a dimensionless decimal;
Q = discharge, or pumping rate, of the well, in cubic feet per day;
T = transmissivity of the hydrogeologic unit, in square feet per day;
t = length of time the well was pumped, in days;
r = radius of the well, in feet; and
s = drawdown in the well, in feet.

The equation was solved for transmissivity (T) using Newton's iterative method (Carnahan and others, 1969, p. 171). Next, the following equation was used to calculate horizontal hydraulic conductivity.

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

where

K_h = horizontal hydraulic conductivity of the hydrogeologic unit, in feet per day;
T = transmissivity, as calculated above; and
b = thickness of the hydrogeologic unit, in feet (approximated using length of the open interval).

The use of the open interval to approximate the thickness of the hydrogeologic unit assumes that a well is open to the entire thickness of the unit, which was almost never the case. Nevertheless, this assumption is necessary because the equations are derived on the assumption that flow to the well is horizontal only; that is, vertical flow is insignificant. In a homogeneous unit, these conditions are present only if a well penetrates the entire thickness of the unit. However, in glacial systems, horizontal flow is likely to be much greater than vertical flow because the unit's heterogeneity leads to horizontal hydraulic conductivities that are generally much larger than the vertical hydraulic conductivities. Thus, even though the wells are rarely open to the entire thickness of the unit, the assumption that they are is reasonable for glacial systems.

Another equation was used to estimate hydraulic conductivities 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 just penetrating an aquifer. When modified for spherical flow to an open-ended well within an aquifer, the equation becomes

$$K_h = \frac{Q}{4\pi s} \times \frac{1}{r} \quad , \qquad (3)$$

where

K_h = horizontal hydraulic conductivity of the hydrogeologic unit, in feet per day;
Q = discharge, or pumping rate of the well, in cubic feet per day;
s = drawdown in the well, in feet; and
r = the well radius, in feet.

Equation 3 is based on the assumption that flow can occur equally in all directions, specifically, that horizontal and vertical hydraulic conductivities are equal. As discussed above, this is not likely to be true for glacial systems. However, the errors associated with violating this assumption are likely to be less than those that would occur in trying to fit the Theis equation to the open-ended well geometry. In fact, hydraulic conductivities were calculated using both approaches for open-ended wells, and the values obtained using the Bear equation for open-ended wells more closely resembled the hydraulic conductivities calculated for the screened wells.

Reconnaissance Sampling for Nitrates and Chloride

All nitrate concentrations are reported in units of milligrams per liter as nitrate nitrogen (NO_3-N). For samples collected during this study, concentrations should properly be reported as nitrate-plus-nitrite because the analytical method used (Fishman and Friedman, 1989) includes both species. In most natural waters, nitrite is a short-lived species produced during the oxidation of ammonia to nitrate or the denitrification of nitrate to nitrogen gas; as such, it is not usually present in significant quantities unless the total concentration of all nitrogen species is small. This is verified in the data on nitrogen species listed in appendix table 8.

In reporting nitrate and chloride concentrations in this study, the operational definition of whether the concentration is "total" or "dissolved" was ignored. This designation depends on whether a sample was filtered at the time of collection through a membrane filter with a nominal pore size of 0.45 micrometers. Filtering, which may have substantial effect on the concentrations of constituents that sorb to sediment or colloidal matter, has little effect on the concentration of either nitrate or chloride, which are soluble in water.

All nitrate samples, both filtered and unfiltered, were treated with mercuric chloride and chilled to inhibit biologically mediated reactions that could alter the concentration of nitrate.

Transformations of Nitrogen

Nitrogen compounds may undergo several transformations during the process of infiltration and percolation to ground water (Lawrence and Pionke, 1989). Nitrogen sources commonly are compounds containing nitrogen in a low-oxidation state. These compounds, referred to as reduced nitrogen species, include organic nitrogen compounds and ammonia. Oxidation of these reduced species to nitrate occurs in the presence of oxygen and the required bacteria, which utilize the energy released during the reactions. The oxidation (or nitrification) of ammonia in water percolating through the unsaturated zone is generally complete if oxygen is present. Alhajjar (1985) found that ammonia was rapidly and almost completely converted to nitrate in the unsaturated zone beneath septic tank drain fields. He also found that much of the organic nitrogen present in septage was converted to ammonia, which in turn was oxidized to nitrate. An exception was observed in a water-logged drain field where lack of oxygen prevented the nitrification of ammonia.

Under anaerobic conditions, nitrate may undergo denitrification to nitrogen gas or nitrous oxide, or it may be reduced to ammonia. Denitrification is believed to occur more readily than reduction except in organic-rich soils (Reddy and others, 1980). In denitrification, the bacteria usually responsible for the biological reduction require organic carbon as an energy source. It is entirely possible that nitrate introduced or formed in the upper soil zones may undergo denitrification in deeper zones where oxygen is not present and organic carbon is available.

Once infiltrating water has reached the water table, some of the same transformations that occur in the unsaturated zone may also occur under saturated conditions. Small concentrations of ammonia in ground water in the study area indicate that inorganic nitrogen is present primarily as nitrate. Nitrate in ground water is relatively stable in the presence of oxygen.

Stable Isotopes of Nitrogen

Two naturally occurring stable isotopes of nitrogen are known: ^{14}N and ^{15}N. The ^{15}N atom, which is the heavier of the two isotopes, makes up only about 0.4 percent of the nitrogen in the earth's atmosphere. Although the isotopic composition of the nitrogen in the earth's atmosphere is relatively constant, the isotopic composition of nitrogen in other compounds is variable and is often different from that of the atmosphere. The variability in the isotopic composition of the nitrogen in the nitrate sometimes makes it possible to infer the source of nitrate in ground water.

Stable-isotope concentrations of nitrogen are generally expressed in delta units (δ) given in per mil (0/00) or parts per thousand (Gat, 1980). These units represent relative deviations in the heavy isotope fraction in water and are defined as

$$\delta^{15}N = \left[\frac{R_{sample}}{R_{standard}} - 1\right] \times 1,000\,, \qquad (4)$$

where

R_{sample} = ratio of isotopic concentration $\left({}^{15}N/{}^{14}N\right)$ of the sample, and

$R_{standard}$ = ratio of isotopic concentration $\left({}^{15}N/{}^{14}N\right)$ of atmospheric nitrogen.

The isotopic composition of nitrogen in ground water is governed by the isotopic composition of the source material and the effects of chemical, biological, and physical processes that may alter the isotopic composition of the source material. The effects of many of the individual processes that alter the isotopic composition of source materials are known, but net effects are difficult to quantify in a field setting where multiple processes are likely to occur. For this reason, the use of nitrogen isotope ratios to infer sources of nitrate in ground water is most suitable in settings where few, if any, chemical, physical, or biological processes occur to alter the isotopic composition of the source material.

Explanation of Milliequivalents and Piper Diagrams

Ground water can be characterized by differences in the concentrations of major cations and anions. Water types as described by Hem (1989) use dominant cations and anions to characterize water samples. To do this, concentrations of the major cations and anions need to be converted from milligrams per liter to milliequivalents per liter to account for differences in atomic weight and electrical charge. A milliequivalent is the amount of a compound, in this case one of the ions, that reacts with a given amount of H^+ or OH^-. When expressed as milliequivalents, all cations and anions are equivalent for the purpose of balancing equations governing electrical charge of the dissolved ions. A milliequivalent of sulfate will combine with a milliequivalent of calcium, as would a milliequivalent of chloride. The milliequivalents of all the cations and anions are then summed separately to obtain a cation sum and anion sum, in milliequivalents. Because the water is electrically neutral, the cation and anion sums should be close in value. The contribution of each ion to the appropriate sum then is calculated as a percentage. The cations and anions that are the largest contributors to their respective sums define the water types. For example, the water type of seawater is sodium/chloride.

To make the determination of water types easier, the percentages of cations and anions for a given sample are plotted on a trilinear diagram, as shown in figure 18. The water type then is determined from the area of the diagram in which the sample is plotted. Piper diagrams consist of three separate plots; two of the plots are trilinear plots that show the percentage contribution of individual or pairs of cations and anions to their respective sums, and a third plot shows the predominant cation and anion association. Combined water types, where more than one cation or anion dominate, are possible and are actually common. For combined water types, the ions are listed in order of dominance. For example, a calcium-magnesium/bicarbonate type has more calcium than magnesium, a magnesium-calcium/bicarbonate type has more magnesium than calcium, but both plot in the same section of the diagram. An inspection of the diagram shows that to be defined as a sole dominant ion, an ion must account for 60 percent or more of the cation or anion sum, and the analysis will be plotted near one of the corners of the trilinear plot. On the other hand, an ion that accounts for less than 20 percent of the sum will not be included in the water type. An exception to the latter case occurs when two ions are included on a single axis of the plot, such as chloride and nitrate. If both together contribute 20 percent, then the sample will plot as though chloride is a dominate anion, even though individually chloride and nitrate contributions may be less than 20 percent. For this study, the actual percentages were used to determine the water type, and if both were less than 20 percent, neither was considered dominant. Also it should be noted that the diagram, which is based on percentages, does not show actual concentrations.

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data

[Ground-water site type: W, well; X, test hole; S, spring. Site use: W, withdrawal; U, unused; O, observation; T, test well; Z, destroyed. Water use: C, commercial; F, fire; D, dewater; H, domestic supply; I, irrigation; P, public supply; R, recreation; S, stock; U, unused. Hydrogeologic units: EVRS, Everson-Vashon semiconfining unit; SUMS, Sumas aquifer; EVRS* and SUMS*, Hydrogeologic units based on data from nearby wells, no log available; VSHN, Vashon semiconfining unit; BDRK, bedrock unit. Lithologic units: 10, unconfined sand and gravel, occasional clay lenses; 11, sand and gravel overlain by peat or peat and clay; 12, sand and gravel overlain by clay; 13, sand and gravel with bog iron; 14, sand and gravel with lenses of clay or till; 15, alluvial sand and gravel; 20, confined sand and gravel in Sumas Valley; 21, confined sand and gravel in Sumas Valley, peat associated with confining clay; 22, sand and gravel unit underlying a second deeper clay in Sumas Valley; 23, thin producing sand lense in surficial silt; 30, confined sand or sand and gravel, confined by glaciomarine drift or till; 31, deeper confined sand or gravel; 40, bedrock; 50, undifferentiated glacial deposits. Source of data: USGS, U.S. Geological Survey; BCME, British Columbia Ministry of Environment; EC, Environment Canada; WDOE, Washington State Department of Ecology; WCPH, Whatcom County Public Health Department; Drill, driller's log; --, not analyzed]

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
092G.008.1.2.1-02	490040	1223215	W	W	S	EVRS	30	109	6	230	USGS	19900605	33.03	99	86	<0.1
092G.008.1.2.1-03	490034	1223202	W	W	H	EVRS	30	99	6	220	USGS	19900605	41.10	280	0.9	<0.1
092G.008.1.2.2-01	490034	1223129	W	W	H	EVRS	30	39	6	205	USGS	19900605	4.19	229	4.8	0.9
092G.008.1.2.3-10	490124	1223214	W	W	R	EVRS	30	230	8	250	USGS	19900605	56.2	4,390	1,100	<0.1
092G.008.1.4.1-07	490214	1223139	W	W	H	EVRS	30	51	6	275	USGS	19900606	30.90	260	19	<0.1
092G.008.1.4.2-01	490150	1223024	W	U	U	EVRS	--	395	6	300	Drill	19720614	115	6,800	1,920	1.6
092G.008.1.4.2-08	490156	1223122	W	W	H	EVRS	30	153	6	251	USGS	19900606	33.32	300	15	<0.1
092G.008.1.4.2-15	490153	1223018	W	W	S	EVRS	30	342	6	300	USGS	19900607	--	2,560	670	<0.1
092G.008.1.4.4-03	490248	1223052	W	W	H	EVRS	30	81	6	305	USGS	19900606	56.16	909	1.6	<0.1
092G.008.1.4.4-06	490259	1223009	W	W	H	EVRS	30	117	6	320	USGS	19910607	92.3	777	1.6	<0.1
092G.008.2.1.1-02	490023	1222926	W	W	H	EVRS	30	164	6	164	USGS	19900607	12.40	259	3.8	<0.1
092G.008.2.1.1-04	490036	1222932	W	W	H	EVRS	30	68	6	180	USGS	19900607	13.19	359	5.8	<0.1
092G.008.2.1.2-03	490017	1222736	W	W	H	EVRS	30	39	6	180	USGS	19900607	10.26	190	1	<0.1
092G.008.2.1.2-04	490017	1222821	W	W	P	SUMS	10	52	8	154	USGS	19900607	13.92	205	8.4	11
092G.008.2.1.3-08	490100	1222929	W	U	U	EVRS	30	302	6	240	USGS	19900608	74.86	--	--	--
092G.008.2.1.4-01	490052	1222808	W	W		EVRS	30	102	8	291	USGS	19900607	45.24	--	--	--
092G.008.2.1.4-09	490106	1222750	W	W	H	SUMS	14	96	6	295	USGS	19900607	54.34	145	11	<0.1
092G.008.2.2.1-03	490022	1222644	W	W	H	SUMS	14	100	6	150	USGS	19900611	4.43	185	1.8	0.4
092G.008.2.2.1-04	490012	1222636	W	W	H	EVRS	31	160	6	150	USGS	19900612	5.65	279	25	<0.1
092G.008.2.2.2-10	490043	1222405	W	W	H	EVRS	30	220	6	152	USGS	19900612	39.33	726	110	<0.1
092G.008.2.2.2-11	490043	1222405	W	U	U	SUMS	10	50	6	152	USGS	19900612	9.99	--	--	--
092G.008.2.2.2-12	490036	1222406	W	W	U	SUMS	10	80	8	152	USGS	19900612	9.44	--	--	--
092G.008.2.2.2-15	490011	1222432	W	W	S	SUMS	10	70	6	148	USGS	19900612	11.24	295	11	4.5
092G.008.2.2.2-ABB1	490042	1222410	W	O	U	SUMS	10	26	2	150	USGS	19900618	8.46	255	9.2	11
092G.008.2.2.3-03	490053	1222600	W	W	H	SUMS	10	60	6	210	USGS	19900611	35.53	179	6.2	5
092G.008.2.2.4-16	490102	1222437	W	W	I	EVRS	30	98	6	170	USGS	19900612	2.47	--	--	--
092G.008.2.3.1-11	490212	1222837	W	W	H	EVRS*	--	44	6	305	USGS	19900608	19.39	198	2	<0.1
092G.008.2.3.1-12	490154	1222842	W	W	H	EVRS	30	50	6	300	USGS	19900608	13.66	215	3.2	<0.1
092G.008.2.3.2-10	490155	1222738	W	W	U	SUMS	10	85	6	362	USGS	19900608	32.54	--	--	--
092G.008.2.3.2-16	490157	1222739	W	W	H	EVRS	30	164	6	358	USGS	19900608	57.58	177	4.2	4.1
092G.008.2.3.3-09	490247	1222932	W	W	H	EVRS	30	73	6	298	USGS	19900608	12.84	269	1	<0.1

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
092G.008.2.3.3-14	490246	1222938	W	W	H	EVRS	30	175	6	298	USGS	19900608	2.18	288	0.6	<0.1
092G.008.2.3.4-04	490241	1222749	W	W	I	SUMS	--	125	8	315	USGS	19900608	--	--	--	9.8
092G.008.2.4.1-18	490151	1222557	W	W	H	SUMS	14	110	6	325	USGS	19900608	58.42	179	1.4	1.2
092G.008.2.4.1-19	490148	1222534	W	W	H	SUMS	14	118	6	325	USGS	19900611	81.92	249	9.8	12
092G.008.2.4.1-41	490150	1222559	W	O	U	SUMS	14	135	6	326	BCME	19880930	--	192	7.4	1
											BCME	19881027	57.85			
											BCME	19881128	49.87			
											BCME	19881129	49.60			
											BCME	19881229	46.85			
											BCME	19890130	43.96			
											BCME	19890227	51.23			
											BCME	19890331	51.70			
											BCME	19890415	49.10			
											BCME	19890428	49.99			
											BCME	19890525	54.79			
											BCME	19890629	56.13			
											BCME	19890730	58.33			
											BCME	19890731	58.31			
											BCME	19890823	58.88			
											BCME	19890924	59.61			
											BCME	19890925	59.56			
											BCME	19891026	60.12			
											BCME	19891127	52.25			
											BCME	19891128	52.17			
											BCME	19891227	51.89			
											BCME	19900125	53.26			
											BCME	19900226	48.43			
											BCME	19900228	48.85			
											BCME	19900330	53.24			
											BCME	19900424	56.42			
											BCME	19900528	58.01			
											BCME	19900608	57.35			
											BCME	19900630	57.22			
											BCME	19900703	57.28			
											BCME	19900802	58.81			
											BCME	19900903	59.99			
											BCME	19900904	60.03			
											BCME	19901005	60.85			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19901106	60.80			
											BCME	19901206	49.74			
											BCME	19910107	51.50			
											BCME	19910114	52.59			
											BCME	19910211	52.55			
											BCME	19910306	52.74			
											BCME	19910405	54.82			
											BCME	19910502	55.22			
											BCME	19910603	57.54			
											BCME	19910604	57.61			
											BCME	19910704	58.86			
											BCME	19910805	60.42			
											BCME	19910807	60.48			
											BCME	19910905	61.08			
											BCME	19911004	61.21			
092G.008.2.4.2-13	490136	1222404	W	W	H	SUMS	10	110	6	321	USGS	19900612	76.58	334	5.6	5.8
092G.008.2.4.2-14	490209	1222420	W	W	H	EVRS	30	129	6	330	USGS	19900612	105.69	191	5.2	8.2
092G.008.2.4.2-xx	490141	1222513	W	W	Q	EVRS*		135	8	210	USGS	19900611	--	347	9.2	5.8
092G.008.2.4.3-14	490219	1222645	W	W	I	SUMS	14	61	6	360	USGS	19900619	47.62	108	2	2.8
092G.008.2.4.4-10	490250	1222408	W	U	X	--	--	110	10	345	USGS	--	--	--	--	--
092G.008.2.4.4-12	490223	1222352	W	W	H	EVRS	30	175	6	270	USGS	19900612	140.58	164	1	2.2
092G.008.2.4.4-18	490253	1222405	W	W	I	SUMS	10	96	8	340	USGS	19900613	70.03	253	10	0.7
092G.008.4.2.1-31	490311	1222647	W	W	I	EVRS*	--	85	6	390	USGS	19900611	14.75	280	1.2	<0.1
092G.008.4.2.2-22	490310	1222516	W	W	H	EVRS*	--	132	6	412	USGS	19900611	--	188	14	<0.1
092G.008.4.2.2-27	490338	1222430	W	W	H	EVRS	30	127	6	400	USGS	19900613	106.89	183	1.2	0.9
092G.009.1.1.1-06-20	490031	1222253	W	O	U	SUMS	10	20	2	160	USGS	19900611	9.36	225	8.5	18
092G.009.1.1.1-06-35	490031	1222253	W	O	U	SUMS	10	35	2	160	USGS	19900611	9.36	257	10	21
092G.009.1.1.1-07-55	490030	1222253	W	O	U	SUMS	10	55	2	160	USGS	19900611	9.42	168	0.3	6.9
092G.009.1.1.1-07-75	490030	1222253	W	O	U	SUMS	10	75	2	160	USGS	19900611	9.42	202	0.5	1.2
092G.009.1.1.1-ABB5	490009	1222331	W	O	U	SUMS	10	29	2	151	USGS	19900618	6.69	204	9	15
092G.009.1.1.2-11-25	490031	1222215	W	O	U	SUMS	10	25	2	168	USGS	19900611	11.60	154	5.8	11
092G.009.1.1.2-11-35	490031	1222215	W	O	U	SUMS	10	35	2	168	USGS	19900611	11.60	258	12	19
092G.009.1.1.2-12-55	490030	1222215	W	O	U	SUMS	10	55	2	168	USGS	19900611	11.56	198	6.9	2.7
092G.009.1.1.2-12-75	490030	1222215	W	O	U	SUMS	10	75	2	168	USGS	19900611	11.71	209	8.5	2
092G.009.1.1.2-29	490011	1222133	W	W	I	SUMS	10	48	8	166	USGS	19900615	14.54	110	3.8	0.1
092G.009.1.1.2-ABB2	490020	1222132	W	O	U	SUMS	10	25	2	167	EC	19891115	13.22			
											EC	19891215	10.79			
											EC	19900115	10.00			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											EC	19900215	7.94			
											EC	19900315	7.54			
											EC	19900415	8.92			
											EC	19900515	10.00			
											EC	19900615	10.63			
											USGS	19900618	--	180	8.8	11
											EC	19900715	11.74			
											EC	19900815	13.35			
											EC	19900915	14.56			
											EC	19901015	15.29			
											EC	19901115	11.55			
											EC	19901215	7.84			
											EC	19910115	7.31			
											EC	19910215	7.02			
											EC	19910315	7.45			
											EC	19910415	8.23			
											EC	19910515	9.32			
											EC	19910615	10.66			
											EC	19910715	11.87			
											EC	19910815	13.45			
											EC	19910915	14.11			
											EC	19911015	14.73			
											EC	19911115	14.24			
092G.009.1.1.4-10	490043	1222107	W	W	H	SUMS	10	41	6	180	USGS	19900614	10.02	265	5.4	17
092G.009.1.1.4-17	490128	1222112	W	W	H	SUMS	10	60	6	200	USGS	19900614	19.37	267	9	15
092G.009.1.1.4-18-25	490101	1222215	W	O	U	SUMS	10	25	2	170	USGS	19900611	10.24	93	2.7	5.9
092G.009.1.1.4-18-35	490101	1222215	W	O	U	SUMS	10	35	2	170	USGS	19900611	10.24	96	2.9	5.5
092G.009.1.1.4-19-55	490100	1222215	W	O	U	SUMS	10	55	2	170	USGS	19900611	10.31	144	0.4	4.6
092G.009.1.1.4-19-75	490100	1222215	W	O	U	SUMS	10	75	2	170	USGS	19900611	10.31	217	1	5
092G.009.1.1.4-ABB6	490046	1222133	W	O	U	SUMS	10	30	2	180	USGS	19900618	17.3	199	5.2	11
092G.009.1.2.1-23	490042	1222007	W	W	I	SUMS	10	161	8	190	EC	19891115	47.97			
											EC	19891215	46.33			
											EC	19900115	44.59			
											EC	19900215	43.44			
											EC	19900315	38.81			
											EC	19900415	38.48			
											EC	19900515	39.66			
											USGS	19900615	41.17	340	11	24

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											EC	19900715	42.78			
											EC	19900815	44.49			
											EC	19900915	45.90			
											EC	19901015	46.98			
											EC	19901115	47.21			
											EC	19901215	43.01			
											EC	19910115	39.14			
											EC	19910215	38.25			
											EC	19910315	37.27			
											EC	19910415	37.60			
											EC	19910515	38.38			
											EC	19910615	39.99			
											EC	19910715	41.73			
											EC	19910815	43.73			
											EC	19910915	45.41			
											EC	19911015	46.33			
											EC	19911115	47.74			
092G.009.1.2.1-ABB4	490011	1221932	W	O	U	SUMS	10	96	2	213	USGS	19900618		305	16	23
092G.009.1.2.1-ABB3	490022	1222012	W	O	U	SUMS	10	58	2	180	USGS	19900618	35.7	305	16	11
092G.009.1.2.2-32	490013	1221810	W	W	I	EVRS	30	160	8	140	USGS	19900618	35.11			
092G.009.1.2.2-46	490023	1221857	W	W	I	SUMS	14	179	8	260	USGS	19900615	116.87	325	9.8	13
092G.009.1.2.3-10	490105	1222030	W	O	U	SUMS	10	63	6	180	BCME	19881031	46.55			
											BCME	19881130	44.51			
											BCME	19881231	41.29			
											BCME	19890131	37.48			
											BCME	19890228	37.32			
											BCME	19890331	37.50			
											BCME	19890430	35.84			
											BCME	19890531	36.75			
											BCME	19890630	38.18			
											BCME	19890731	39.96			
											BCME	19890831	41.14			
											BCME	19890930	42.70			
											BCME	19891031	43.92			
											BCME	19891130	42.46			
											BCME	19891231	40.13			
											BCME	19900131	39.10			
											BCME	19900228	34.80			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19900331	34.02			
											BCME	19900430	35.04			
											BCME	19900531	37.44			
											BCME	19900614	37.55			
											BCME	19900630	38.20			
											BCME	19900731	39.95			
											BCME	19900831	41.67			
											BCME	19900930	43.00			
											BCME	19901031	44.11			
											BCME	19901130	39.82			
											BCME	19901231	36.07			
											BCME	19910131	34.27			
											BCME	19910228	33.3			
											BCME	19910331	33.37			
											BCME	19910430	34.27			
											BCME	19910531	35.65			
											BCME	19910630	37.43			
											BCME	19910731	39.84			
											BCME	19910831	41.22			
											BCME	19910930	42.30			
092G.009.1.2.3-39	490043	1222002	W	W	I	SUMS	10	81	8	193	USGS	19900615	51.78	284	9.4	18
092G.009.1.2.3-59	490102	1222043	W	W	I	SUMS	10	84	8	175	USGS	19900614	27.02			
092G.009.1.2.3-69	490133	1221934	W	W	I	SUMS	10	175	8	225	USGS	19900618	69.11	231	17	4.4
092G.009.1.2.3-29	490132	1222007	W	W	I	SUMS	10	40	6	200	USGS	19900618	39.48	254	6.6	4.4
092G.009.1.2.3-CDA1	490046	1221953	W	O	U	SUMS	10	20	2	200	EC	19891115	58.29			
											EC	19891215	56.62			
											EC	19900115	54.91			
											EC	19900215	53.77			
											EC	19900315	49.11			
											EC	19900415	48.75			
											EC	19900515	49.34			
											EC	19900615	51.57	234	16	32
											EC	19900715	53.21			
											EC	19900815	54.88			
											EC	19900915	56.33			
											EC	19901015	57.37			
											EC	19901115	57.67			
											EC	19901215	53.50			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											EC	19910115	49.57			
											EC	19910215	48.61			
											EC	19910315	47.63			
											EC	19910415	47.99			
											EC	19910515	48.78			
											EC	19910615	50.35			
											EC	19910715	52.06			
											EC	19910815	54.09			
											EC	19910915	55.96			
											EC	19911015	56.72			
											EC	19911115	58.13			
092G.009.1.2.4-31	490120	1221847	W	W	H	EVRS	30	163	6	240	USGS	19900619	91.20	269	13	5.4
092G.009.1.3.1-16	490205	1222331	W	U	U	EVRS*		140	6	210	USGS	19900613	38.20		>250	
092G.009.1.3.2-40	490147	1222116	W	W	I	SUMS	10	55	36	200	USGS	19900614	17.63			
											USGS	19870729		175	3.1	6.1
092G.009.1.3.3-08	490230	1222248	W	O	U	SUMS	10	52	8	180	BCME	19881027	11.88			
											BCME	19881128	7.06			
											BCME	19881129	7.10			
											BCME	19881229	7.35			
											BCME	19890227	7.69			
											BCME	19890331	6.75			
											BCME	19890428	7.67			
											BCME	19890525	9.07			
											BCME	19890626	9.98			
											BCME	19890628	10.15			
											BCME	19890730	11.69			
											BCME	19890731	11.66			
											BCME	19890823	12.56			
											BCME	19890924	13.53			
											BCME	19890925	13.56			
											BCME	19891026	14.20			
											BCME	19891127	6.83			
											BCME	19891128	6.94			
											BCME	19891227	7.92			
											BCME	19900125	6.30			
											BCME	19900226	5.86			
											BCME	19900227	5.87			
											BCME	19900330	7.34			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19900427	8.65			
											BCME	19900529	10.08			
											BCME	19900630	9.69			
											BCME	19900703	9.86			
											BCME	19900802	11.70			
											BCME	19900903	13.09			
											BCME	19900904	13.13			
											BCME	19901005	13.73			
											BCME	19901106	13.32			
											BCME	19901206	4.77			
											BCME	19910107	7.62			
											BCME	19910111	7.77			
											BCME	19910211	6.15			
											BCME	19910308	6.28			
											BCME	19910403	8.17			
											BCME	19910502	8.70			
											BCME	19910603	10.32			
											BCME	19910606	10.44			
											BCME	19910704	11.68			
											BCME	19910805	13.26			
											BCME	19910807	13.33			
											BCME	19910905	13.16			
											BCME	19911004	13.88			
092G.009.1.3.3-20	490224	1222303	W	W	H	SUMS	10	49	6	183	USGS	19900613	13.87	289	17	5.7
092G.009.1.3.4-26	490233	1222156	W	W	H	SUMS	10	45	6	195	USGS	19900614	17.05	145	6.4	5.9
092G.009.1.3.4-34	490216	1222133	W	W	I	SUMS	10	85	6	195	USGS	19900614	30.42	167	12	1.9
092G.009.1.4.2-50	490157	1221853	W	W	H	SUMS	14	88	6	230	USGS	19400619	--	245	7	5.4
092G.009.2.1.1-37	490036	1221641	W	O	U	SUMS	10	112	6	50	BCME	19860304	--	190	4.6	0.7
											USGS	19900618	24.80			
092G.009.2.1.1-38	490036	1221644	W	W	P	SUMS	14	133	12	50	USGS	19900619	--	254	7	4.6
092G.009.2.1.2-19	490033	1221628	W	W	P	SUMS	10	145	18	45	USGS	19911002	--	231	5.8	9.1
092G.009.2.1.2-24	490031	1221628	W	O	U	SUMS	10	119	6	45	USGS	19900618	18.63			
092G.009.2.1.3-41	490058	1221632	W	O	U	SUMS	10	220	6	150	BCME	19881014	138.33			
											BCME	19881027	138.21			
											BCME	19881128	137.98			
											BCME	19881129	137.96			
											BCME	19881229	137.52			
											BCME	19890116	136.97			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19890130	136.24			
											BCME	19890204	136.15			
											BCME	19890227	135.78			
											BCME	19890304	135.84			
											BCME	19890331	135.40			
											BCME	19890428	134.99			
											BCME	19890525	134.77			
											BCME	19890526	134.74			
											BCME	19890625	135.24			
											BCME	19890628	135.25			
											BCME	19890730	135.53			
											BCME	19890731	135.51			
											BCME	19890823	135.63			
											BCME	19890924	135.94			
											BCME	19890925	135.96			
											BCME	19891026	136.36			
											BCME	19891127	136.29			
											BCME	19891227	136.45			
											BCME	19900125	136.44			
											BCME	19900226	135.84			
											BCME	19900228	135.75			
											BCME	19900330	134.99			
											BCME	19900427	134.61			
											BCME	19900527	135.06			
											BCME	19900529	135.11			
											USGS	19900618	135.08			
											BCME	19900630	135.30			
											BCME	19900703	135.38			
											BCME	19900802	136.04			
											BCME	19900904	136.79			
											BCME	19900926	137.11			
											BCME	19901005	136.98			
											BCME	19901025	136.52			
											BCME	19901106	136.48			
											BCME	19901114	136.30			
											BCME	19901128	136.21			
											BCME	19901206	136.12			
											BCME	19910105	135.32			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19910111	135.20			
											BCME	19910211	134.55			
											BCME	19910228	134.24			
											BCME	19910403	133.85			
											BCME	19910430	133.77			
											BCME	19910530	133.93			
											BCME	19910628	134.20			
											BCME	19910727	134.65			
											BCME	19910731	134.69			
											BCME	19910830	135.53			
											BCME	19910927	135.43			
092G.009.2.1.3-47	49010	1221714	W	O	U	SUMS	10	87	6	175	BCME	19881014	63.91			
											BCME	19881027	63.99			
											BCME	19881128	63.96			
											BCME	19881229	62.87			
											BCME	19890130	60.75			
											BCME	19890227	59.43			
											BCME	19890331	58.84			
											BCME	19890428	57.86			
											BCME	19890524	57.71			
											BCME	19890626	58.40			
											BCME	19890730	59.60			
											BCME	19890823	60.22			
											BCME	19890924	61.04			
											BCME	19891026	61.82			
											BCME	19891127	62.29			
											BCME	19891227	61.66			
											BCME	19900125	60.97			
											BCME	19900226	58.70			
											BCME	19900228	58.86			
											BCME	19900330	57.47			
											BCME	19900427	56.97			
											BCME	19900529	57.72			
											USGS	19900618	58.62			
											BCME	19900703	58.72			
											BCME	19900802	59.90			
											BCME	19900903	60.83			
											BCME	19901005	61.66			

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											BCME	19901106	62.23			
											BCME	19901206	61.56			
											BCME	19910107	59.31			
											BCME	19910111	59.10			
											BCME	19910228	56.54			
											BCME	19910401	56.02			
											BCME	19910403	55.92			
											BCME	19910430	56.35			
											BCME	19910530	57.09			
											BCME	19910628	57.85			
											BCME	19910730	59.02			
											BCME	19910731	59.06			
											BCME	19910830	60.11			
											BCME	19910927	60.87			
092G.009.2.1.4-20	490123	1221621	W	O	U	SUMS	10	160	6	100	USGS	19900618	42.54	--	--	--
092G.009.2.1.4-23	490112	1221621	W	O	U	SUMS		320	8	90	USGS	19900618	38.21	--	--	--
092G.009.2.1.4-26	490113	1221623	W	W	P	SUMS	10	265	20	80	USGS	19911002	--	327	8.1	6.9
092G.009.2.2.1-03	490010	1221439	W	W	I	SUMS	20	78	10	30	USGS	19900619	3.59	--	--	--
092G.009.2.2.3-11	490106	1221350	W	W	I	SUMS	20	65	8	32	USGS	19900619	5.16	752	210	0.05
092G.009.2.3.1-32	490140	1221735	W	W	H	SUMS	14	90	6	210	USGS	19900619	58.33	254	15	0.1
092G.009.3.1.2-20	490338	1222149	W	W	H	EVRS	30	157	6	375	USGS	19900614	84.80	180	0.8	0.3
092G.009.3.1.2-23	490310	1222137	W	U	U	SUMS	10	125	6	215	USGS	19900614	13.93	--	--	--
38N/03E-04E01	484848	1222628	W	T	U			200		308	Drill					
38N/04E-06D01	484902	1222102	W	W	H	EVRS	30	132		276	USGS	19900427	3.1	687	49	<0.05
39N/02E-01N01	485335	1223015	W	W	H	SUMS	10	25	36	75	USGS	19900410	9.83	114	4.8	3.8
39N/02E-01P02	485337	1222948	W	W	H	SUMS	10	34	36	80	USGS	19900412	11.28	223	14	10
											USGS	19901018	15.11	247	17	14
											USGS	19901114	13.22	205	13	9.5
											USGS	19901218	10.43	152	7.8	6.1
											USGS	19910119	9.70	153	7	--
											USGS	19910220	9.89	165	10	--
											USGS	19910313	10.00	171	11	7.6
											USGS	199103425	10.66	167	--	6.5
											USGS	19910521	11.39	238	20	5.4
											USGS	19910626	12.65	240	20	9.9
											USGS	19910718	13.68	239	20	9.6
											USGS	19910823	14.75	--	--	7.9
											USGS	19910925	14.60	240	18	7.9

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											USGS	19911023	14.90	238	--	8.4
39N/02E-01Q01	485340	1222927	W	W	I	SUMS	10	31	36	80	USGS	19900410	10.14	--	--	--
39N/02E-02A01	485412	1223040	W	U	U	SUMS	11	40	6	60	USGS	19900413	9.18	--	--	--
39N/02E-02H01	485408	1223040	W	W	I	SUMS	10	19	36	60	USGS	19900412	7.03	--	--	--
39N/02E-03G01	485358	1223207	W	W	H	SUMS	10	32	36	35	USGS	19900410	4.90	146	12	3.5
39N/02E-05B02	485419	1223449	W	T	U			735		60	Drill					
39N/02E-10F01	485316	1223226	W	W	H	SUMS	10	20	12	55	USGS	19900412	8.16	248	15	14
											USGS	19901016	11.91	180	14	3.7
											USGS	19901116	9.27	161	14	1.6
											USGS	19901218	6.78	186	14	8.6
											USGS	19910116	6.62	243	16.4	15
											USGS	19910220	6.23	214	13.5	12
											USGS	19910313	6.70	208	15	9.8
											USGS	19910425	7.46	201	--	8.3
											USGS	19910521	8.39	236	15	12
											USGS	19910626	9.45	233	15	11
											USGS	19910718	10.20	214	14	8.4
											USGS	19910823	11.96	216	16	6.3
											USGS	19910925	11.67	198	14	3.7
											USGS	19911023	11.84	187	13	3
39N/02E-10J01	485253	1223155	W	W	I	SUMS	11	21	36	75	USGS	19900411	5.07	--	--	--
39N/02E-10Q02	485239	1223216	W	U	U	SUMS	10	27	24	60	USGS	19900411	3.27	--	--	--
39N/02E-11B01	485328	1223102	W	W	H	SUMS	10	26	36	65	USGS	19900410	9.45	162	8.2	6.9
39N/02E-11B02	485322	1223102	W	T	U			525		71	Drill					
39N/02E-11M01	485258	1223141	W	W	H	SUMS	10	40	6	75	USGS	19900410	2.79	50	1	0.6
39N/02E-12H04	485305	1222921	W	W	I	SUMS	10	45	36	82	USGS	19900501	5.48	--	--	--
39N/02E-12K03	485258	1222939	W	W	H	SUMS	10	27	6	85	USGS	19900413	9.57	195	3.4	12.
39N/02E-12Q01	485244	1222939	W	W	H	SUMS	10	44	6	80	USGS	19900413	2.68	180	7	<0.1
39N/02E-13B01	485234	1222934	W	W	P	SUMS	10	52	5	80	USGS	19900413	9.73	244	12	<0.1
39N/02E-14L01	485202	1223106	W	W	H	SUMS	10	21	36	60	USGS	19900412	5.45	360	23	<0.1
39N/02E-14M01	485209	1223125	W	W	H	SUMS	10	34	36	60	USGS	19900411	5.91	280	14	8
39N/02E-16A01	485229	1223305	W	U		SUMS	10	19	12	48	USGS	19900418	3.22	--	--	--
39N/02E-16H03	485223	1223305	W	W	H	SUMS	11	19	12	50	USGS	19900418	2.54	198	11	0.7
39N/02E-21K01	485117	1223328	W	U	U	SUMS	12	19	8	50	USGS	19900410	4.87			
39N/02E-22D02	485138	1223246	W	W	H	SUMS	10	48	6	50	USGS	19900410	17.49	307	27	<0.1
39N/02E-22K02	485112	1223215	W	W	H	SUMS	10	17	6	45	USGS	19900410	2.87	259	14	<0.1
39N/02E-22K03	485106	1223221	W	W	H	SUMS	10	25	12	58	USGS	19900411	5.18	131	3.2	0.3
39N/02E-22L01	485118	1223226	W	Z	U			175		45	Drill					

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/02E-23F01	485121	1223113	W	W	S	SUMS	10	20	12	61	USGS	19900412	2.40	241	3.4	<0.1
39N/02E-23G02	485131	1223058	W	W	H	SUMS	10	10	36	50	USGS	19900410	2.63	309	19	<0.1
39N/02E-23J01	485118	1223039	W	T	U			1060		75	Drill					
39N/02E-24B01	485144	1222938	W	T	U			869		68	Drill					
39N/02E-24C02	485137	1222954	W	W	H	SUMS	10	22	12	62	USGS	19900410	7.95	159	12	3.8
39N/02E-24F02	485130	1222948	W	T	U			846		70	Drill					
39N/02E-24K01	485118	1222931	W	T	U			380		90	Drill					
39N/02E-24N02	485055	1223009	W	W	H	SUMS	10	29	12	76	USGS	19900412	2.58	303	19	<0.1
39N/02E-24Q01	485056	1222925	W	U	U	EVRS	30	59	6	110	USGS	19900411	4.66	--	--	--
39N/02E-24R02	485054	1222924	W	W	H	EVRS	30	41	6	134	USGS	19900421	19.56	280	17	10
39N/02E-25C01	485045	1222955	W	T				867		75	Drill					
39N/02E-26C01	485052	1223119	W	W	H	SUMS	12	30	36	70	USGS	19900418	5.91	278	10	1.7
39N/02E-26H01	485031	1223041	W	W	H	SUMS	12	14	36	110	USGS	19900418	6.46	309	8.8	12
39N/02E-26N01	485003	1223139	W	W	H	SUMS	12	24	36	92	USGS	19900412	3.34	121	3.8	3.6
39N/02E-27F03	485031	1223242	W	W	H	SUMS	12	44	6	106	USGS	19900411	15.00	304	16	14
											USGS	19901018	18.45	268	15	14
											USGS	19901114	18.18	271	12	12
											USGS	19901218	15.14	274	12	12
											USGS	19910116	13.77	287	13	13
											USGS	19910220	13.85	297	14	13
											USGS	19910314	13.76	298	14	14
											USGS	19910425	14.32	294	13	14
											USGS	19910521	15.08	303	12	13
											USGS	19910626	15.99	294	13	13
											USGS	19910717	16.70	283	12	12
											USGS	19910823	17.59	--	11	11
											USGS	19910925	18.15	258	--	11
											USGS	19911023	18.60	265	11	11
39N/02E-27F04	485034	1223227	W	W	H	SUMS	12	36	36	108	USGS	19900411	17.39	283	9.2	2.5
39N/02E-27J01	485024	1223145	W	W	H	SUMS	12	29	36	110	USGS	19900418	16.54	287	11	15
39N/02E-27K01	485023	1223219	W	W	H	SUMS	12	35	18	110	USGS	19900411	11.84	149	2.6	2.8
39N/02E-27N01	485005	1223255	W	W	H	SUMS	10	32	12	95	USGS	19900411	4.08	335	40	8.9
39N/02E-27P01	485009	1223238	W	T				923		100	USGS					
39N/02E-27Q04	485005	1223207	W	W	P	SUMS	10	22	36	95	USGS	19910710	--	198	13	5.8
39N/02E-28J02	485015	1223316	W	W	H	SUMS	10	25	18	93	USGS	19900501	5.20	251	3	6.7
39N/02E-28J03	485022	1223314	W	W	H	SUMS	12	24	18	90	USGS	19900501	9.76	120	26	1.3
39N/03E-01C01	485420	1222153	W	W	H	SUMS	10	49	6	96	USGS	19900427	9.39	285	54	0.4
											USGS	19901018	14.27	295	54	0.4

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											USGS	19901115	12.54	289	54	0.3
											USGS	19901217	7.67	282	51	0.3
											USGS	19910116	6.8	280	52	0.3
											USGS	19910220	7.48	284	50	0.3
											USGS	19910313	8.05	278	50	0.3
											USGS	19910422	9.57	286	54	0.4
											USGS	19910522	10.82	291	51	0.3
											USGS	19910625	12.16	296	52	0.3
											USGS	19910717	12.84	270	51	0.3
											USGS	19910822	13.67	281	47	0.3
											USGS	19910926	13.13	261	46	0.3
											USGS	19911023	14.63	274	47	0.3
39N/03E-01D01	485410	1222223	W	W	N	SUMS	10	39	36	100	USGS	19900320	13.21	229	44	0.5
39N/03E-01R01	485330	1222124	W	W	H	SUMS	12	46	6	120	USGS	19900320	--	263	46	1.2
39N/03E-02A01	485411	1222235	W	W	H	SUMS	10	39	6	100	USGS	19900330	15.77	229	43	0.7
39N/03E-02B02	485418	1222254	W	W	H	SUMS	10	40	6	93	USGS	19900319	6.42	362	59	0.2
39N/03E-02B03	485413	1222259	X	T				180		93	Drill					
39N/03E-02K01	485353	1222254	W	U	U	SUMS	10	39	6	100	USGS	19900329	13.58	--	--	--
39N/03E-02N02	485330	1222330	W	W	H	SUMS	10	30	6	100	USGS	19900319	--	75	3.2	1.5
39N/03E-02N03	485333	1222344	W	W	H	SUMS	10	36	6	95	USGS	19900320	15.02	80	3.6	1.8
39N/03E-02Q01	485332	1222258	W	W	H	SUMS	10	32	6	106	USGS	19900321	--	57	2.6	0.5
39N/03E-03E01	485358	1222504	W	W	H	SUMS	10	43	6	100	USGS	19900320	20.38	133	8.6	0.3
39N/03E-03G01	485408	1222421	W	W	I	SUMS	10	24	36	80	USGS	19900411	4.32	--	--	--
39N/03E-03M01	485346	1222448	W	Z	U			262		95	USGS					
39N/03E-03R02	485332	1222357	W	W	I	SUMS	10	40	6	95	USGS	19900320	12.95	173	7.8	<0.1
39N/03E-04B01	485422	1222530	W	W	I	SUMS	10	31	6	83	USGS	19900321	15.21	521	35	<0.1
39N/03E-04M01	485346	1222618	W	W	I	SUMS	10	41	36	100	USGS	19900321	23.56	--	--	--
39N/03E-04M02	485346	1222619	W	W	H	SUMS	10	37	6	100	USGS	19900321	22.96	242	8.4	10
39N/03E-04P01	485338	1222557	W	W	I	SUMS	10	41	36	97	USGS	19900321	21.43	--	--	--
39N/03E-04R02	485334	1222509	W	W	I	SUMS	10	20	36	80	USGS	19900320	2.96	--	--	--
39N/03E-05L01	485354	1222712	W	W	H	SUMS	10	30	36	83	USGS	19900321	14.83			
39N/03E-05L02	485356	1222713	W	W	H	SUMS	10	38	6	83	USGS	19900321	--	228	12	4.9
39N/03E-05Q01	485333	1222657	W	W	H	SUMS	10	9	--	90	USGS	19900321	--	106	4.6	5.3
39N/03E-05Q02	485334	1222658	W	W	I	SUMS	10	28	36	90	USGS	19900321	9.42			
39N/03E-06K01	485402	1222816	W	T	U			3490		65	Drill					
39N/03E-06M01	485353	1222902	W	T	U			2000		75	Drill					

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/03E-07K01	485256	1222823	W	W	I	SUMS	10	26	36	80	USGS	19900322	2.57	--	--	--
39N/03E-07K02	485304	1222820	W	W	H	SUMS	10	24	36	83	USGS	19900322	3.57	304	14	18
39N/03E-07L01	485304	1222830	W	W	I	SUMS	10	30	36	83	USGS	19900322	2.07	--	--	--
39N/03E-08C02	485330	1222726	W	W	H	SUMS	10	27	12	90	USGS	19900322	12.03	208	7.8	15
											USGS	19900830	15.40	218	7.2	--
39N/03E-08F02	485307	1222720	W	W	H	SUMS	10	20	12	85	USGS	19900322	5.98	223	8.4	14
39N/03E-09C01	485328	1222554	W	W	I	SUMS	10	25	36	82	USGS	19900323	4.89	--	--	--
39N/03E-09D02	485324	1222624	W	W	P	SUMS	10	38	8	95	USGS	19900323	15.76	279	16	9.5
39N/03E-09Q02	485241	1222534	W	W	H	SUMS	10	20	18	95	USGS	19900329	7.63	255	5.6	0.7
39N/03E-10E01	485313	1222447	W	U	U	SUMS	10	40	6	90	USGS	19900327	9.58	--	--	--
39N/03E-10H02	485317	1222402	W	W	H	SUMS	10	47	6	97	USGS	19900329	19.89	167	8.2	<0.1
39N/03E-10J04	485254	1222351	W	W	H	BDRK	40	160	6	117	USGS	19900329	2.39	--	--	--
39N/03E-10L01	485257	1222441	W	W	H	SUMS	10	35	36	96	USGS	19900430	12.17	147	9	1.9
											USGS	19901015	15.58		8.8	0.3
											USGS	19901116	13.73	--	10	0.7
											USGS	19901217	9.6	140	7.8	2.6
											USGS	19910116	8.68	153	11.3	--
											USGS	19910221	9.80	150	10.6	2.8
											USGS	19910314	10.27	147	10.6	--
											USGS	19910429	--	--	9.6	2.5
											USGS	19910522	13.12	158	11	1.9
											USGS	19910625	--	--	12	1
											USGS	19910717	14.79	166	11	1.4
											USGS	19910823	15.58	168	11	1.8
											USGS	19910926	16.16	165	12	0.34
											USGS	19911024	16.81	163	12	0.14
39N/03E-10Q01	485239	1222409	W	Z	H			210		140	USGS					
39N/03E-10Q02	485245	1222422	W	W	H	SUMS		28		100	USGS	19900323	11.7	--	--	--
39N/03E-10Q03	485245	1222424	W	U	U	BDRK		120		105	USGS	19900323	Flow	--	>250	--
39N/03E-11A02	485326	1222236	W	W	H	SUMS	10	37	6	105	Drill	19900412	14.5	84	3.6	0.4
39N/03E-11M01	485253	1222337	W	W	H	BDRK	40	80	6	125	USGS	19900329	Flow	414	19	<0.1
39N/03E-11P01	485241	1222314	W	U	U	BDRK	40	101	6	150	USGS	19900328	7.19	--	--	--
39N/03E-12C01	485325	1222153	W	U	U	SUMS	12	37	6	117	USGS	19900327	23.54	--	--	--
39N/03E-12D02	485328	1222207	W	W	H	SUMS	12	43	6	115	USGS	19900409	23.16	187	35	0.4
39N/03E-12G01	485314	1222138	W	W	H	SUMS	10	48	6	125	USGS	19900327	27.84	167	5	<0.1
39N/03E-12J02	485257	1222122	W	U	U	SUMS	12	50	6	130	USGS	19900412	32.28	--	--	--
39N/03E-12R03	485237	1222128	W	Z	U	SUMS	10	47	6	135	USGS	19900328	--	--	--	--
39N/03E-13E01	485211	1222225	W	W	H	BDRK	40	100	6	145	USGS	19900412	7.83	1,030	210	<0.1

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/03E-13R01	485147	1222111	W	W	H	BDRK	40	120	6	210	USGS	19900327	19.05	219	2.8	0.4
39N/03E-13R02	485149	1222135	W	W	H	SUMS	12	20	36	142	USGS	19900409	--	424	10	0.7
39N/03E-14A01	485230	1222248	W	W	I	BDRK	40	130	6	130	USGS	19900328	Flow	--	--	--
39N/03E-15C02	485233	1222428	W	W	H	BDRK	40	115	6	122	USGS	19900328	10.18	584	40	<0.1
39N/03E-15D02	485234	1222503	W	W	H	SUMS	10	35	12	97	USGS	19900329	13.13	84	1.2	3
39N/03E-15J01	485208	1222408	W	W	H	BDRK	40	72	6	180	USGS	19900328	7.82	256	4.6	<0.1
39N/03E-15L01	485209	1222445	W	W	H	BDRK	40	99	6	150	USGS	19900328	17.46	668	100	1.6
39N/03E-16B02	485237	1222536	W	W	H	SUMS	10	23	12	95	USGS	19900329	8.63	240	5	5.9
39N/03E-16F01	485214	1222604	W	W	H	SUMS	10	28	36	100	USGS	19900411	14.02	221	12	10
39N/03E-16F02	485213	1222559	W	W	H	SUMS	10	37	8	95	USGS	19910430	--	120	3.3	--
39N/03E-16L03	485203	1222608	W	W	I	SUMS	10	21	36	100	USGS	19900411	9.78	--	--	--
39N/03E-16N02	485149	1222620	W	T	U			140		98	USGS					
39N/03E-17R03	485148	1222640	W	W	H	SUMS	10	60	6	97	USGS	19900409	18.84	528	42	<0.1
39N/03E-18Q01	485147	1222808	W	W	H	SUMS	10	21	36	90	USGS	19900411	5.61	184	6.8	6.5
39N/03E-19L01	485110	1222830	W	W	H	EVRS	30	54	6	140	USGS	19900328	23.33	217	5.4	1.1
39N/03E-19N01	485056	1222853	W	W	C	EVRS	30	62	6	141	USGS	19900328	27.62	302	6	1.3
											USGS	19901016	31.26	287	6	1.4
											USGS	19901116	29.27	293	6	1.4
											USGS	19901218	26.7	--	--	--
											USGS	19910116	26.69		5.7	1.3
											USGS	19910220	26.58	287	5.7	1.3
											USGS	19910313	26.68	297	5.7	1.3
											USGS	19910423	27.28	304	7.8	<0.05
											USGS	19910521	28.44	302	6.3	1.1
											USGS	19910626	29.40	--	--	--
											USGS	19910717	29.89	--	--	--
											USGS	19910823	30.53	283	6	1.1
											USGS	19910926	30.92	272	6	1.1
											USGS	19911023	31.23	276	6	1.3
39N/03E-19Q01	485055	1222808	W	W	H	EVRS	30	97	6	181	USGS	19900409	72.65	276	5.8	0.2
39N/03E-20F02	485129	1222713	W	W	H	EVRS	30	40	6	141	USGS	19900329	15.42	202	4.4	1.6
39N/03E-20K01	485117	1222652	W	W	H	EVRS	30	45	6	153	USGS	19900329	33.58	228	4.6	1.5
39N/03E-20L01	485117	1222712	W	W	H	EVRS	30	51	6	150	USGS	19900329	39.55	171	3.4	1
39N/03E-20R01	485054	1222637	W	W	H	EVRS	31	287	6	220	USGS	19900421	122.98	>2,000	170	<0.1
39N/03E-21E01	485123	1222623	W	W	H	EVRS	30	40	6	140	USGS	19900407	11.01	216	7	1
39N/03E-21K01	485118	1222538	W	W	H	EVRS	31	158	6	190	USGS	19900420	96.96	1,160	23	--
39N/03E-21M01	485117	1222621	W	T	U					160	USGS					
39N/03E-22M01	485115	1222502	W	W	H	EVRS	30	163	6	210	USGS	19900322	105.77	295	20	<0.1

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/03E-23A01	485142	1222240	W	W	H	SUMS	10	32	6	165	USGS	19900323	11.39	131	5	<0.1
39N/03E-23D01	485138	1222339	W	U	U	BDRK	40	185	6	165	USGS	19900322	19.28	--	--	--
											USGS	19901016	20.75	--	--	--
											USGS	19901116	20.09	--	--	--
											USGS	19901218	19.07	--	--	--
											USGS	19910117	19.08	--	--	--
											USGS	19910220	18.93	--	--	--
											USGS	19910313	18.85	--	--	--
											USGS	19910422	18.88	--	--	--
											USGS	19910522	19.13	--	--	--
											USGS	19910626	20.71	--	--	--
											USGS	19910717	19.80	--	--	--
											USGS	19910823	20.23	--	--	--
											USGS	19910926	20.25	--	--	--
											USGS	19911023	20.40	--	--	--
39N/03E-23E01	485131	1222333	W	W	H	SUMS	12	21	12	135	USGS	19900322	1.82	130	6.6	0.2
39N/03E-23J01	485109	1222238	W	W	H	BDRK	40	126	6	192	USGS	19900406	65.71	2,300	990	<0.1
39N/03E-23M01	485113	1222338	W	W	H	EVRS	30	100	6	165	USGS	19900406	62.99	1,040	110	<0.1
39N/03E-24B01	485136	1222136	W	W	H	SUMS	10	18	36	149	USGS	19900409	9.29	75	0.80	0.2
39N/03E-24D01	485134	1222227	W	T	U			100	6	169	Drill					
39N/03E-25A01	485046	1222113	W	W	H	EVRS	30	148	6	227	USGS	19900404	47.7	1,330	240	<0.1
39N/03E-25E01	485025	1222215	W	W	H	EVRS	30	131	6	208	USGS	19900320	76.09	1,210	170	<0.1
39N/03E-26D01	485043	1222343	W	W	H	EVRS	30	90	6	190	USGS	19900320	68.70	324	5.6	<0.1
39N/03E-26E01	485029	1222342	W	W	H	EVRS	30	129	6	230	USGS	19900322	99.11	339	5.2	<0.1
39N/03E-26J01	485020	1222247	W	W	H	EVRS	31	182	6	230	USGS	19900320	114.7	3,690	1,100	<0.1
39N/03E-26P02	485005	1222311	W	W	P	EVRS	31	155	6	262	USGS	19900323	--	655	52	<0.1
											USGS	19901017	135.62	676	52	<0.1
											USGS	19901116	--	643	52	<0.1
											USGS	19901218	--	650	52	<0.1
											USGS	19900117	--	658	52	<0.1
											USGS	19910221	--	663	--	--
											USGS	19910313	--	663	--	<0.05
											USGS	19910422	--	660	52	<0.05
											USGS	19910522	--	700	52	<0.05
											USGS	19910620	--	694	52	<0.05
											USGS	19910717	--	663	52	<0.05
											USGS	19910823	--	692	52	<0.05
											USGS	19910926	--	662	52	<0.05

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											USGS	19911023	--	703	52	<0.05
39N/03E-27A01	485041	1222406	W	W	H	EVRS	30	150	6	195	USGS	19900407	15.69	388	4.6	<0.1
39N/03E-27H01	485038	1222353	W	U	U	EVRS	30	62		190	USGS	19900407	20.15	--	--	--
											USGS	19901016	21.92	--	--	--
											USGS	19901116	14.37	--	--	--
											USGS	19901218	17.13	--	--	--
											USGS	19910117	16.86	--	--	--
											USGS	19910220	17.76	--	--	--
											USGS	19910313	16.72	--	--	--
											USGS	19910422	17.15	--	--	--
											USGS	19910522	18.40	--	--	--
											USGS	19910625	19.40	--	--	--
											USGS	19910717	19.96	--	--	--
											USGS	19910823	20.82	--	--	--
											USGS	19910926	21.00	--	--	--
											USGS	19911023	21.14	--	--	--
39N/03E-27H02	485036	1222353	W	W	H	EVRS	30	98	6	218	USGS	19900420	79.95	--	6	<0.1
39N/03E-28F01	485031	1222604	W	W	H	EVRS	30	286	6	225	USGS	19900420	--	2,400	680	<0.1
39N/03E-28J01	485023	1222518	W	W	H	EVRS	30	85	6	230	USGS	19900420	43.70	725	6.6	<0.1
39N/03E-28Q02	485003	1222547	W	W	H	EVRS	31	180	6	290	USGS	19900404	158.70	262	4	<0.1
39N/03E-28R01	485008	1222513	W	W	H	EVRS	31	199	6	270	USGS	19900420	148.96	541	9.2	<0.1
39N/03E-29B01	485050	1222656	W	W		EVRS	30	97	6	180	USGS	19900327	--	389	15	0.1
39N/03E-29C01	485044	1222719	W	W	H	EVRS	30	105	6	180	USGS	19900327	68.32	294	5.2	<0.1
39N/03E-29D01	485043	1222734	W	W	H	EVRS	30	74		160	USGS	19900407	49.99	161	5.8	0.9
39N/03E-30A01	485044	1222758	W	W	H	EVRS	30	82		160	USGS	19900501	49.98	260	7	0.2
39N/03E-30B02	485052	1222818	W	W	H	EVRS	30	59	6	161	USGS	19900328	45.29	244	6.4	2
39N/03E-30D02	485050	1222847	W	W	H	EVRS	30	68	6	150	USGS	19900328	35.55	309	5.2	1.5
39N/03E-30N01	485005	1222850	W	W	H	EVRS	30	131	6	190	USGS	19900328	72.39	425	8	<0.1
39N/03E-30R01	485010	1222754	W	W	H	EVRS	30	217	6	302	USGS	19900327	--	437	10	<0.1
39N/03E-31B02	484959	1222818	W	T	U			1,990		250	Drill					
39N/03E-31Q02	484909	1222814	W	W	H	EVRS	30	215	6	282	USGS	19900403	177.26	470	12	<0.1
39N/03E-31R02	484919	1222805	W	W	H	EVRS	30	214	6	310	USGS	19900407	199.69	429	6.6	<0.1
39N/03E-31R03	484915	1222805	W	W	H	EVRS	30	232	6	305	USGS	19900407	194.53	440	9.4	<0.1
39N/03E-32A02	484959	1222632	W	T	U			1,520		278	Drill					
39N/03E-32E01	484947	1222735	W	W	H	EVRS	30	244	6	330	USGS	19900330	220.52	480	12	<0.1
39N/03E-32J01	484925	1222637	W	W	H	EVRS	31	218	6	310	USGS	19900420	186.14	445	30	<0.1
39N/03E-32M01	484922	1222731	W	T	U			1,720		290	Drill					
39N/03E-33K01	484923	1222537	W	W	H	EVRS	30	198	6	325	USGS	19900330	192.49	342	5.4	<0.1

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/03E-33M01	484933	1222627	W	W	H	EVRS	30	205	6	318	USGS	19900330	193.37	406	4.8	<0.1
39N/03E-33R01	484911	1222528	W	W	H	BDRK	40	270	6	310	USGS	19900403	170.8	1,660	190	<0.1
39N/03E-34C01	484957	1222439	W	T	U			500		295	Drill					
39N/03E-34N01	484909	1222504	W	W	H	SUMS	10	20	12	303	USGS	19900330	4.66	262	3.0	--
39N/03E-34P02	484911	1222447	W	W	H	EVRS	31	198	6	310	USGS	19900403	173.93	277	3.8	<0.1
39N/03E-34Q01	484913	1222418	W	W	H	EVRS	31	206	6	304	USGS	19900403	173.79	222	7.8	<0.1
39N/03E-35L01	484931	1222328	W	W	H	EVRS	30	100	6	232	USGS	19900407	84.88	571	48	<0.1
39N/03E-35R01	484908	1222249	W	W	H	EVRS	30	60	6	260	USGS	19900403	--	354	8	<0.1
39N/03E-36B01	484958	1222138	W	U	H	EVRS	30	166	8	305	USGS	19900323	141.82	--	--	--
											USGS	19901015	141.90	--	--	--
											USGS	19901116	142.06	--	--	--
											USGS	19901218	141.37	--	--	--
											USGS	19910117	141.98	--	--	--
											USGS	19910220	141.67	--	--	--
											USGS	19910313	141.44	--	--	--
											USGS	19910422	141.38	--	--	--
											USGS	19910522	142.42	--	--	--
											USGS	19910717	141.52	--	--	--
											USGS	19910823	141.60	--	--	--
											USGS	19910926	141.53	--	--	--
											USGS	19911023	141.53	--	--	--
39N/03E-36B03	484956	1222138	W	U	U	EVRS	30	31		315	USGS	19900323	12.97	--	--	--
											USGS	19901015	21.63	--	--	--
											USGS	19901116	15.48	--	--	--
											USGS	19901218	8.78	--	--	--
											USGS	19910117	8.54	--	--	--
											USGS	19910220	8.71	--	--	--
											USGS	19910313	9.91	--	--	--
											USGS	19910422	13.02	--	--	--
											USGS	19910522	17.15	--	--	--
											USGS	19910626	18.74	--	--	--
											USGS	19910717	19.66	--	--	--
											USGS	19910823	20.76	--	--	--
											USGS	19910926	21.19	--	--	--
											USGS	19911023	21.80	--	--	--
39N/03E-36L01	484922	1222154	W	W	H	EVRS	30	223	6	275	USGS	19900404	32.89	1,250	180	<0.1
39N/03E-36P01	484908	1222213	W	W	H	EVRS	30	73	6	260	USGS	19900404	31.26	329	11	<0.1
39N/03E-36P02	48490	1222158	W	W	H	EVRS	30	107	6	260	USGS	19900404	--	279	6.8	<0.1

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/04E-03C01	485410	1221642	W	W	H	VSHN	50	37	6	150	USGS	19900522	16.73	1,250	310	<0.1
39N/04E-03P01	485336	1221634	W	W	H	VSHN	50	117	6	370	USGS	19900522	45.41	2,050	640	<0.1
											USGS	19900831	55.25	2,290	690	<0.1
											USGS	19901016	--	2,160	690	<0.1
											USGS	19901115	--	2,360	731	<0.1
											USGS	19910117	--	--	750	<0.1
											USGS	19910219	--	--	743	<0.1
											USGS	19910424	--	2,510	815	<0.1
											USGS	19910522	--	--	793	<0.1
											USGS	19910717	--	--	779	<0.1
											USGS	19910925	--	2,610	820	<0.1
											USGS	19911023	--	2,680	840	
39N/04E-03P02	485337	1221634	W	U	U	VSHN	40	260	6	370	USGS	19900831	53.40	--	--	--
											USGS	19901016	53.77	--	--	--
											USGS	19901115	53.68	--	--	--
											USGS	19910117	55.13	--	--	--
											USGS	19910219	54.14	--	--	--
											USGS	19910315	54.01	--	--	--
											USGS	19910423	53.46	--	--	--
											USGS	19910522	53.20	--	--	--
											USGS	19910625	53.57	--	--	--
											USGS	19910717	54.72	--	--	--
											USGS	19910822	56.50	--	--	--
											USGS	19910925	58.50	--	--	--
											USGS	19911023	57.74	--	--	--
39N/04E-04H01	485355	1221719	W	W	H	SUMS	12	41	6	135	USGS	19900522	32.10	290	12	1.1
39N/04E-04Q01	485329	1221749	W	W	H	SUMS	12	74	6	140	USGS	19900523	29.10	233	8.6	4.5
39N/04E-04Q02	485332	1221748	W	W	I	SUMS	12	58	8	138	USGS	19900523	29.21	--	--	--
39N/04E-06D01	485411	1222051	X	T				188		100	Drill					
39N/04E-06E01	485404	1222104	W	W	H	SUMS	12	63	8	105	USGS	19900423	20.27	161	7.4	1.5
39N/04E-06E02	485407	1222050	W	W	I	SUMS	12	67	8	107	USGS		--	--	--	--
39N/04E-08C02	485324	1221925	W	W	I	SUMS	15	46	8	107	USGS	19900522	9.91	305	14	2.8
39N/04E-10D01	485316	1221654	W	W	H	VSHN	50	51		260	USGS	19900522	10.83	438	61	<0.1
39N/04E-10M01	485251	1221658	W	W	H	VSHN	50	44	6	260	USGS	19900522	8.04	>2,060	620	<0.1
39N/04E-16B01	485231	1221740	W	W	S	VSHN	50	57	6	145	USGS	19900524	35.10	--	--	--
39N/04E-16B02	485229	1221743	W	W	S	SUMS	10	77	6	130	USGS	19900524	35.38	--	--	--
39N/04E-16D01	485223	1221818	W	W	I	SUMS	15	26	36	125	USGS	19900524	23.98	--	--	--
39N/04E-16F01	485212	1221805	W	W	H	SUMS	15	22	36	130	USGS	19900524	24.93	143	3.4	1.6

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/04E-16H01	485217	1221731	W	W	H	VSHN	50	48	6	130	USGS	19900525	33.39	298	13	6.2
39N/04E-16L02	485209	1221811	W	W	H	SUMS	15	29	4	130	USGS	19900524	--	181	4.8	3.6
39N/04E-16Q02	485154	1221736	W	W	H	SUMS	15	33	6	130	USGS	19900523	20.98	167	5.6	2.7
39N/04E-17C01	485224	1221918	W	W	H	SUMS	15	53	6	120	USGS	19900523	10.72	133	3	0.2
39N/04E-18E01	485209	1222104	W	U	U	BDRK	40	121	6	210	USGS	19900424	--	--	--	--
39N/04E-18M01	485202	1222107	W	W	H	BDRK	40	154	6	190	USGS	19900424		461	41	<0.1
39N/04E-18R01	485144	1221956	W	W	H	EVRS	30	28		125	USGS	19900425	10.0	274	24	<0.1
39N/04E-19C01	485141	1222036	W	W	H	BDRK	40	167	6	230	USGS	19900424	56.42	974	120	<0.1
39N/04E-19E01	485119	1222105	W	Z	U			242	6	215	USGS	19900424	--	--	--	--
39N/04E-19E02	485122	1222049	W	W	H	BDRK	40	110	6	200	USGS	19900424	1.54	88	1.4	0.5
39N/04E-19F02	485122	1222042	W	W	H	BDRK	40	170	6	190	USGS	19900424	7.06	751	20	<0.1
39N/04E-19M01	485110	1222106	W	W	H	BDRK	40	200	6	220	USGS	19900424	69.32	886	18	<0.1
39N/04E-20H01	485118	1221840	W	W	H	SUMS	15	41	6	130	USGS	19900426	14.19	109	3	0.4
39N/04E-20L01	485104	1221925	W	W	H	SUMS	10	37	6	150	USGS	19900424	21.06	181	3.6	<0.1
39N/04E-20M02	485105	1221940	W	W	H	SUMS	10	33	6	155	USGS	19900424	21.33	293	18	<0.1
39N/04E-20M03	485105	1221946	W	U	U	SUMS	10	26	6	155	USGS	19900424	9.73	--	--	--
39N/04E-22F01	485125	1221642	W	W	H	VSHN	50	71	6	180	USGS	19900524	30.51	1,530	410	<0.1
39N/04E-22L01	485117	1221654	W	W	H	SUMS	15	30	6	155	USGS	19900523	13.50	722	50	15
39N/04E-22N01	485103	1221702	W	W	H	SUMS	15	39	6	150	USGS	19900524	12.51	342	19	2.4
39N/04E-28F01	485032	1221758	W	W	H	SUMS		52	6	160	USGS	19900425	23.6	119	4.4	0.9
39N/04E-28K02	485018	1221734	W	W	H			54	6	170	USGS	19900525	27.25			
39N/04E-29A01	485040	1221839	W	U	U	BDRK	40	275		200	USGS	19900508	--	--	--	--
39N/04E-29B01	485038	1221908	W	W	H	EVRS	10	79	6	203	USGS	19900426	69.09	263	8.2	0.3
39N/04E-29H01	485028	1221844	W	W	H	SUMS	12	20	5	205	USGS	19900425	3.42	621	25	<0.1
39N/04E-29H02	485034	1221839	W	W	H	EVRS	30	73	6	200	USGS	19900425	66.68	213	4.2	0.3
39N/04E-29M01	485021	1221938	W	W	I	EVRS	30	30	36	200	USGS	19900426	2.63	--	--	--
39N/04E-29N01	485009	1221937	W	U	U	BDRK	40	610	6	210	USGS	19900426	5.88	--	--	--
39N/04E-30D01	485044	1222049	W	W	H	EVRS	30	99	6	185	USGS	19900426	28.01	1,110	180	<0.1
39N/04E-30F01	485025	1222047	W	T	U			70		225	Drill	19900426	--	--	--	--
39N/04E-30M01	485023	1222107	W	W	H	EVRS		65		235	USGS	19900323	48.79			
39N/04E-31B01	484948	1222029	W	W	H	EVRS	30	225	6	220	USGS	19900425	Flow	1,150	260	<0.1
39N/04E-31D01	484951	1222111	X	T	U			311		250	Drill	19900426	--	--	--	--
39N/04E-31Q02	484907	1222014	W	W	H	EVRS	30	92	6	265	USGS	19900427	Flow	606	16	<0.1
39N/04E-32A01	484954	1221838	W	W	H	EVRS	30	71	6	270	USGS	19900425	23.81	1,030	77	0.2
39N/04E-32D01	484957	1221950	X	T	U			230	6	215	Drill	Flow	--	--	--	--
39N/04E-32E01	484939	1221948	W	W	H	EVRS	30	139	6	230	USGS	19900425	Flow	1,030	210	<0.1
39N/04E-32F01	484932	1221921	W	W	H	BDRK	40	231	6	290	USGS	19900920	--	--	--	--
39N/04E-32M01	484932	1221939	W	W	H	EVRS	30	101	6	265	USGS	19900920	Flow	--	--	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Lati-tude	Longi-tude	Ground water site type	Site use	Wat-er use	Hydro-geo-logic unit	Litho-logic unit	Well depth (feet)	Well dia-meter (inches)	Alti-tude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conduc-tance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
39N/04E-32N01	484916	1221947	W	W	H	EVRS	30	107	6	280	USGS	19900426	3.83	887	56	<0.1
39N/04E-33E01	484943	1221829	W	W	H	EVRS	30	123	6	340	USGS	19900426	--	927	70	<0.1
39N/04E-34C02	484952	1221649	W	W	H	EVRS	31	146	6	300	USGS	19900425	142.88	418	7.6	<0.1
40N/02E-01C01	485931	1222959	W	U	U	SUMS	10	40	36	125	USGS	19900814	4.56	--	--	--
40N/02E-01F02	485917	1222958	W	W	I	SUMS	10	28	36	121	USGS	19900814	4.3	--	--	--
40N/02E-01N01	485851	1223002	W	W	I	SUMS	10	21	36	115	USGS	19900816	5.77	--	--	--
40N/02E-02B01	485934	1223059	W	W	P	EVRS	31	149	8	180	USGS	19901218	48.8	--	--	--
											USGS	19910118	49.16	--	--	--
											USGS	19910220	48.82	--	--	--
											USGS	19910314	49.02	--	--	--
											USGS	19910423	49.20	--	--	--
											USGS	19910606	49.76	--	--	--
											USGS	19910625	50.02	--	--	--
											USGS	19910717	50.53	--	--	--
											USGS	19910822	51.01	--	--	--
											USGS	19910925	50.74	--	--	--
											USGS	19911023	50.85	--	--	--
40N/02E-02D01	485935	1223127	W	W	H	EVRS	31	138		220	USGS	19900810	70.44	187	2.4	<0.1
40N/02E-02D02	485931	1223132	W	U	U			8		220	USGS	19900815	6.19	--	--	--
40N/02E-02D03	485931	1223132	X	Z	U			155		220	USGS	19900815	--	--	--	--
40N/02E-02Q01	485854	1223048	W	W	I	SUMS	10	23	36	114	USGS	19900815	8.19	310	12	0.8
40N/02E-02Q02	485854	1223100	W	W	I	SUMS	10	23	36	115	USGS	19900830	8.67	--	--	--
40N/02E-03C01	485936	1223229	W	W	H	EVRS	30	100	6	240	USGS	19900810	50.52	390	2.6	<0.1
											USGS	19901116	49.85	369	3.2	<0.1
											USGS	19910220	48.93	383	3	<0.1
											USGS	19910314	48.82	378	5.1	<0.05
											USGS	19910521	49.18	391	2.8	<0.05
											USGS	19910625	50.41	387	2.5	<0.05
											USGS	19910717	49.90	374	2.8	<0.05
											USGS	19910822	50.50	378	3	<0.05
											USGS	19910925	50.10	380	3	<0.05
											USGS	19911023	49.99	391	3	0.14
40N/02E-03K01	485903	1223207	W	W	P	EVRS	30	208	6	250	USGS	19990815	--	--	--	--
40N/02E-04A02	485927	1223305	W	W	H	EVRS	30	51	6	237	USGS	19900810	41.55	303	5.4	<0.1
40N/02E-09H01	485829	1223306	W	U	U	EVRS	30	80	6	200	USGS	19900816	61.45	--	--	--
40N/02E-10N02	485758	1223244	W	W	H	SUMS	10	38	6	107	USGS	19900814	--	566	43	0.3
40N/02E-11M01	485814	1223135	W	W	I	SUMS	13	19	36	107	USGS	19900815	5.42	--	--	--
40N/02E-12C01	485834	1222948	W	W	I	SUMS	10	26	36	112	USGS	19910822		435	--	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/02E-12L01	485820	1222959	W	W	I	SUMS	10	31	36	111	USGS	19900814	9.84	--	--	--
40N/02E-13H01	485734	1222912	W	W	I	SUMS	12	26	36	103	USGS	19900815	--	335	13	<0.1
40N/02E-13J02	485720	1222919	W	W	I	SUMS	10	40	36	100	USGS	19900817	--	390	18	<0.1
40N/02E-13J03	485720	1222920	W	W	I	SUMS	10	20	36	100	USGS	19900817	9.34	--	--	--
40N/02E-13J04	485721	1222920	W	O	U	SUMS	10	16	1	99	USGS	19910521	3.85	323	6	--
40N/02E-13J05	485719	1222920	W	O	U	SUMS	10	16	1	99	USGS	19910521	3.79	--	--	--
40N/02E-13J06	485719	1222918	W	O	U	SUMS	10	18	1	99	USGS	19910521	5.18	--	--	--
40N/02E-13J07	485719	1222917	W	O	U	SUMS	10	16	1	99	USGS	19910521	3.64	1,090	49	--
40N/02E-14P02	485706	1223108	W	W	H	SUMS	10	39	36	91	USGS	19900814	21.62	307	12	23
40N/02E-14R01	485704	1223039	W	W	I	SUMS	10	30	36	95	USGS	19900815	--	207	9.4	2.6
40N/02E-15A02	485754	1223146	W	W	I	SUMS	10	12	18	106	USGS	19900821	--	90	--	3.2
40N/02E-15C01	485748	1223233	W	W	I	SUMS	10		--	99	USGS	19900821		373		0.1
40N/02E-15H03	485736	1223158	W	W	I	SUMS	10		36	97	USGS	19900822		251		0.7
40N/02E-15H02	485736	1223148	W	W	U	SUMS	10	15	10	100	USGS	19900821		156		3.2
40N/02E-15J01	485726	1223147	W	W	H	SUMS	10	24	36	95	USGS	19900816	9.26	351	6.4	<0.1
40N/02E-15P01	485705	1223241	W	W	H	SUMS	10	24	36	90	USGS	19900814	--	182	6.8	3
40N/02E-15Q01	485708	1223221	W	Z	U			26	36	90	USGS	--	--	--	--	--
40N/02E-15R03	485709	1223147	W	W	H	SUMS	10	26	36	92	USGS	19900821	--	223	--	8.2
40N/02E-16B02	485753	1223329	W	W	H	SUMS	10	20	30	105	USGS	19900815	--	237	12	6.7
40N/02E-21A01	485658	1223312	W	W	H	SUMS	13	21	36	90	USGS	19900814	--	178	4	0.6
40N/02E-21D01	485658	1223409	W	W	S	SUMS	10	18	18	88	USGS	19900820	--	306	--	0.59
40N/02E-21J01	485629	1223305	W	W	H	SUMS	10	21	36	83	USGS	19900817	7.60	178	9.6	8
40N/02E-21J05	485632	1223317	W	W	H	SUMS	10	17	24	82	USGS	19900821	--	128	--	4.8
40N/02E-21N02	485704	1223422	W	W	F	SUMS	10	24	36	71	USGS	19910822	--	--	--	8.2
40N/02E-21R01	485611	1223308	W	W	H	SUMS	10	24	36	73	USGS	19900814	8.02	318	24	18
40N/02E-21R02	485611	1223314	W	W	I	SUMS	10	23	36	74	USGS	19900816	--	244	11	16
40N/02E-21R03	485607	1223307	W	W	H	SUMS	10	--	18	74	USGS	19910823	--	318	--	22
40N/02E-22E02	485638	1223301	W	W	H	SUMS	10	21	36	86	USGS	19900814	7.23	130	6	4.3
40N/02E-22N02	485614	1223301	W	W	H	SUMS	10		24	74	USGS	19910822	--	313	--	13
40N/02E-22N07	485609	1223246	W	W	H	SUMS	10	30	30	74	USGS	19910822	--	142	--	5
40N/02E-22R02	485608	1223201	W	W	H	SUMS	10	30	6	60	USGS	19900815	19.46	134	6.8	3.8
40N/02E-23A03	485650	1223043	W	W	H	SUMS	10	23	6	90	USGS	19910820	--	194	--	6.7
40N/02E-23B02	485659	1223102	W	W	H	SUMS	10			92	USGS	19910821	--	222	--	11
40N/02E-23C01	485701	1223121	W	W	H	SUMS	10	38	18	90	USGS	19900814	24.20	139	4	5.6
40N/02E-23D01	485659	1223126	W	W	H	SUMS	10	30	18	91	USGS	19900710	21.3	206	7.4	5.6
40N/02E-23D02	485700	1223134	W	W	H	SUMS	10	48	6	90	USGS	19900814	19.15	357	25	8
40N/02E-23D04	48565	1223133	W	W	H	SUMS	10	42	36	83	USGS	19910822	--	248	--	13
40N/02E-23N01	485612	1223141	W	W	H	SUMS	10	34	36	75	USGS	19900816	18.1	205	10	3.6

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/02E-23P01	485613	1223104	W	U	U	SUMS	10	29	36	77	USGS	19900816	13.03	291	--	20
40N/02E-23Q01	485612	1223047	W	W	I	SUMS	10	25	36	78	USGS	19900816	9.46	--	--	--
40N/02E-26A03	485602	1223034	W	W	P	SUMS	10	33	36	76	USGS	19900817	20.23	390	24	14
40N/02E-26A04	485555	1223024	W	W	I	SUMS	10	25		60	USGS	19900816	--	288	16	11
40N/02E-26B02	485502	1223054	W	W	H	SUMS	10	32	36	65	USGS	19910822	--	220	--	7.6
40N/02E-26C03	485602	1223107	W	W	H	SUMS	10	--	36	62	USGS	19910905	--	202	--	2.2
40N/02E-26C04	485602	1223104	W	W	H	SUMS	10	25	24	65	USGS	19910805	--	206	--	4
40N/02E-26D02	485559	1223128	W	W	I	SUMS	10	25	36	70	USGS	19910905	--	190	--	5.6
40N/02E-26E01	485542	1223125	W	W	P	SUMS	10	35	10	73	USGS	19900817	21.89	--	--	--
40N/02E-27B01	485607	1223214	W	W	H	SUMS	10	41	18	65	USGS	19900815	25.56	219	9.8	9.3
												19900830	--	220	9.1	11
											USGS	19901017	25.12	235	7	12
											USGS	19901114	22.21	--	7.5	11
											USGS	19901218	21.62	206	6.2	10
											USGS	19910118	21.24	201	5.7	
											USGS	19910220	22.21	198	5.3	7.4
											USGS	19910314	22.84	195	3.9	6.3
											USGS	19910521	23.95	200	3.9	7.9
											USGS	19910626	25.10	194	3.4	8.1
											USGS	19910718	24.95	190	4.2	9.2
											USGS	19910813	25.20	194	5	9.2
											USGS	19910925	25.53	203	--	9.2
											USGS	19911023	25.48	205	6	
40N/02E-27C01	485607	1223224	W	W	H	SUMS	10	--	18	74	USGS	19910822	--	267	--	7.8
40N/02E-27D02	485558	1223248	W	W	H	SUMS	10	32	36	60	USGS	19910822	--	--	--	7.2
40N/02E-27N02	485522	1223257	W	W	H	SUMS	10	26	36	65	USGS	19900817	14.82	229	9.4	10
40N/02E-28G01	485551	1223343	W	W	H	SUMS	10	--	8	65	USGS	19910823	--	--	--	7.4
40N/02E-33B02	485506	1223324	W	W	P	SUMS	10	36	36	65	USGS	19911002	--	213	14	1.8
40N/02E-35G01	485448	1223058	W	U	U	SUMS	15	18	36	35	USGS	19900816	8.60	--	--	--
40N/02E-36N01	485425	1223003	W	W	I	SUMS	10	44	36	68	USGS	19900501	12.92	--	--	--
40N/03E-01R01	485847	1222104	W	W	I	SUMS	10	26	36	119	USGS	19900622	11.66	--	--	--
40N/03E-02B01	485935	1222242	W	W	H	SUMS	10	25	36	157	USGS	19900706	12.59	131	5.6	7.5
40N/03E-02B03	485927	1222252	W	W	I	SUMS	10	59	8	153	USGS	19900706	11.37	--	--	--
40N/03E-02C01	485930	1222308	W	W	I	SUMS	10	24	36	152	USGS	19900709	11.99	--	--	--
40N/03E-02M02	485858	1222339	W	W	I	SUMS	10	57	8	141	USGS	19900725	8.37	--	--	--
40N/03E-02N01	485849	1222321	W	W	I	SUMS	10	20	36	134	USGS	19900725	10.75	--	--	--
40N/03E-03A02	485936	1222355	W	W	H	SUMS	10	26	6	147	USGS	19900710	10.88	54	2.2	1.2

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/03E-03B01	485932	1222416	W	W	H	SUMS	10	29	6	144	USGS	19900712	9.95	158	6.4	8.3
											USGS	19900830	11.76	--	7.8	--
											USGS	19901018	11.76	143	4.6	6.3
											USGS	19901114	6.89	--	4.6	7
											USGS	19901218	4.04	--	4.4	6.7
											USGS	19910117	4.12	146	5	
											USGS	19910220	4.15	153	5.3	7.4
											USGS	19910314	4.88	161	--	8.2
											USGS	19910423	6.19	193	5.7	1
											USGS	19910521	7.52	184	6	11
											USGS	19910625	8.70	170	5.7	10
											USGS	19910717	11.08	171	5.9	10
											USGS	19910821	11.78	162	--	9.3
											USGS	19910929	11.05	143	4	
											USGS	19911023	11.42	139	4	
40N/03E-03N02	485849	1222449	W	W	I	SUMS	12	23	36	128	USGS	19900709	7.26	--	--	--
40N/03E-03R02	485847	1222358	W	W	P	SUMS	10	73	8	135	USGS	19900713	--	252	9.4	9.9
40N/03E-03R03	485847	1222355	W	W	P	SUMS	10	73	10	135	USGS	19900713	12.45	--	--	--
40N/03E-05E01	485915	1222728	W	W	I	SUMS	10	33	36	129	USGS	19900629	5.75	--	--	--
40N/03E-05E02	485919	1222737	W	W	I	SUMS	10	30	36	131	USGS	19900629	4.40	--	--	--
40N/03E-05L01	485900	1222719	W	O	U	SUMS	10	18	36	125	USGS	19900725	11.8	1,220	58	<0.05
40N/03E-05L02	485900	1222714	W	O	U	SUMS	10	13	36	125	USGS	19900725	9.87	--	--	--
40N/03E-05M03	485900	1222725	W	O	U	SUMS	10	14	36	126	USGS	19900725	10.4	--	--	--
40N/03E-05M04	485859	1222722	W	O	U	SUMS	10	14	36	126	USGS	19900725	10.0	--	--	--
40N/03E-05M05	485905	1222722	W	O	U	SUMS	10	12	36	127	USGS	19900725	9.15	340	15	18
40N/03E-05N01	485848	1222740	W	W	H	SUMS	10	18	18	123	USGS	19900711	--	252	15	0.1
40N/03E-05N02	485848	1222727	W	W		SUMS	10	20	6	118	USGS	19900725	9.64	138	10	1.3
40N/03E-06B01	485930	1222819	W	W	I	SUMS	12	29	36	132	USGS	19900710	3.05	--	--	--
40N/03E-06C01	485934	1222826	W	W	I	SUMS	11	33	36	130	USGS	19900629	3.55	--	--	--
40N/03E-06M01	485909	1222900	W	U	U	EVRS	30	156	6	123	USGS	19900710	5.85	--	--	--
40N/03E-06M02	485907	1222900	W	W	I	SUMS	12	30	36	122	USGS	19900710	4.71	--	--	--
40N/03E-06N02	485852	1222855	W	W	I	SUMS	12	30	36	118	USGS	19900629	3.39	--	--	--
40N/03E-07A02	485835	1222743	W	W	H	SUMS	11	21	18	116	USGS	19900712	7.49	237	10	11
40N/03E-07J01	485809	1222745	W	W	I	SUMS	10	31	36	111	USGS	19900710	4.69	--	--	--
40N/03E-07M02	485810	1222844	W	W	I	SUMS	10	24	36	111	USGS	19900723	11.51	--	--	--
40N/03E-07M03	485810	1222849	W	W		SUMS	10	25	8	111	USGS	1990072	--	--	--	--
40N/03E-08J01	485811	1222623	W	W	I	SUMS	11	26	36	113	USGS	19900720	4.61	--	--	--
40N/03E-08N03	485802	1222739	W	U	U	SUMS	10	24	36	112	USGS	19900725	6.13	--	--	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/03E-09A04	485838	1222512	W	W	I	SUMS	12	27	36	123	USGS	19900712	7.94	--	--	--
40N/03E-09D01	485837	1222612	W	W	I	SUMS	12	22	36	118	USGS	19900712	4.94	--	--	--
40N/03E-09G01	485830	1222523	W	W	S	SUMS	10	65	6	122	USGS	19900712	7.41	252	13	<0.1
40N/03E-10C02	485839	1222425	W	W	H	SUMS	10	18	--	132	USGS	19910503	5.58	--	5.7	6.2
40N/03E-10K01	485816	1222418	W	W	H	SUMS	10	30	6	132	USGS	19900803	15.27	286	12	10
40N/03E-10R02	485752	1222346	W	W	H	SUMS	10	38	36	115	USGS	19900809	13.96	237	11.5	1.1
40N/03E-11E03	485818	1222340	W	W	H	SUMS	10	36	18	130	USGS	19900808	17.40	219	8.8	12
40N/03E-11E04	485818	1222336	W	W	H	SUMS	10	44	6	130	USGS	19900808	17.05	188	6.6	8.1
40N/03E-12A05	485841	1222106	W	W	I	SUMS	10	80	10	133	USGS	19900621	23.97	--	--	--
40N/03E-12H01	485824	1222105	W	T	U	SUMS	10	120	8	100	Drill	--	--	--	--	--
40N/03E-13N01	485705	1222222	X	Z	U			175		85	Drill	--	--	--	>250	--
40N/03E-13Q01	485659	1222142	W	U	U			225	--	86	USGS	--	--	--	--	--
40N/03E-14B01	485747	1222254	W	Z	U			265	--	95	USGS	--	--	--	--	--
40N/03E-14B02	485748	1222255	W	U	H	EVRS	99	9		95	USGS	19900807	4.13	--	--	--
40N/03E-15B02	485750	1222407	W	Z	U			33	18	125	USGS	--	--	--	--	--
40N/03E-15B03	485751	1222406	W	U	U	SUMS	10	30	6	125	USGS	19900807	24.06	--	--	--
40N/03E-16A02	485746	1222503	W	W	H	SUMS	10	29	12	117	USGS	19900723	11.60	197	10	2.7
											USGS	19900827	12.93	216	14	7.4
											USGS	19901017	13.24	235	15	8.3
											USGS	19901114	11.71	239	14	8.3
											USGS	19901217	6.45	216	12	8.2
											USGS	19910119	5.50	224	12	--
											USGS	19910221	5.78	200	9.6	6.5
											USGS	19910314	6.04	185	8.9	6.4
											USGS	19910423	7.18	228	9	12
											USGS	19910521	8.39	260	8.9	14
											USGS	19910625	9.64	257	8.2	15
											USGS	19910717	11.10	241	8.2	13
											USGS	19910822	12.42	261	7.2	14
											USGS	19910926	13.07	284	9	16
											USGS	19911023	13.07	281	8	--
40N/03E-16D01	485745	1222617	W	W	I	SUMS	10	27	36	111	USGS	19900808	10.71	356	27	4.6
40N/03E-16F01	485736	1222559	W	W	H	SUMS	10	21	12	106	USGS	19900723	5.07	260	14	<0.1
40N/03E-16H03	485737	1222507	W	W	H	SUMS	10	--	--	114	USGS	19900720	--	214	7.6	6.3
40N/03E-16H04	485737	1222509	W	W	I	SUMS	10	58	6	114	USGS	19900720	13.21	--	--	--
40N/03E-16H05	485727	1222520	W	W	P	SUMS	10	45	36	117	USGS	19900808	31.69	--	--	--
40N/03E-16H06	485727	1222508	W	W	I	SUMS	10	28	36	96	USGS	19900808	6.96	202	9	5.2
40N/03E-16K01	485719	1222536	W	W	H	SUMS	10	33	36	105	USGS	19900723	--	166	6.8	7.2

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/03E-16M01	485723	1222622	W	T	U	EVRS		344	6	100	Drill	19840223	30	12,200	>5,000	<0.1
40N/03E-16Q01	485706	1222533	W	W	I	SUMS	10	50	8	104	USGS	19900719	1.30	205	9.6	1.5
40N/03E-17E01	485734	1222733	W	W	I	SUMS	10	28	36	104	USGS	19900719	4.10	--	--	--
40N/03E-18E01	485737	1222857	W	W	I	SUMS	10	36	36	103	USGS	19900713	5.15	--	--	--
40N/03E-18G01	485738	1222818	W	W	I	SUMS	10	30	36	106	USGS	19900709	3.68	--	--	--
40N/03E-19A01	485659	1222756	W	W	I	SUMS	12	40	8	98	USGS	19900719	6.06	148	8.2	0.2
40N/03E-22C01	485654	1222431	W	U	U	SUMS	15	15	--	55	USGS	19900809	10.0	--	--	--
40N/03E-24E01	485643	1222222	W	W	U	EVRS	30	147	--	75	USGS	19911002	7.93	10,100	2,800	0.06
40N/03E-25F01	485545	1222159	W	W	I	SUMS	15	29	12	76	USGS	19900621	5.03	467	--	1.2
40N/03E-25J01	485538	1222107	W	W	I	SUMS	21	45	8	78	USGS	19900621	2.98	--	--	--
40N/03E-26H01	485546	1222233	W	W	I	SUMS	15	24	36	70	USGS	19900622	6.93	--	--	--
40N/03E-31J01	485948	1222751	W	W	H	SUMS	10	12	36	73	WCHD	19910129	7.1	--	--	13
40N/03E-31L01	485445	1222838	W	W	H	SUMS	10	30	18	62	USGS	19900424	16.66	118	5	3.4
40N/03E-31L02	485447	1222830	W	W	H	SUMS	10	19	6	61	USGS	19900424	10.4	--	3.6	3.4
40N/03E-31N02	485428	1222903	W	W	U	SUMS	10	53	6	80	USGS	19900424	26.42	--	--	--
40N/03E-31P03	485425	1222829	W	W	H	SUMS	10	36	18	75	USGS	19900424	23.81	308	12	18
40N/03E-31R01	485430	1222749	W	W	H	SUMS	10	16	36	70	WCHD	19910129	8.9	--	--	9.4
40N/03E-32G01	485453	1222706	W	T	U	EVRS		442	4	77	Drill	19850315	80	--	>2,500	--
40N/03E-32K02	485438	1222658	W	W	H	SUMS	10	57	6	90	USGS	19900425	23.8	117	23	<0.1
40N/03E-32L01	485445	1222712	W	W		SUMS	10	50	36	87	USGS	19900425	27.55	203	4.4	12
40N/03E-32L03	485443	1222711	W	W	H	SUMS*	10	41	24	89	WCHD	19910121	24.3	--	--	3.6
40N/03E-32M01	485444	1222728	W	W	H	SUMS	10	26	18	76	USGS	19900427	12.93	187	8.2	11
											USGS	19901017	15.29	181	6	11
											USGS	19901116	13.86	--	6.8	11
											USGS	19901217	12.23	162	6.2	8.9
											USGS	19910119	11.73	195	7.9	11
											USGS	19910221	11.72	194	7.4	11
											USGS	19910313	11.91	185	7.1	12
											USGS	19910424	12.36	190	8	13
											USGS	19910521	12.80	175	7.1	11
											USGS	19910625	13.30	175	6.4	10
											USGS	19910718	12.80	184	6.7	12
											USGS	19910823	14.55	188	8	12
											USGS	19910926	14.94	190	8	12
40N/03E-32M02	485438	1222735	W	W	H	SUMS	10	23	24	73	WCHD	19910129	8.6			
40N/03E-32P01	485427	1222717	W	W	H	SUMS	10	40	6	85	USGS	19900424	17.77	153	3.2	5.6
40N/03E-32P02	485434	1222720	W	T				900		92	Drill		--	--	>250	--
40N/03E-32Q01	485428	1222658	W	W	H	SUMS	10	25	18	83	USGS	19900322	15.47	107	5.2	1.2

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/03E-33F01	485450	1222555	W	W	U	SUMS	10	29	12	76	USGS	19900424	17.27	--	--	--
40N/03E-33G01	485450	1222546	W	W	H	SUMS	10	28	12	74	USGS	19900427	19.16	200	6	1.3
40N/03E-33J02	485446	1222517	W	W	H	SUMS	10	33	6	65	USGS	19900425	10.54	263	17	<0.1
40N/03E-34E01	485454	1222504	W	W	I	SUMS	11	18	30	58	USGS	19900425	5.53	--	--	--
40N/03E-34P01	485427	1222429	W	W	I	SUMS	10	34	36	80	USGS	19900320	9.34	--	--	--
40N/03E-34Q01	485434	1222425	X	T	U			256	6	80	Drill	19900825	19.03	--	--	--
40N/03E-35R01	485423	1222228	W	U	U	SUMS	10	23	36	108	USGS	19900425	18.96	--	--	--
40N/03E-35R02	485425	1222232	W	W	H	SUMS	10	51	6	105	USGS	19900425	20.34	392	59	0.1
40N/03E-36J01	485446	1222121	W	Z	U	SUMS	10	30	84	90	USGS	--	--	--	--	--
40N/03E-36J02	485445	1222123	W	W	P	SUMS	10	32	36	86	USGS	19900426	9.9	--	--	--
40N/03E-36J03	485446	1222117	W	W	P	SUMS	10	36	36	90	USGS	19900426	10.65	--	--	--
40N/03E-36Q01	485431	1222127	W	W	P	SUMS	10	45	8	105	Drill	19900426	18.2	237	33	--
40N/04E-01C01	485932	1221400	W	W	I	SUMS	22	119	8	44	USGS	19900515	--	--	--	--
40N/04E-01K02	485900	1221350	W	W	I	SUMS	22	97	8	40	USGS	19900516	11.1	283	10	<0.05
40N/04E-02L02	485907	1221524	W	W	I	SUMS	22	69	8	35	USGS	19900516	3.49	--	--	--
40N/04E-03J01	485856	1221558	W	W	I	SUMS	20	59	8	45	USGS	19900518	4.83	--	--	--
40N/04E-04D01	485934	1221812	W	W	H	SUMS	14	95	6	154	USGS	19900522	62.8	252	7.6	8.4
40N/04E-05D01	485935	1221938	W	U	U	SUMS	10	61	36	183	USGS	19790523	56.65	--	--	--
40N/04E-05D02	485934	1221944	W	W	I	SUMS	10	80	8	181	USGS	19900518	45.03	--	--	--
40N/04E-05E01	485910	1221932	W	W	I	SUMS	10	34	8	95	USGS	19900516	4.16	--	--	--
40N/04E-05E02	485921	1221944	W	W	I	SUMS	10	77	8	162	USGS	19900516	29.40	--	--	--
40N/04E-05L01	485906	1221927	W	W	H	SUMS	10	38	6	100	USGS	--	--	--	12.8	--
40N/04E-05N01	485846	1221935	W	W	H	SUMS	14	28	6	70	USGS	19900515	14.30	--	4.6	--
40N/04E-05N02	485853	1221946	W	W	H	SUMS	14	85	6	139	USGS	19900515	62.72	250	6.1	--
40N/04E-05P01	485848	1221913	W	W	H	SUMS	14	23	36	74	USGS	19900530	15.72	216	6.8	8.4
40N/04E-05P02	485850	1221914	W	W	H	SUMS	14	28	36	56	USGS	19900530	14.72	--	13	--
40N/04E-06B01	485935	1222017	W	W	H	SUMS	10	75	6	168	USGS	19900518	31.78	134	3	<0.1
40N/04E-06B02	485935	1222023	W	W	I	SUMS	10	88	8	166	USGS	19900518	28.28	--	--	--
40N/04E-06G01	485911	1222021	W	W	H	SUMS	10	32	36	155	USGS	19900522	23.21	--	--	--
40N/04E-06G02	485910	1222022	W	U	U	SUMS	10	25	6	136	USGS	19900522	8.69	--	--	--
40N/04E-07G01	485829	1222019	W	W	C	SUMS	10	78	8	110	USGS	19900522	2.39	--	--	--
40N/04E-07H04	485826	1221948	W	W	P	SUMS	14	89	--	74	USGS	--	--	--	--	--
40N/04E-08A02	485839	1221839	W	W	I	SUMS	20	57	10	56	USGS	19900522	7.18	--	--	--
40N/04E-08L01	485811	1221913	W	W	I	SUMS	20	58	8	60	USGS	19900524	7.37	--	--	--
40N/04E-09B01	485830	1221732	W	W	I	SUMS	20	49	9	48	USGS	19900522	0.89	235	11	<0.1
											USGS	19910314	-0.83			
											USGS	19910626	0.81			
											USGS	19910717	1.77			

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											USGS	19910822	1.71			
											USGS	19910925	1.17			
											USGS	19911023	1.37			
40N/04E-09N03	485759	1221819	W	W	I	SUMS	22	78	8	59	USGS	19900524	7.5	384	19	<0.1
											USGS	19900828	9.18			
											USGS	19901017	8.43			
											USGS	19901116	3.81			
											USGS	19901218	3.52			
											USGS	19910117	3.51			
											USGS	19910221	3.91			
											USGS	19910314	5.20			
											USGS	19910425	6.24			
											USGS	19910521	6.92			
											USGS	19910626	7.46			
											USGS	19910718	8.40			
											USGS	19910822	8.51			
											USGS	19910926	7.95			
											USGS	19911023	8.24			
40N/04E-09Q01	485755	1221746	W	W	I	SUMS	20	59	8	55	USGS	19900523	2.87	--	--	--
40N/04E-09Q02	485752	1221603	W	W	I	SUMS	22	78	8	45	USGS	19900518	6.36	--	--	--
40N/04E-10B01	485841	1221624	W	W	I	SUMS	20	50	9	46	USGS	19900523	5.25	--	--	--
40N/04E-10C01	485843	1221644	W	W	I	SUMS	20	60	8	44	USGS	19900524	3.38	--	5	--
40N/04E-10E02	485828	1221707	W	W	I	SUMS	21	38	10	46	USGS	19900523	2.36	--	--	--
40N/04E-10G01	485828	1221627	W	W	I	SUMS	22	69	8	47	USGS	19900530	8.74	--	--	--
40N/04E-10R03	485759	1221557	W	W	I	SUMS	20	63	8	52	USGS	19900523	5.79	--	--	--
40N/04E-11C01	485834	1221515	W	W	I	SUMS	15	21	36	43	USGS	19900523	3.77	--	--	--
40N/04E-12B01	485831	1221345	W	W	I	SUMS	22	107	8	50	USGS	19900530	12.81	--	--	--
40N/04E-12C01	485838	1221408	W	W	I	SUMS	22	104	8	45	USGS	19900530	5.59	--	--	--
40N/04E-15B01	485744	1221621	W	W	I	SUMS	20	25	36	56	USGS	19900523	5.08	--	--	--
40N/04E-15C01	485750	1221640	W	W	I	SUMS	22	82	8	55	USGS	19900607	4.65	--	--	--
40N/04E-15J01	485713	1221600	W	W	H	SUMS	--	130	6	78	USGS	19900605	9.78	146	2.6	1.2
40N/04E-16A02	485742	1221723	W	U	U	SUMS	15	26	36	55	USGS	19900607	1.75	--	--	--
40N/04E-17B02	485748	1221857	W	W	I	SUMS	15	57	8	62	USGS	19900606	5.00	--	--	--
40N/04E-17G01	485731	1221900	W	W	I	SUMS	15	26	36	65	USGS	19900606	1.82	321	16	0.06
40N/04E-17N01	485704	1221929	W	W	I	SUMS	20	30	8	66	USGS	19900607	1.66	--	--	--
40N/04E-18R01	485659	1221958	W	W	I	SUMS	20	67	8	65	USGS	19900607	2.68	--	--	--
40N/04E-19G01	485648	1222017	W	Z	U	SUMS	20	57	4	70	USGS	--	--	--	--	--
40N/04E-19G02	485648	1222018	W	Z	U	BDRK	40	435	6	70	USGS	19480702	27	--	>250	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/04E-19G03	485645	1222018	W	U	U	SUMS	20	40	6	70	USGS	19900712	5.15	--	--	--
40N/04E-19K01	485626	1222026	W	W	I	SUMS	20	57	10	70	USGS	19900614	4.13	--	--	--
40N/04E-20D01	485652	1221930	W	W	I	SUMS	20	57	8	69	USGS	19900607	4.94	--	--	--
40N/04E-20F01	485642	1221912	W	W	H	SUMS	15	18	18	72	USGS	19900607	3.94	--	12	0.1
											USGS	19900830	7.05	--	12	0.1
											USGS	19901017	6.74	309	13	0
											USGS	19901115	2.02	267	12	0.7
											USGS	19901217	1.15	241	11	1.5
											USGS	19910117	1.22	161	9.9	--
											USGS	19910219	0.95	230	10	1.5
											USGS	19910314	2.65	252	9.9	0.8
											USGS	19910423	3.57	260	10	0.62
											USGS	19910522	4.50	291	13	0.36
											USGS	19910625	5.05	--	--	--
											USGS	19910717	5.92	--	--	--
											USGS	19910822	6.24	320	--	0.14
											USGS	19910925	5.95	306	13	0.13
											USGS	19911023	6.36	315	--	0.22
40N/04E-21F01	485632	1221810	W	U	U	SUMS	10	55	18	130	USGS	19900607	47.25	--	--	--
40N/04E-22G01	485639	1221618	W	W	H	SUMS	10	42	6	150	USGS	19900621	18.02	128	4.8	5.2
40N/04E-22J01	485624	1221607	W	W	H	SUMS	10	56	6	176	USGS	19900608	28.14	86	1.9	2.0
40N/04E-22J02	485628	1221609	W	T	U	--		200		178	Drill	--	--	--	--	--
40N/04E-22R01	485607	1221611	W	W	H	VSHN	50	60	6	178	USGS	19900608	33.11	210	1.6	<0.1
40N/04E-23N01	485608	1221535	W	W	H	VSHN	50	82	6	360	USGS	19900606	56.72	423	21	--
40N/04E-27K01	485538	1221620	W	U	U	VSHN	50	62	6	210	USGS	19900615	22.2	--	--	--
40N/04E-28D02	485555	1221815	W	W	H	SUMS	10	67		130	USGS	19900613	33.86	156	3.8	1.6
40N/04E-28H01	485544	1221714	W	W	I	SUMS	10	36	8	115	USGS	19900614	0.47	--	--	--
40N/04E-28R01	485515	1221722	X	T	S	SUMS	10	32	12	111	USGS	19900608	2.16	--	--	--
40N/04E-29H02	485542	1221833	W	W	H	SUMS	10	59	6	110	USGS	19900614	7.11	109	8.6	<0.1
40N/04E-29R01	485515	1221846	W	W	I	SUMS	15	31	8	85	USGS	19900614	2.58			
40N/04E-30D01	485601	1222102	W	W	I	SUMS	21	27	36	75	USGS	19900807	2.84	--	--	--
40N/04E-30E01	485553	1222103	W	W	I	SUMS	21	33	8	75	USGS	19900807	5.82	--	--	--
40N/04E-30G01	485546	1222026	W	W	I	SUMS	20	37	8	75	USGS	19900621	2.55	438	28	<0.05
40N/04E-31R02	485429	1221959	W	W	I	SUMS	15	32	8	90	USGS	19900615	6.45	393	19	<0.05
40N/04E-33A03	485505	1221718	W	W	I	SUMS	12	34	8	125	USGS			308	5.8	2.7
40N/04E-33R01	485430	1221715	W	W	H	SUMS	10	62	6	125	USGS	19900614	33.87	284	6.8	0.9
40N/04E-34F01	485454	1221651	W	W	H	SUMS	10	51	36	160	USGS	19900614	36	511	3.4	1.8
40N/04E-34P01	485433	1221648	W	W	C	SUMS	12	57		150	USGS	19900614	27.07	235	6.4	1.2

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
40N/05E-06D01	485932	1221253	W	W	I	SUMS	20	43	36	38	USGS	19900510	5.6	--	--	--
40N/05E-06K01	485907	1221214	W	O	Z	SUMS	23	7	1	32	USGS	19910702	4.3	301	11	<0.05
40N/05E-06L02	485859	1221251	W	W	I	SUMS	22	74	8	37	USGS	19900510	6.95	--	--	--
40N/05E-06M01	485859	1221307	W	W	I	SUMS	22	90	8	38	USGS	--	--	--	--	--
41N/02E-33J01	485958	1223301	W	W	H	EVRS	30	79	6	250	USGS	19900810	48.27	498	39	--
41N/02E-35P01	485939	1223106	W	W	H	EVRS	30	73		160	USGS	19900815	28.43	328	27	<0.1
41N/02E-35Q02	485944	1223049	W	T	U			424		150	Drill	--	--	--	--	--
41N/02E-36J01	485954	1222908	W	U	U	SUMS	12	24		129	USGS	19900814	6.29	--	--	--
41N/02E-36K01	485954	1222936	W	W	I	SUMS	10	29	36	129	USGS	19900814	7.80	229	18	6.6
41N/02E-36M01	485957	1223002	W	W	I	SUMS	10	30	36	134	USGS	19900814	24.5	--	--	--
41N/03E-31E01	490008	1222900	W	W	H	SUMS	10	30	6	141	USGS	19900629	7.02	218	14	12
41N/03E-31Q01	485944	1222820	W	W	I	SUMS	11	33		136	USGS	19900629	3.61	--	--	--
41N/03E-32Q01	485949	1222700	W	W	H	SUMS	10	25		137	USGS	19900725	9.85	517	15	--
41N/03E-33E01	490005	1222620	W	W	S	SUMS	10	43	6	146	USGS	19900629	8.70	312	16	2.3
41N/03E-33G01	490008	1222538	W	T				283		141	Drill	--	--	--	--	--
41N/03E-34F01	490008	1222427	W	W	H	SUMS	10	22		146	USGS	19900705	9.79	436	14	15
41N/03E-34G01	490003	1222420	W	W	I	SUMS	10	38	8	141	USGS	19900705	3.73	--	--	--
41N/03E-34M01	490002	1222443	W	W	H	SUMS	10	20	36	141	USGS	19900705	4.60	388	9.5	20
41N/03E-34Q01	485938	1222404	W	W	H	SUMS	10	61	6	146	USGS	19900706	9.62	198	5.8	<0.1
41N/03E-35L01	485957	1222304	W	W	H	SUMS	10	25	6	158	USGS	19900709	--	271	8.4	20
41N/03E-36J01	485951	1222106	W	W	H	SUMS	10	37	18	163	USGS	19900706	26.3	146	5.2	9.9
41N/03E-36J02	485953	1222109	W	W	H	SUMS	10	92	6	162	USGS	19900607	25.00	120	6.2	<0.1
41N/03E-36N01	485946	1222218	W	W	I	SUMS	10	26	36	159	USGS	19900706	12.48	--	--	--
41N/04E-31J01	485952	1221947	W	U	U	SUMS	10	59	6	175	USGS	--	--	--	--	--
41N/04E-31J02	485955	1221949	W	W	H	SUMS	10	80	8	185	USGS	19900508	44.62	199	6.5	13
											USGS	19901018	50.31	231	7.4	14
											USGS	19901114	50.45	244	7.2	2.9
											USGS	19901218	46.4	232	6.6	13
											USGS	19910117	43.77	234	6.7	13
											USGS	19910219	43.54	220	7.1	11
											USGS	19910314	43.01	215	6.7	10
											USGS	19910423	43.39	212	7	8.1
											USGS	19910521	44.08	215	7.1	8.6
											USGS	19910625	45.28	224	8.4	10
											USGS	19910717	46.33	200	6.4	11
											USGS	19910822	46.89	225	6	13
											USGS	19910929	48.92	224	7	13
											USGS	19911023	49.79	219	6	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
41N/04E-31R01	485945	1221952	W	W	I	SUMS	10	71	8	174	USGS	19900509	33.37	--	--	--
41N/04E-31R02	485946	1221944	W	W	H	SUMS	10	77		169	USGS	19900509	33.63	180	5.8	3.4
41N/04E-32E01	490003	1221942	W	T				400		206	Drill	--	--	--	--	--
41N/04E-32M01	485953	1221937	W	W	H	SUMS	10	95	8	189	USGS	19900510	49.81	--	--	--
41N/04E-32Q01	485948	1221853	W	W	H	SUMS	10	26		132	USGS	19900508	6.46	273	8.4	15
41N/04E-32R01	485944	1221838	W	W	H	SUMS	14	92	6	194	USGS	19900516	76.70	308	8.8	15
41N/04E-33H01	490004	1221717	W	W	P	SUMS	20	58	8	48	USGS	19900604	Flow	259	7.4	2
41N/04E-33H01S	490003	1221715	S		U	SUMS	--	--	--	46	USGS	19900604	Flow	243	6.2	5
41N/04E-33H02	490003	1221718	W	W	P	SUMS	20	58	12	48	USGS	19900604	Flow	268	7	6.3
41N/04E-33H03	490006	1221718	W	W	P	SUMS	20	58	12	49	USGS	19900604	Flow	265	7.2	6.3
41N/04E-33H04	490005	1221716	W	W	P	SUMS	20	69		50	USGS	19900604	Flow	274	7.2	5.1
41N/04E-33N02	485947	1221820	W	T	U	SUMS	14	87	6	119	USGS	19900508	18.91	--	--	--
											USGS	19901017	21.97	--	--	--
											USGS	19901114	21.95	--	--	--
											USGS	19901201	19.85	--	--	--
											USGS	19910117	18.14	--	--	--
											USGS	19910219	18.08	--	--	--
											USGS	19910315	18.06	--	--	--
											USGS	19910522	18.88	--	--	--
											USGS	19910626	19.43	--	--	--
											USGS	19910717	19.84	--	--	--
											USGS	19910821	20.53	--	--	--
											USGS	19910925	21.11	--	--	--
											USGS	19911023	21.69	--	--	--
41N/04E-33N03	485948	1221803	W	T	U	SUMS	14	76	6	86	USGS	19900509	Flow	--	--	--
41N/04E-33N04	485946	1221803	W	T	U	SUMS	14	72	6	87	USGS	19900509	Flow	148	9.2	--
41N/04E-33N05	485938	1221803	W	T	U	SUMS	14	73	6	109	USGS	19900508	22.86	--	--	--
											USGS	19901017	24.80	--	--	--
											USGS	19901114	24.72	--	--	--
											USGS	19901217	23.23	--	--	--
											USGS	19910117	21.98	--	--	--
											USGS	19910219	22.20	--	--	--
											USGS	19910315	22.22	--	--	--
											USGS	19910522	22.83	--	--	--
											USGS	19910626	23.21	--	--	--
											USGS	19910717	23.50	--	--	--
											USGS	19910821	23.92	--	--	--
											USGS	19910925	24.31	--	--	--

Appendix Table 1. Well, water-level, hydrogeologic, and reconnaissance water-quality data--Continued

Local well number	Latitude	Longitude	Ground water site type	Site use	Water use	Hydrogeologic unit	Lithologic unit	Well depth (feet)	Well diameter (inches)	Altitude (feet)	Source of data	Water-level or sample date	Water level, feet below land surface	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Nitrogen NO_2+NO_3 total (mg/L as N)
											USGS	19911023	24.64	--	--	--
41N/04E-36H01	490004	1221309	W	T	U			167	8	35	USGS	--	--	--	--	--
41N/04E-36L01	485954	1221343	W	W	I	SUMS	22	63	8	30	USGS	19900509	6.41	--	--	--
41N/05E-31M01	485959	1221247	W	W	I	SUMS	22	71	8	35	USGS	19900515	5.81	--	--	--
41N/05E-31N02	485942	1221252	W	W	I	SUMS	22	78	8	30	USGS	19900509	8.2	--	--	--
41N/05E-31P01	485944	1221226	W	W	I	SUMS	22	95	8	34	USGS	19900510	8.91	--	--	--
41N/05E-32L01	485953	1221059	W	W	I	SUMS	15	34	8	27	USGS	19900510	7.6	--	--	--
41N/05E-32L02	490000	1221108	X	Z	U	--		180	8	27	USGS	--	--	--	--	--

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
Sumas aquifer						
092G.008.2.2.2-11	6	5	25	10.0	360	80
092G.008.2.2.2-15	36	4	21	8.0	120	52
092G.008.2.2.3-03	6	5	12	26.0	90	9.9
092G.008.2.4.1-41	6	5	30	22.0	480	42
092G.009.2.1.1-38	12	20	1,100	22.6	4,300	560
092G.009.2.3.1-32	6	5	20	10.0	120	55
39N/02E-01P02	36	1	85	2.5	60	350
39N/02E-02A01	6	5	12	16.0	30	14
39N/02E-10J01	36	1	100	10.0	60	100
39N/02E-12Q01	6	5	30	20.0	60	36
39N/02E-14M01	36	1	175	12.0	240	150
39N/02E-16A01	12	4	20	1.0	240	830
39N/02E-16H03	12	4	20	9.0	240	71
39N/02E-21K01	8	3	100	4.0	60	13
39N/02E-22D02	6	5	20	8.2	120	69
39N/02E-22K02	6	9	5	5.0	60	13
39N/02E-23F01	12	10	30	4.0	240	110
39N/02E-23G02	36	3	7	3.5	60	40
39N/02E-24C02	12	4	30	2.0	240	600
39N/02E-24N02	12	10	15	2.0	480	120
39N/02E-26C01	36	2	200	14.0	48	890
39N/02E-26N01	36	6	50	5.0	120	170
39N/02E-27F03	6	5	18	4.0	180	140
39N/02E-27J01	36	6	20	1.5	120	240
39N/02E-27K01	18	6	16	7.5	240	40
39N/02E-27N01	12	6	80	6.0	240	350
39N/02E-28J02	18	6	25	4.0	240	140
39N/02E-28J03	18	6	60	4.0	120	340
39N/03E-01D01	36	9	120	5.0	240	350
39N/03E-01R01	6	2	18	1.0	240	170
39N/03E-02B02	6	8	14	17.0	240	15
39N/03E-02N02	6	1	10	10.0	60	61
39N/03E-03R02	8	2	32	5.0	120	480
39N/03E-04M02	6	6	10	1.0	30	240
39N/03E-04R02	36	1	88	10.0	360	90
39N/03E-07A01	36	1	265	21.0	120	120
39N/03E-07K02	36	6	40	3.0	240	270
39N/03E-08C01	36	1	100	6.0	720	170
39N/03E-08F02	12	1	20	1.0	240	613
39N/03E-09D02	8	10	85	5.0	300	310
39N/03E-10E01	6	5	15	7.0	180	63
39N/03E-10H02	6	5	15	6.0	120	71
39N/03E-11A02	6	5	10	4.0	30	59
39N/03E-12D02	6	3	18	4.0	240	25

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number--Continued

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
Sumas aquifer--Cont.						
39N/03E-15D02	12	8	60	2.0	360	670
39N/03E-16B02	12	5	20	6.0	240	90
39N/03E-16F01	36	1	85	10.0	60	87
39N/03E-17R03	6	5	13	16.0	30	16
39N/03E-18Q01	36	1	50	7.0	60	73
39N/03E-23A01	6	3	15	1.5	60	510
39N/03E-23E01	12	3	20	4.0	240	240
39N/03E-24B01	36	3	24	0.5	1,200	2,700
39N/03E-34N01	12	2	8	2.5	240	220
39N/04E-16Q02	6	5	17	20.0	360	24
39N/04E-17C01	6	5	25	1.0	120	900
39N/04E-20H01	6	5	15	1.7	180	300
39N/04E-20M03	6	10	10	2.0	180	80
39N/04E-22L01	6	1	16	1.0	60	981
39N/04E-29H01	5	5	10	13.2	120	19
40N/02E-02Q01	36	8	200	10.0	240	320
40N/02E-10N02	6	5	20	4.0	30	130
40N/02E-11G01	36	8	180	10.0	240	280
40N/02E-12C01	36	8	320	11.0	240	490
40N/02E-12L01	36	5	300	15.0	240	510
40N/02E-13H01	36	8	160	9.0	240	280
40N/02E-15J01	36	1	15	6.0	480	26
40N/02E-15P01	36	4	300	7.0	240	1,500
40N/02E-21J01	36	1	85	10.0	60	87
40N/02E-21R01	36	1	85	10.0	60	87
40N/02E-21R02	36	1	85	10.0	60	87
40N/02E-22E02	36	4	50	13.0	60	70
40N/02E-22R02	6	9	10	3.0	480	63
40N/02E-23C01	18	6	12	5.0	240	46
40N/02E-23D02	6	5	7	22.0	120	6.8
40N/02E-23Q01	36	8	160	6.0	240	440
40N/02E-27B01	18	6	25	4.0	240	140
40N/02E-27N02	36	6	180	8.0	240	490
40N/02E-33B02	36	3	210	5.0	60	2,000
40N/02E-35G01	36	4	120	3.0	240	1,400
40N/03E-01R01	36	8	200	6.0	240	570
40N/03E-02B03	8	16	120	4.5	30	250
40N/03E-02M02	8	15	200	3.0	30	730
40N/03E-02N01	36	1	140	3.0	240	480
40N/03E-03A02	6	20	5	2.0	240	19
40N/03E-03R02	8	21	200	5.5	30	270
40N/03E-03R03	10	20	150	8.0	30	130
40N/03E-05E01	36	1	170	2.5	60	700
40N/03E-05N01	8	1	26	0.2	300	4,800

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number--Continued

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
Sumas aquifer--Cont.						
40N/03E-07A02	18	1	85	7.0	60	250
40N/03E-07M03	8	5	50	8.0	60	170
40N/03E-08N03	36	8	160	14.0	240	170
40N/03E-09A04	36	12	150	6.0	120	250
40N/03E-09D01	36	8	200	6.0	240	510
40N/03E-09G01	6	10	30	8.0	120	56
40N/03E-11E03	18	1	500	6.0	60	1,700
40N/03E-11E04	6	3	27	3.0	240	530
40N/03E-12A05	10	10	300	15.0	120	32
40N/03E-16A02	12	10	40	2.0	30	26
40N/03E-16D01	36	8	250	12.0	240	340
40N/03E-16F01	12	3	20	4.0	60	200
40N/03E-16H04	6	5	20	1.0	30	620
40N/03E-16K01	36	1	85	4.0	60	220
40N/03E-16Q01	8	11	50	5.0	30	130
40N/03E-17E01	36	8	160	8.0	600	360
40N/03E-18E01	36	15	250	10.0	120	200
40N/03E-18G01	36	30	150	6.0	60	90
40N/03E-19A01	8	15	75	12.0	30	52
40N/03E-25J01	8	5	200	3.0	60	3,900
40N/03E-26H01	36	8	200	5.0	240	700
40N/03E-31N02	6	6	20	8.2	120	58
40N/03E-31P03	18	6	40	4.0	120	210
40N/03E-32K02	6	5	15	12.0	240	36
40N/03E-32L01	36	9	12	6.0	120	16
40N/03E-32M01	18	6	10	4.0	120	43
40N/03E-32P01	6	3	12	15.0	120	33
40N/03E-32Q01	18	6	10	3.0	240	67
40N/03E-33G01	12	10	5	3.0	480	22
40N/03E-33J02	6	3	10	1.0	30	470
40N/03E-34P01	36	12	440	8.0	120	610
40N/03E-35R02	6	5	20	1.0	30	690
40N/03E-36J01	84	1	350	10.0	270	150
40N/03E-36J02	36	16	350	8.5	90	320
40N/03E-36J03	36	1	250	4.0	240	640
40N/04E-01C01	8	15	200	10.8	120	350
40N/04E-01K02	8	88	225	3.0	30	240
40N/04E-02L02	8	10	160	3.0	60	1,526
40N/04E-03J01	8	10	150	4.0	60	1,100
40N/04E-04D01	24	9	12	6.0	90	18
40N/04E-05L01	6	3	16	4.0	60	180
40N/04E-05N01	6	1	10	4.0	240	150
40N/04E-05P01	36	1	85	2.0	60	440
40N/04E-07G01	8	15	200	2.5	30	900

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number--Continued

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
<u>Sumas aquifer--Cont.</u>						
40N/04E-08A02	10	15	150	1.5	60	1,900
40N/04E-08L01	8	16	200	0.5	30	7,700
40N/04E-09N03	8	10	180	2.0	30	2,600
40N/04E-09Q01	8	10	280	5.0	240	1,700
40N/04E-09Q02	10	15	600	12.0	120	960
40N/04E-10C01	8	10	560	7.0	240	2,500
40N/04E-10E02	10	11	110	20.0	240	130
40N/04E-10G01	8	10	125	5.0	60	690
40N/04E-10R03	8	12	200	2.0	30	2,400
40N/04E-11C01	36	12	225	9.0	240	280
40N/04E-17B02	8	16	200	2.0	30	1,100
40N/04E-17N01	36	8	200	10.0	240	610
40N/04E-20D01	8	15	200	0.8	30	5,200
40N/04E-22G01	6	5	25	3.0	180	280
40N/04E-28H01	8	5	200	5.5	30	1,100
40N/04E-30D01	36	31	144	21.0	240	50
40N/04E-30E01	8	8	150	4.0	30	1,400
40N/04E-31R02	8	5	40	0.7	180	2,200
40N/04E-33A03	8	5	160	20.0	240	260
40N/04E-33R01	6	5	18	3.3	180	180
40N/05E-06D01	36	1	100	16.0	60	64
40N/05E-06M01	8	11	150	4.0	30	920
41N/02E-36K01	36	2	300	3.0	240	7,800
41N/02E-36M01	36	8	90	16.0	240	74
41N/03E-31E01	6	5	30	11.2	240	83
41N/03E-33E01	6	5	40	3.0	60	420
41N/03E-34G01	8	10	250	6.0	30	650
41N/03E-34M01	36	8	200	6.0	240	570
41N/03E-34Q01	6	7	15	4.5	120	66
41N/03E-36N01	36	4	200	5.0	240	1,400
41N/04E-31J01	6	4	13	1.9	720	370
41N/04E-32R01	6	1	15	1.5	240	610
41N/04E-33N04	6	17	902	39.0	1,002	290
41N/04E-36L01	8	10	225	30.0	60	190
41N/05E-31M01	8	10	160	5.0	60	890
41N/05E-31N02	8	10	125	3.0	60	1,200
41N/05E-31P01	8	15	150	4.0	60	730
41N/05E-32L01	8	16	180	4.0	30	460
<u>Everson-Vashon unit</u>						
092G.008.1.2.1-2	6	8	15	28.5	240	17
092G.008.1.2.3-10	8	11	30	155.0	90	3.5
38N/04E-06D01	6	1	5	102.0	240	3

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number--Continued

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
Everson-Vashon unit--Cont.						
39N/02E-24Q01	6	10	17	10.0	120	43
39N/02E-24R02	6	4	10	7.0	30	80
39N/03E-19N01	6	4	20	39.0	240	36
39N/03E-19Q01	6	3	12	2.0	240	570
39N/03E-20F02	6	1	7	4.0	240	100
39N/03E-22M01	6	1	15	4.0	60	230
39N/03E-23M01	6	5	9	62.0	30	5.4
39N/03E-25A01	6	2	4	85.0	240	4.8
39N/03E-25E01	6	3	4	45.0	6	4.5
39N/03E-26D01	6	5	15	3.0	240	280
39N/03E-26P02	6	5	10	3.0	240	180
39N/03E-27H02	6	1	15	8.0	30	120
39N/03E-28F01	6	1	15	50.0	120	18
39N/03E-28Q02	6	3	15	15.0	120	81
39N/03E-29C01	6	5	20	5.0	60	200
39N/03E-29D01	6	1	15	5.0	240	180
39N/03E-30N01	6	5	35	15.0	120	120
39N/03E-31R03	6	5	10	2.0	240	280
39N/03E-32E01	6	5	10	4.0	240	130
39N/03E-32J01	6	5	10	12.0	120	40
39N/03E-34Q01	6	5	11	6.0	120	93
39N/03E-36B01	8	5	17	20.0	240	41
39N/03E-36P01	6	1	20	3.0	240	410
39N/04E-32A01	6	5	20	10.0	180	100
39N/04E-32N01	6	1	24	22.0	30	67
40N/02E-02B01	8	11	60	80.0	9,600	20
40N/02E-03K01	6	9	80	30.0	240	80
40N/02E-09H01	6	5	4.5	16.0	240	13
41N/02E-33J01	6	5	12	4.3	120	140
Vashon unit						
39N/04E-10D01	6	1	6	29.0	180	12
39N/04E-22F01	6	5	4	65.5	120	2.4
40N/04E-22R01	6	5	15	0.5	120	1,800
40N/04E-23N01	6	1	15	10.0	240	92
Bedrock unit						
39N/03E-13R01	6	1	25	20.0	60	77
39N/03E-15C02	6	1	2	87.0	180	1.4
39N/03E-23J01	6	45	11	2.0	180	34
39N/03E-33R01	6	1	5	40.0	240	7.7
39N/04E-18E01	6	102	20	73.0	240	0.62

Appendix Table 2. Data used to estimate hydraulic conductivity, by hydrogeologic unit and local well number--Continued

Local well number	Casing diameter (inches)	Screen length (feet)	Discharge (gallons per minute)	Drawdown (feet)	Time (minutes)	Hydraulic conductivity (feet per day)
Bedrock--Cont.						
39N/04E-18M01	6	135	20	39.0	180	0.90
39N/04E-19C01	6	124	1.7	60.0	30	0.01
39N/04E-19E02	6	91	15	76.0	180	0.48
39N/04E-19F02	8	140	2	150.0	60	0.01
39N/04E-19M01	6	135	2	132.0	180	0.02
39N/04E-29A01	6	1	1	200.0	60	0.31
39N/04E-32F01	6	103	2	225.0	60	0.0013

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
AG 092G.008.1.4.2-01. Altitude 300 feet. Drilled, L Johnson, 1972		
Clay, brown	20	20
Clay, blue	17	37
Clay, blue, and sandy	122	159
Clay, blue, and silty	22	181
Till, clayey	19	200
Clay, blue, and stoney	93	293
Till	40	333
Sand, water bearing, saltwater	1	334
Clay and till	36	370
Sand, water bearing, and saltwater	2	372
Clay and pebbles	15	387
Sand, fine, and silt	4	391
Sand, compact	1	392
Sand, water bearing	1	393
Clay	2	395
AJ 092G.008.1.4.4-03. Altitude 305 feet. Drilled by Linder's Well Drilling, 1980.		
Clay, brown	16	16
Clay, blue	74	90
Till	5	95
Sand, water bearing, and gravel	10	105
Sand, water bearing	12	117
AK 092G.008.2.1.1-02. Altitude 164 feet. Drilled by Linder's Well Drilling, 1986.		
Topsoil	6	6
Gravel, sandy, and clay	24	30
Sand, silty, and clay	30	60
Sand, silty, and some gravel	37	97
Sand and gravel	7	104
AL 092G.008.2.1.1-04. Altitude 180 feet. Drilled by John Beers Construction, 1984.		
Topsoil	3	3
Clay, stoney	15	18

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Materials	Well number	Thickness (feet)	Depth (feet below land surface)
Gravel		1	19
Clay, stoney		33	52
Till		4	56
Sand		7	63
Silt, clay layers		5	68
AO	092G.008.2.1.3-08. Altitude 240 feet.	Drilled 1986.	
Sand		3	3
Clay, brown		11	14
Clay, blue		73	87
Till		3	90
Clay, stoney		8	98
Boulders		2	100
Clay, blue		30	130
Clay, blue, and layers of water bearing silt		68	198
Till		59	257
Till with layers of water bearing silt		41	298
Sand, water bearing, and gravel		4	302
AZ	092G.008.2.2.4-16. Altitude 170 feet.	Drilled by Linder's Well Drilling, 1985.	
Sand		2	2
Clay		19	21
Sand, water bearing, and gravel		4	25
Clay, blue		25	50
Till with layers of silt, water bearing		37	87
Sand, water bearing, and gravel		10	97
Clay		1	98
BN	092G.008.2.4.2-14. Altitude 330 feet.	Drilled by Valley Water, 1981.	
Clay		2	2
Gravel		43	45
Till		5	50
Clay, sandy		5	55
Gravel		25	80

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Till	35	115
Sand, water bearing	14	129
BQ 092G.008.2.4.4-10. Altitude 345 feet.	Drilled by Western Water Wells, 1960.	
Boulders and gravel, with sand	35	35
Gravel, fine to medium, and sand	25	60
Sand, with some gravel	5	65
Sand, silty	33	98
Sand, fine to medium, and gravel	12	110
Sand, silty, and fine	21	131
Sand, silty, with saturated gravel	181	312
Sand	3	315
Clay, sandy, with some gravel	85	400
Boulders	2	402
Clay, stickey, with some gravel	196	598
Sand, silty, and bearing water	3	601
Clay, blue, with pebbles	74	675
BW 092G.008.4.2.2-27. Altitude 400 feet.	Drilled by Valley Water, 1981.	
Clay, brown, and sandy	20	20
Clay, blue, and stoney	58	78
Gravel, dry	31	109
Sand, brown, water bearing	12	121
Sand, grey, water bearing	6	127
CE 092G.009.1.1.2-12-75. Altitude 168 feet.	Drilled by Langley Water Wells, 1988.	
Topsoil	7	7
Sand and gravel, with lenses of sand	68	75
CM 092G.009.1.1.4-19-75. Altitude 170 feet.	Drilled by Langley Water Wells, 1988.	
Topsoil	5	5
Sand and gravel, with lenses of sand	70	75

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
CQ 092G.009.1.2.1-ABB4 Altitude 213 feet. Drilled 1988.		
Sand and gravel, red-brown	2.77	2.77
Sand, grey, very coarse	18.1	20.9
Sand, grey, fine to very coarse	12.5	33.4
Sand, very fine	10.7	44.1
Sand, coarse	0.50	44.6
Sand, grey, fine to very coarse, some silt	7.90	52.5
Sand, grey, very fine, silty	0.40	52.9
Sand, grey, coarse	6.10	59.0
Sand, grey, very fine	2.80	61.8
Sand, grey, fine to very coarse	13.0	74.8
Sand and gravel, very fine to coarse, cobbles	0.90	75.7
Sand, very fine to very coarse	4.20	79.9
Sand, greenish-grey, coarse	7.00	86.9
Sand and gravel, grey, very coarse	9.10	96.0
DB 092G.009.1.2.4-31. Altitude 240 feet. Drilled by A & H, 1970.		
Soil	4	4
Gravel	77	81
Sand	11	92
Clay, blue	40	132
Sand and gravel	13	145
Sand	6	151
Sand and gravel	12	163
DI 092G.009.1.3.4-34. Altitude 195 feet. Drilled by Linder's Well Drilling, 1985.		
Unknown	36	36
Sand and gravel, water bearing	9	45
Sand, fine, water bearing	29	74
Sand and gravel, water bearing	10	84
DW 092G.009.3.1.2-20. Altitude 375 feet. Drilled by Valley Well Drilling, 1970.		
Topsoil	3	3

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, grey, hardpan, and till	21	24
Clay, blue, and sand	11	35
Clay, grey, and sand	15	50
Clay, blue	10	60
Clay, grey, and fine gravel	45	105
Sand, fine, and water	7	112
Clay, blue, fine gravel, and seepage	40	152
DX 092G.009.3.1.2-23. Altitude 215 feet. Drilled by Hi-land, 1974.		
Gravel	32	32
Clay	93	125
DY 38N/03E-04E01. Altitude 308 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Topsoil	2	2
Clay, tan	13	15
Clay, grey	48	63
Clay, grey, gravel, and sand	35	98
Gravel, dry, and little clay	23	121
Sand, dry, and little clay	9	130
Sand, medium, and dry	19	149
Gravel, dry, and sand, course	13	162
Sand, little clay, and water	7	169
Sand, medium, and water	6	175
Sandstone, green	1	176
Sandstone, brown	14	190
Sandstone, grey	10	200
EA 38N/04E-06D01. Altitude 276 feet. Radke Well Drilling, 1974.		
Topsoil	1	1
Hardpan	24	25
Clay, blue	82	107
Clay, black, and fine	3	110
Sand, fine, and clay strips	11	121
Sand, fine, clay strips, and water	11	132

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
EB 39N/02E-01N01. Altitude 75 feet. Drilled by Don Mulka, 1951.		
Topsoil	2	2
Sand	23	25
EC 39N/02E-01P02. Altitude 80 feet. Drilled by Snowden Well Digging, 1974.		
Sandy loam	2	2
Sand, coarse	24	26
Sand, fine	5	31
Sand, coarse	2.5	33.5
ED 39N/02E-01Q01. Altitude 80 feet. Drilled by G. A. Wetzel, 1951.		
Sandy loam	3	3
Sand	28	31
EA 39N/02E-05B02. Altitude 60 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Sand, brown	5	5
Sand and gravel, brown	10	15
Sand	20	35
Clay, silty	125	160
Clay, silty, shells, and gravel	40	200
Clay, silty, and gravel	175	375
Sand and gravel with clay, silty	210	585
Clay, silty, with sand and gravel	50	635
Sand, clay, silty, and gravel	45	680
Clay, silty, sand, and gravel	55	735
Bedrock at bottom of hole		
EI 39N/02E-10F01. Altitude 55 feet. Drilled by B & C Well Drilling Inc., 1987.		
Topsoil	1	1
Gravel, sandy brown	7	8
Sand, gravel, and water	12	20
Clay and silt, fine	2	22

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
EM 39N/02E-11B02. Altitude 71 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Sand	15	15
Sand, grey, and water	20	35
Sand, fine and gravel, scattered	10	45
Sand, fine, grey, and clay	11	56
Clay, grey	9	65
Sand, grey, fine and clay	24	89
Clay, grey	121	210
Clay, grey and gravel, scattered clam shells	80	290
Clay, grey, sandy	77	367
Clay, grey, sand, coarse	53	420
Clay, gravelly, grey, and boulders	55	475
Clay, grey, hard, and sand	37	512
Clay, grey, and cobble	8	520
Sandstone	5	525
EP 39N/02E-12K03. Altitude 85 feet. Drilled by B & C Well Drilling Inc., 1985.		
Topsoil, sandy	1	1
Sand, brown	8	9
Clay and brown sand mix	2	11
Sand, brown, and fine	16	27
EQ 39N/02E-12Q01. Altitude 80 feet. Drilled by Livermore & Son Inc., 1989.		
Topsoil	1	1
Loam, sandy, brown	4	5
Sand, blue, and fine	32	37
Sand, fine, and blue clay lenses	1	38
Sand and water	6	44
ER 39N/02E-13B01. Altitude 80 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1987.		
Topsoil	1	1
Sand, brown, fine, dry	13	14
Sand, rusty-brown, fine, and water	9	23

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, dirty grey, fine to medium and water	6	29
Sand, clean grey, fine to medium and water	18	47
Sand, dirty grey, fine, little clay, and water	5	52
Sand, dirty grey, fine, clay, and water	5	57
EW 39N/02E-21K01. Altitude 50 feet.	Drilled by James L. Asplund, 1972.	
Topsoil, sandy	3	3
Clay	1	4
Water bearing sand	15	19
Clay, blue at bottom of hole		
FA 39N/02E-22L01. Altitude 45 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1973.	
Sandy loam, tan	9	9
Clay, grey	54	63
Sand, fine, and clay with slight seepage	8	71
Clay, blue, and sandy	69	140
Sandstone	2	142
Clay, grey, sandy, and hard	6	148
Gravel and sand	2	150
Sand, medium, and saltwater	10	160
Clay and sand	15	175
FB 39N/02E-23F01. Altitude 61 feet.	Drilled by B & C Well Drilling Inc., 1987.	
Hardpan	3	3
Sand, brown	7	10
Clay, grey	1	11
Sand, grey-black	9	20
FD 39N/02E-23J01. Altitude 75 feet.	Drilled by Sprague & Henwood, G.J., Colo., 1959.	
Sand	30	30

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
EM 39N/02E-11B02. Altitude 71 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Sand	15	15
Sand, grey, and water	20	35
Sand, fine and gravel, scattered	10	45
Sand, fine, grey, and clay	11	56
Clay, grey	9	65
Sand, grey, fine and clay	24	89
Clay, grey	121	210
Clay, grey and gravel, scattered clam shells	80	290
Clay, grey, sandy	77	367
Clay, grey, sand, coarse	53	420
Clay, gravelly, grey, and boulders	55	475
Clay, grey, hard, and sand	37	512
Clay, grey, and cobble	8	520
Sandstone	5	525
EP 39N/02E-12K03. Altitude 85 feet. Drilled by B & C Well Drilling Inc., 1985.		
Topsoil, sandy	1	1
Sand, brown	8	9
Clay and brown sand mix	2	11
Sand, brown, and fine	16	27
EQ 39N/02E-12Q01. Altitude 80 feet. Drilled by Livermore & Son Inc., 1989.		
Topsoil	1	1
Loam, sandy, brown	4	5
Sand, blue, and fine	32	37
Sand, fine, and blue clay lenses	1	38
Sand and water	6	44
ER 39N/02E-13B01. Altitude 80 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1987.		
Topsoil	1	1
Sand, brown, fine, dry	13	14
Sand, rusty-brown, fine, and water	9	23

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, dirty grey, fine to medium and water	6	29
Sand, clean grey, fine to medium and water	18	47
Sand, dirty grey, fine, little clay, and water	5	52
Sand, dirty grey, fine, clay, and water	5	57
EW 39N/02E-21K01. Altitude 50 feet.		Drilled by James L. Asplund, 1972.
Topsoil, sandy	3	3
Clay	1	4
Water bearing sand	15	19
Clay, blue at bottom of hole		
FA 39N/02E-22L01. Altitude 45 feet.		Drilled by Hayes Well Drilling & Pumps, Inc., 1973.
Sandy loam, tan	9	9
Clay, grey	54	63
Sand, fine, and clay with slight seepage	8	71
Clay, blue, and sandy	69	140
Sandstone	2	142
Clay, grey, sandy, and hard	6	148
Gravel and sand	2	150
Sand, medium, and saltwater	10	160
Clay and sand	15	175
FB 39N/02E-23F01. Altitude 61 feet.		Drilled by B & C Well Drilling Inc., 1987.
Hardpan	3	3
Sand, brown	7	10
Clay, grey	1	11
Sand, grey-black	9	20
FD 39N/02E-23J01. Altitude 75 feet.		Drilled by Sprague & Henwood, G.J., Colo., 1959.
Sand	30	30

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand and gravel	5	35
Sand, grey, and medium	10	45
Sand and gravel	5	50
Clay, bluish-grey	60	110
Sand, grey	5	115
Clay, bluish-grey and sand, fine	25	140
Sand and gravel	10	150
Sand	25	175
Sand, gravel, and boulders	15	190
Gravel and boulders	20	210
Sand and gravel	25	235
Sand	55	290
Sand and gravel	45	335
Sand, medium	15	350
Sand and gravel	15	365
Sand, medium	30	395
Sand and clay	5	400
Sand, medium, gravel, and clay, bluish-grey	5	405
Sand, fine, gravel, and clay, bluish-grey	5	410
Sand, medium, gravel, and clay, bluish-grey	5	415
Sand, gravel, clay, and coal	5	420
Sandstone and shale	642	1,062
FE 39N/02E-24B01. Altitude 68 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1982.		
Topsoil	1	1
Sand, brown	11	12
Sand, grey, and dark	5	17
Clay, grey	57	74
Clay, grey, and gravel	7	81
Sand, grey, with seeage	5	86
Clay, grey	3	89
Gravel, grey, and water	5	94
Clay, brown	0.5	94.5
Clay, grey	7.5	102
Clay, grey, and gravel	70	172
Clay, grey, and some gravel	49	221
Clay, grey, and gravel	21	242

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Gravel, grey, sand, and water	8	250
Gravel, grey, sand, clay sandstone and coal	17	267
Gravel, grey, and clay sandstone	25	292
Gravel, grey, and water	9	301
Clay, grey, and gravel	27	328
Gravel, grey, and water	59	387
Clay, grey, and gravel	8	395
Quartz rock, hard	46	441
Gravel, grey, and clay	44	485
Sand, grey, coarse, and gravel	45	530
FH 39N/02E-24K01. Altitude 90 feet. Drilled by Whatcom County Wildcat Drilling Project.		
Sand, brown, and medium	10	10
Sand, brown, medium, and gravel lenses	28	38
Clay, silty, grey, and zones of sand and gravel	87	125
Boulders	2	127
Sand and gravel, grey	55	182
Clay, silty, grey, with occasional sand and gravel	44	226
Sand, fine to medium and gravel	9	235
Sand and gravel, grey	5	240
Sand, fine	10	250
Sand and gravel, grey	70	320
Sand, fine, gravel, and saltwater	35	355
Sand, clay, very compact	25	380
Bedrock at bottom of hole		
FO 39N/02E-26N01. Altitude 92 feet. Drilled by B & K Water Well Inc., 1980.		
Topsoil	2	2
Clay and sand, brown	4	6
Sand, brown, and gravel	18	24
FT 39N/02E-27N01. Altitude 95 feet. Drilled by B & K Water Well Inc., 1984.		

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Topsoil, sandy loam	3	3
Gravel and some sand	29	32
FV 39N/02E-27P01. Altitude 100 feet. Drilled by Western Core Drilling, Inc., 1959.		
Sand and gravel (undifferentiated deposits)	269	269
Shale and sandstone	654	923
FW 39N/02E-28J02. Altitude 93 feet. Drilled by B & K Water Well Inc., 1989.		
Topsoil	2	2
Sand and gravel, brown	6	8
Sand, grey, and some gravel	17	25
FY 39N/03E-01C01. Altitude 96 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1985.		
Topsoil	3	3
Gravel, dry	14	17
Gravel and seepage	8	25
Gravel and water	11	36
Gravel and dirty water	7	43
Sand and water	7	50
Clay, grey at 50 (bottom of hole)		
GA 39N/03E-01R01. Altitude 120 feet. Drilled by B & C Well Drilling, Inc., 1983.		
Clay, gravely	18	18
Gravel, with sand	28	46
GD 39N/03E-02B03. Altitude 93 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Sand, brown, and gravel	2	2
Sand, brown, gravel, and water	33	35
Sand, grey, and gravel	3	38
Clay, grey	22	60

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, dark grey, and scattered gravel	5	65
Clay, lighter grey, and gravel	108	173
Sandstone, grey, and coarse	27	200
GJ 39N/03E-03G01. Altitude 80 feet. Drilled by Snowden Well Digging, 1978.		
Gravel and loam	2	2
Gravel	3	5
Sand, medium	23	28
GK 39N/03E-03M01. Altitude 95 feet. Drilled by E.W. McClure, 1939.		
Gravel, sandy	5	5
Sand, gravel, and boulders	5	10
Boulders, gravel, and sand	2	12
Gravel, hard	2	14
Gravel, slightly water bearing	1	15
Gravel, cemented	5	20
Gravel, sand, rock, and water bearing	1	21
Quicksand, dark	1	22
Clay, yellow	1	23
Quicksand, dark	42	65
Clay, blue	55	120
Sand, silty, fine, and water	6	126
Clay, grey, and water runoff	21	147
Sand, fine	4	151
Clay, grey	19	170
Rock, hard	1	171
Clay, grey, with gravel	9	180
Shale	22	202
Clay, gravel, and saltwater	1	203
Shale, grey	10	213
Shale, brown, and water	4	217
Shale, grey	11	228
Coal	4	232
Sand and water	1	233
Shale, sandy, light grey	7	240
Sandstone	18	258
Sandstone, smell of gas	2	260

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sandstone, hard	2	262
GM 39N/03E-04B01. Altitude 83 feet. Drilled by Bezona Drill Co., 1981.		
Sand and gravel, brown	10	10
Sand, grey, and gravel	22	32
Clay, blue	10	42
Till, glacial, and hardpan	2	44
Sand, silt, gravel, and quicksand	2	46
Silt, fine, and quicksand	8	54
Clay, blue, soft	36	90
GO 39N/03E-04M02. Altitude 100 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1982.		
Topsoil	2	2
Sand, brown	10	12
Sand, brown, and gravel	8	20
Sand, brown, gravel, and water	12	32
Sand, brown	5	37
Clay, tan	1	38
Sand, brown, and fine	4	42
Silt, grey, fine, and sand	13	55
Clay, grey at bottom of hole		
QU 39N/03E-06M01. Altitude 75 feet. Drilled by Sprague & Henwood, G.J., Colo., 1960.		
Sand, grey, and medium	65	65
Sand, grey, fine, and clay	85	150
Clay and coarse-grained sand	25	175
Clay	15	190
Clay, grey	50	240
Sand and gravel	50	290
Clay, grey	20	310
Clay, grey, with fine sand	40	350
Clay, grey	15	365
Gravel	5	370
Gravel and boulders	10	380
Sand and gravel	50	430

(Mapcode) Well number Materials			Thickness (feet)	Depth (feet below land surface)
Gravel and cobbles			50	480
Boulders			6	486
Clay, blue, and little sand			49	535
Sand, gravel, and clay			35	570
Sandstone and shale			1,430	2,000
HG	39N/03E-09D02.	Altitude 95 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1984.	
Topsoil			2	2
Sand, brown, and gravel			6	8
Sand, brown, gravel, and clay			19	27
Sand, brown, and fine			11	38
Clay, tan			2	40
HI	39N/03E-10E01.	Altitude 90 feet.	Drilled by Livermore & Son Inc., 1987.	
Topsoil			1	1
Sand and gravel, brown			17	18
Sand, blue, and fine			22	40
Clay, blue			1	41
Sand, fine, and clay seams			2	43
Clay, blue, and soft			5	48
HO	39N/03E-10Q03.	Altitude 105 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1989.	
Topsoil			1	1
Sand, brown, coarse, and gravel			21	22
Gravel, brown, sand, and water			1	23
Clay, brown			2	25
Clay, grey, and some gravel			8	33
Sandstone, grey			18	51
Coal			1	52
Sandstone, grey, and fine			13	65
Sandstone, grey, and coarse			14	79
Siltstone, grey			1	80
Sandstone, grey			22	102
Siltstone, grey			2	104
Sandstone, grey			6	110

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Siltstone, grey	1	111
Sandstone, grey, green-brown, and hard	2	113
Siltstone and sandstone, grey, layered	1	114
Sandstone, grey	6	120
Sandstone, grey, and saltwater	2	122
HV 39N/03E-12J02. Altitude 130 feet. Drilled by B & C Well Drilling, Inc., 1979.		
Loam, sandy	7	7
Gravel, with hardpan	11	18
Sand, cemented, and gravel	17	35
Gravel, coarse, with sand and water	15	50
Clay, with gravel at bottom of hole		
HW 39N/03E-12R03. Altitude 135 feet. Drilled by B & C Well Drilling, Inc., 1979.		
Sand, fine	37	37
Sand, with gravel	10	47
HY 39N/03E-13R01. Altitude 210 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1973.		
Topsoil	4	4
Clay	8	12
Shale, sandy	73	85
Sandstone	20	105
Water	15	120
IB 39N/03E-15C02. Altitude 122 feet. Radke Well Drilling, 1979.		
Topsoil	2	2
Gravel	2	4
Hardpan	25	29
Sandstone, hard	81	110
Sandstone, soft, water	1	111
Sandstone, hard	4	115

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Materials	Well number	Thickness (feet)	Depth (feet below land surface)
IE	39N/03E-15L01.	Altitude 150 feet.	Drilled by B & C Well Drilling, Inc., 1980.
Clay		7	7
Siltstone		13	20
Sandstone		6	26
Siltstone		8	34
Siltstone and coal		7	41
Siltstone		27	68
Sandstone		7	75
Siltstone		24	99
IG	39N/03E-16F01.	Altitude 100 feet.	Drilled by Snowden Well Digging, 1974.
Topsoil		2	2
Sand, brown		11	13
Sand and water		15	28
II	39N/03E-16L03.	Altitude 100 feet.	Drilled by Snowden Well Digging, 1977.
Loan, sandy		3	3
Clay and sand, layers		8	11
Gravel		10	21
IS	39N/03E-16N02.	Altitude 98 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1982.
Sand, brown		11	11
Sand, brown, and gravel		4	15
Sand, grey, and little clay, brown		18	33
Sand, gravel, brown, and water		3	36
Clay, brown, and gravel		1	37
Gravel, brown, and water		8	45
Gravel, brown, clay, and water		6	51
Clay, grey		1	52
Sand, grey, and water		7	59
Clay, grey		21	80
Clay, grey, and clam shells		16	96
Clay, grey		15	111
Siltstone		5	116

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sandstone	17	133
Coal	2	135
Sandstone	5	140
IN 39N/03E-19L01. Altitude 140 feet. Drilled by Livermore & Son Inc., 1982.		
Topsoil	1	1
Hardpan	6	7
Clay, blue, and soft	16	23
Clay, blue, and sandy	9	32
Gravel, sand, and water	22	54
IR 39N/03E-20K01. Altitude 153 feet. Drilled by Star Drilling Service, 1986.		
Clay, red	10	10
Hardpan	3	13
Clay, grey	11	24
Hardpan	18	42
Gravel with water	3	45
Clay, brown, at bottom of hole		
IS 39N/03E-20L01. Altitude 150 feet. Drilled by Star Drilling Service, 1986.		
Clay, red	7	7
Gravel	8	15
Clay, grey	12	27
Gravel, dry	1	28
Hardpan	21	49
Gravel with water	2	51
Sand, grey, and fine	1	52
IU 39N/03E-21E01. Altitude 140 feet. Drilled by Livermore & Son Inc., 1988.		
Topsoil	2	2
Sand, gravel, and hardpan	7	9
Sand, gravel, and clay, blue	13	22
Sand, gravel, little clay, and water	12	34

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials		Thickness (feet)	Depth (feet below land surface)
Sand, gravel, and water		6	40
Sand, gravel, and clay blue		3	43
IV 39N/03E-21K01.	Altitude 190 feet.	Drilled by Star Drilling Service, 1989.	
Clay, red		12	12
Clay, grey		58	70
Clay, grey, with stones		20	90
Sand, dry		30	120
Clay, hard, and gravel		17	137
Hardpan		19	156
Gravel with water		2	158
IW 39N/03E-21M01.	Altitude 160 feet.		
Clay, silty, and gravel, brown		10	10
Clay, silty, and gravel, grey		65	75
Gravel, sandy silty, grey		20	95
Sand, medium, brown, and water bearing		25	120
Sand and gravel, light brown		20	140
Silt, sandy with gravel		75	215
Sand and gravel, water bearing		10	225
Sand, silty with gravel, grey		5	230
Sand, medium, and gravel, water bearing		30	260
Sand, fine to medium		15	275
Silt, sandy with gravel, grey		5	280
Sand, grey, and fine		5	285
Clay, grey, and silty		8	293
Sand, grey, fine to medium		7	300
Clay, silty, grey, and sandy		5	305
Clay, silty, and sandy with gravel		15	320
Sand, grey, and fine		10	330
Sand, fine to coarse, gravel, grey, water		15	345
Sand, fine to medium, and gravel, grey		5	350
Gravel		25	375
Gravel, with sand and bearing water		35	410
Clay, sandy, with gravel, and till hard, and grey		40	450
Bedrock at bottom of hole		10	460

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials			Thickness (feet)	Depth (feet below land surface)
IX	39N/03E-22M01.	Altitude 210 feet.	Drilled by B & C Well Drilling, Inc., 1980.	
Clay, brown			15	15
Clay, grey			38	53
Gravel, coarse			5	58
Clay, brown			9	67
Clay, grey			8	75
Clay, grey, and hardpan			16	91
Gravel, hardpan			10	101
Clay, hardpan			8	109
Hardpan with boulders			9	118
Gravel, grey, and hardpan			8	126
Clay, grey, and hardpan			12	138
Hardpan, with coarse gravel			7	145
Gravel cemented, and grey			9	154
Clay, grey, and sandy			3	157
Gravel, hardpan and grey			4	161
Sand, dark, water, and clay			2	163
JB	39N/03E-23J01.	Altitude 192 feet.	Drilled by Livermore & Son Inc., 1986.	
Topsoil			1	1
Sand, gravel, and hardpan			13	14
Sand, gravel, and little blue clay			33	47
Sand, gravel, and blue clay soft			23	70
Sand, gravel, and blue clay hard			9	79
Sand, and water			1	80
Sandstone			15	95
Sandstone, water			35	130
JC	39N/03E-23M01.	Altitude 165 feet.	Drilled by Star Drilling Service, 1984.	
Clay, red			24	24
Clay, grey			6	30
Clay and sand			5	35
Clay and gravel			19	54
Clay, grey, and hard			16	70
Gravel, fine			1	71
Clay, grey			14	85

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand cemented	10	95
Sand, fine	5	100
Hardpan at bottom of hole		
JF 39N/03E-25A01. Altitude 227 feet. Drilled by B & C Well Drilling, Inc., 1983.		
Soil	2	2
Clay, with gravel, brown	25	27
Clay, blue, with gravel	112	139
Gravel with water	9	148
JK 39N/03E-26P02. Altitude 262 feet. Drilled by B & C Well Drilling Inc., 1978.		
Topsoil	1	1
Clay, brown	9	10
Clay, blue	12	22
Quicksand	3	25
Sand and gravel	25	50
Clay, sandy, and gravel	14	64
Sand, with gravel	6	70
Clay, grey, sand, and gravel	39	109
Sand, brown, with clay	20	129
Gravel, sandy, with clay	9	138
Sand, gravel, and water	15	153
Clay, blue, and sandy	2	155
JO 39N/03E-28F01. Altitude 225 feet. Drilled by Bezona Well Service, 1987.		
Clay, brown, and gravel	8	8
Clay, blue, and till	7	15
Hardpan and till	58	73
Hardpan and boulders	27	100
Clay, soft, and till	122	222
Hardpan	3	225
Gravel, layered, and silty	55	280
Gravel and sand aquifer	6	286

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
JP 39N/03E-28J01. Altitude 230 feet. Drilled by B & C Well Drilling Inc., 1977.		
Topsoil	1	1
Clay, yellow	4	5
Sand, brown, and wet	6	11
Sand, blue, with clay	4	15
Clay, blue, with pebbles	51	66
Gravel and sand	4	70
Clay, blue, with gravel	4	74
Gravel, sandy, with water	10	84
Sand and clay, fine	1	85
JQ 39N/03E-28Q02. Altitude 290 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1977.		
Sand, tan loam	3	3
Clay, grey, and gravel	57	60
Gravel, dry, clean	25	85
Clay, grey, and sandy	5	90
Clay, grey	20	110
Sand, grey, dry	10	120
Gravel, dry	20	140
Clay, grey, and sand	37	177
Sand, grey, and water	3	180
Sand, clay, brown, and water	4	184
Clay, brown, and gravel	1	185
JR 39N/03E-28R01. Altitude 270 feet. Drilled by B & C Well Drilling Inc., 1977.		
Topsoil	5	5
Gravel, cemented, and boulders	11	16
Clay, grey, with gravel	4	20
Clay, brown, with gravel	15	35
Sand, brown, and clay	21	56
Clay, blue, with gravel	1	57
Clay, grey, with gravel	3	60
Clay, blue, and hard	10	70
Clay, brown, hard, with gravel	5	75
Sand, brown, and clay	14	89
Sand and clay, brown	7	96

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand and gravel	26	122
Clay, brown, with gravel	2	124
Sand and gravel	3	127
Clay, brown, with sand and gravel	9	136
Sand, medium	11	147
Sand and blue clay	2	149
Sand and water	6	155
Silt	25	180
Clay, blue	12	192
Sand, gravel, and water	5	197
Clay, brown, with pebbles	2	199
JY 39N/03E-30N01. Altitude 190 feet.	Drilled by Livermore & Son Inc., 1974.	
Topsoil	1	1
Hardpan	8	9
Sand, gravel, and hardpan	6	15
Sand, gravel, and little blue clay	11	26
Sand, gravel, and little blue clay, soft	28	54
Sand, gravel, and little brown clay	6	60
Sand, and dry gravel	8	68
Sand, dry gravel, and blue clay	23	91
Sand, gravel, coarse, and blue clay	35	126
Sand, gravel, and water	5	131
Sand, gravel, and blue clay at bottom of hole		
JZ 39N/03E-30R01. Altitude 302 feet.	Drilled by B & C Well Drilling Inc., 1978.	
Topsoil	1	1
Clay, brown	8	9
Clay, brown, and grey	3	12
Clay, blue	6	18
Clay, brown, and gravel	11	29
Sand and gravel	61	90
Sand, gravel, and clay	10	100
Gravel, large	10	110
Sand, medium, with gravel	4	114
Sand, fine, with gravel	6	120

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Gravel	27	147
Sand with gravel	19	166
Clay, grey, and sandy	8	174
Gravel	7	181
Sand, fine, with gravel	4	185
Sand, coarse, with gravel	5	190
Sand, medium, gravel, and water	13	203
Sand, fine, with gravel, and water	11	214
Sand, medium, gravel, and water	3	217
KA 39N/03E-31B02. Altitude 250 feet. Drilled by Sprague and Henwood, G.J., Colo., 1961.		
Soil	5	5
Boulders, gravel, clay, and sand	63	68
Gravel and sand	65	133
Gravel, boulders, sand, and clay	127	260
Clay, blue-grey, and few boulders	110	370
Clay, boulders, and sand	30	400
Gravel and boulders	57	457
Gravel	13	470
Boulders	4	474
Clay	6	480
Shale and sandstone	1,512	1,992
KE 39N/03E-32A02. Altitude 278 feet. Drilled by Sprague & Henwood, G.J., Colo., 1961.		
Alluvium	2	2
Clay	8	10
Sand, grey, with few boulders	85	95
Gravel	15	110
Sand, grey	10	120
Sand, gravel, with few boulders	100	220
Sand and gravel	5	225
Clay, grey	17	242
Clay and sand	58	300
Clay mainly, with gravel	115	415
Shale and sandstone	1,102	1,517

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
KG 39N/03E-32J01. Altitude 310 feet. Drilled by Bezona Well Service, 1986.		
Till, glacial, brown, and soft	16	16
Clay, blue, and till, soft	26	42
Till, glacial, and hardpan	23	65
Gravel, hard-packed, and till	23	88
Sand, loose, and gravel, alluvium	17	105
Gravel, coarse, loose, and alluvium	11	116
Sand and some gravel, alluvium	13	129
Clay, blue, and sandy	11	140
Sand, coarse, and alluvium	7	147
Gravel, coarse, and alluvium	23	170
Sand, coarse, and alluvium	7	177
Gravel, pea, and alluvium	8	185
Sand and gravel, aquifer	33	218
KI 39N/03E-33K01. Altitude 325 feet. Drilled by Star Drilling Service, 1985.		
Sand	3	3
Clay, red	6	9
Clay, grey	15	24
Hardpan	22	46
Gravel and traces of water	0.6	46.6
Hardpan	2.4	49
Clay, hard, and dry	18	67
Hardpan	48	115
Hardpan took water	18	133
Clay, brown, and sandy	22	155
Sand, cemented	21	176
Hardpan	20	196
Gravel with water	1	197
Sand, grey, and cemented	6	203
KJ 39N/03E-33M01 Altitude 318 feet. Drilled by B & C Well Drilling, Inc., 1987.		
Clay, brown	10	10
Clay, grey	32	42
Gravel, with clay	100	142
Clay, fine, and sandy	14	156

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials		Thickness (feet)	Depth (feet below land surface)
Sand and gravel, with clay		24	180
Sand, brown, fine, and dry		11	191
Sand and gravel, with clay		6	197
Sand, with gravel and water		3	200
Sand, with water		5	205
Quicksand at bottom of hole			
KK 39N/03E-33R01.	Altitude 310 feet.	Drilled by B & C Well Drilling Inc., 1981.	
Topsoil		4	4
Hardpan		2	6
Clay, blue		18	24
Gravel, dry		2	26
Clay, blue, with cobbles		13	39
Sand, coarse		2	41
Sand, coarse, with gravel, dry		15	56
Clay, blue		36	92
Gravel, dry		3	95
Clay, with rock		10	105
Sand, soupy		51	156
Gravel, fine		11	167
Gravel, with sand, dry		8	175
Clay, blue, with rock		9	184
Oil shale, dark brown		8	192
Oil shale, light brown		9	201
Shale, grey		24	225
Sandstone, white		7	232
Clay, grey, and dry		2	234
Oil shale, dark brown		15	249
Shale, grey		6	255
Clay, oil, grey, and blue		15	270
KL 39N/03E-34C01.	Altitude 295 feet.	Drilled by Hayes Well Drilling and Pumps, Inc., 1981.	
Topsoil		1	1
Clay, brown		9	10
Clay, grey, and gravel		30	40
Gravel, grey, and clay		50	90
Sand, grey, dry		40	130

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Gravel, grey, dry	9	139
Gravel, brown, dry	4	143
Sand and gravel, dry	7	150
Sand, grey, fine, dry	10	160
Sand, grey, coarse, dry	5	165
Gravel, grey, dry	10	175
Sand, fine, and seepage	4	179
Sand, grey, coarse, and water	19	198
Clay, grey	7	205
Clay, wood, and sand	28	233
Gravel, grey, and clay, hard	95	328
Gravel, grey, and saltwater	15	343
Sandstone, siltstone, and coal	157	500
KR 39N/03E-36B01. Altitude 305 feet. Drilled by Livermore & Son Inc., 1970.		
Fill	3	3
Hardpan	3	6
Boulder	4	10
Hardpan and gravel	3	13
Clay, blue, and gravel washes	4	17
Sand and gravel washes, little clay	93	110
Clay, blue, and gravel, soft	14	124
Clay, blue, soft, and sandy	24	148
Sand, gravel, and blue clay hard	10	158
Sand, gravel, and water	8	166
Clay, blue at bottom of hole		
KY 39N/04E-03P02. Altitude 370 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1990.		
Topsoil	3	3
Clay, brown	5	8
Clay, brown, and little gravel	3	11
Gravel, brown, and sand	16	27
Clay, brown, and gravel	4	31
Clay, grey	11	42
Clay, grey, and gravel	76	118
Gravel, grey, sand, and saltwater	21	139
Sandstone, grey, coarse	60	199

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials		Thickness (feet)	Depth (feet below land surface)
Sandstone, medium		16	215
Sandstone, coarse		45	260
LA 39N/04E-04Q01.	Altitude 140 feet.	Drilled by B & C Well Drilling Inc., 1981.	
Clay, with gravel		14	14
Sand and gravel, silty		31	45
Pebble cobbles, and silty gravel		20	65
Gravel, sand, and silty		9	74
LC 39N/04E-06D01.	Altitude 100 feet.	Drilled 1982.	
Sand, and gravel, grey		80	80
Sand, grey		37	117
Clay, grey, silty, and seashells		13	130
Clay, grey, silty, and gravel		107	237
Sand, medium to coarse		5	242
Clay, silty and grey		108	350
Sand, grey, and minor silt		123	473
Bedrock at bottom of hole			
LD 39N/04E-06E01.	Altitude 105 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1980.	
Topsoil		2	2
Gravel, brown, and clay		34	36
Gravel, brown, sand, and water		31	67
LF 39N/04E-08C02.	Altitude 107 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1977.	
Topsoil		2	2
Clay, brownish-grey		14	16
Gravel, fine and little sand		4	20
Gravel, large, and water		26	46
Gravel and less water at bottom of hole			

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials			Thickness (feet)	Depth (feet below land surface)
LQ	39N/04E-18E01.	Altitude 210 feet.	Radke Well Drilling, 1977.	
Topsoil			1	1
Hardpan			2	3
Sandstone			16	19
Rock, hard			42	61
Sandstone			13	74
Rock, hard			44	118
Sandstone, coal, and water			3	121
LR	39N/04E-18M01.	Altitude 190 feet.	Radke Well Drilling, 1974.	
Topsoil			2	2
Hardpan			1	3
Sandstone			52	55
Coal, trace			1	56
Sandstone			90	146
Sandstone, soft, and water			4	150
Sandstone, hard			6	156
LV	39N/04E-19E01.	Altitude 215 feet.	Drilled by Star Drilling Service, 1988.	
Clay, red			6	6
Sandstone, hard			27	33
Sandstone, soft			5	38
Sandstone, very soft			49	87
Shale, black, and soft			28	115
Sandstone, moderate			19	134
Sandstone, soft			53	187
Sandstone, very soft, and brown			2	189
Sandstone, moderate			18	207
Sandstone, hard			35	242
LY	39N/04E-19M01.	Altitude 220 feet.	Radke Well Drilling, 1978.	
Topsoil			1	1
Hardpan			18	19
Clay, blue			9	28

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials			Thickness (feet)	Depth (feet below land surface)
Hardpan			37	65
Sandstone, hard			130	195
Sandstone, soft, and water			1	196
Sandstone, hard			4	200
MB	39N/04E-20M02.	Altitude 155 feet.	Drilled by B & C Well Drilling, Inc., 1980.	
Clay, brown, gravel, and silt			19	19
Sand, black with gravel			15	34
Clay, grey, and soft at bottom of hole				
MC	39N/04E-20M03.	Altitude 155 feet.	Radke Well Drilling, 1977.	
Topsoil			1	1
Hardpan			8	9
Gravel coarse			4	13
Sand and gravel cemented			12	25
Sand, gravel, and water			1	26
MD	39N/04E-22F01.	Altitude 180 feet.	Drilled by Livermore & Son Inc., 1981.	
Topsoil			1	1
Sand, gravel, and hardpan			9	10
Loam, sandy			8	18
Sand, gravel, and clay, blue			7	25
Sand, gravel, and clay, brown			30	55
Sand, gravel, and clay, blue			23	78
ME	39N/04E-22L01.	Altitude 155 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1973.	
Loam, sandy, and brown			2	2
Clay, brown, sand, and gravel			16	18
Hardpan, grey, and gravelly			2	20
Sand, gravel, and silt, brown			4	24
Sand, gravel, and water			5	29
Gravel			1	30

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
MF 39N/04E-22N01. Altitude 150 feet. Drilled by Bezona Well Service, 1977.		
Alluvial sand	5	5
Gravel, medium	33	38
Sand and gravel	1	39
MI 39N/04E-29A01. Altitude 200 feet. Drilled by Star Drilling Service, 1983.		
Sand, fine, and clay	12	12
Sand, coarse	15	27
Silt, black, and water	10	37
Sand, black, and water	6	43
Clay, grey, and hard	14	57
Clay, wet, and soft	15	72
Hardpan, brown	20	92
Silt, fine, and mud	17	109
Gravel	1	110
Clay, grey, and wet	83	193
Clay, grey,	1	194
Sandstone, soft	64	258
Sandstone and coal	8	266
Sandstone, grey	9	275
MQ 39N/04E-30F01. Altitude 225 feet. Drilled by Deer Creek Drilling Project.		
Clay, silty, with gravel and sand, brown	10	10
Clay, silty, with gravel and sand, and occasional boulders	55	65
Sand and gravel, with clay, grey	5	70
MS 39N/04E-31B01. Altitude 220 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1982.		
Topsoil	2	2
Clay, tan	11	13
Sand, clay, grey, and gravel	85	98
Sand, grey, fine, and clamshells	2	100
Clay, dark grey	12	112
Clay, grey, and gravel	103	215

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Gravel, dry, and little clay	6	221
Rock, green	1.5	222.5
Sand, coarse, little gravel, and water	2.5	225
MT 39N/04E-31D01. Altitude 250 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Topsoil	2	2
Clay, brown	13	15
Clay, grey, and gravel scattered	101	116
Clay, grey, and gravel	34	150
Gravel and water	12	162
Gravel, clay, grey, and scattered boulders	63	225
Gravel and water	1	226
Sand, grey, hard	2	228
Gravel, little clay and scattered boulders	22	250
Clay, grey	4	254
Clay, grey, and gravel	1	255
Clay, grey	40	295
Sand, coarse, little gravel, coal, and water	5	300
Clay, grey	5	305
Sandstone, grey	7	312
MV 39N/04E-31Q02 Altitude 265 feet. Drilled by B & C Well Drilling, Inc., 1979.		
Hardpan, brown	15	15
Clay, grey, and gravel	37	52
Hardpan, grey, and coarse	14	66
Clay, grey, and sandy	19	85
Sand with clay	4	89
Sand with gravel	3	92
Sand, brown, with gravel	55	147
Sand, grey, and fine	42	189
Sand, grey, with gravel	15	204
Sand, with gravel	8	212
Gravel, coarse, sandy, and with water	3	215

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Materials	Well number	Thickness (feet)	Depth (feet below land surface)
MX	39N/04E-32E01.	Altitude 230 feet.	Drilled by Dahlman Pump & Drilling Inc., 1984.
Clay, brown		15	15
Clay, blue, and gravel		124	139
Sand, clay, and water		3	142
MY	39N/04E-32F01.	Altitude 290 feet.	Drilled by Bezona Well Service, 1990.
Clay, brown, and hard		17	17
Clay, blue, and till		91	108
Glacial till, hard		7	115
Till, light, brown, and sandy		5	120
Shale, weathered, carbonaceous		8	128
Shale, grey		16	144
Sandstone, grey, and hard		36	180
Sandstone, coarse		18	198
Shale, grey		17	215
Shale, carbonaceous, water		10	225
Sandstone		6	231
NB	39N/03E-33E01.	Altitude 340 feet.	Drilled by G. Cowden, 1939.
Hardpan		11	11
Clay, blue		109	120
Gravel		3	217
NC	39N/04E-34C02.	Altitude 300 feet.	Drilled by Aut Hillard, 1946.
Hardpan		22	22
Clay, blue		39	61
Gravel and sand		18	79
Clay, blue		15	94
Sand, fine, with clay, and some water		52	146
Bedrock at bottom of hole			
NF	40N/02E-01N01.	Altitude 115 feet.	Drilled by Snowden Well Digging, 1975.

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay loam	1	1
Gravel, sandy brown	4	5
Sand, coarse, and gravel	15	20
Clay	1	21
NG 40N/02E-02B01. Altitude 180 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1983.		
Topsoil	1	1
Clay, brown, and gravel	6	7
Clay, brown, tan, and gravel	28	35
Clay, sandy, and brown and gravel	31	66
Sand, brown, fine, dirty	30	96
Siltstone, grey	13	109
Clay, grey	3	112
Clay, grey, and gravel	3	115
Gravel and sand, grey	1.5	116.5
Clay, grey, and gravel	6.5	123
Peat and wood	3	126
Clay, grey, hard	2.5	128.5
Clay, grey, and gravel	5.5	134
Gravel, grey, coarse, and water	13	147
Sand, grey, and water	4	151
Clay, grey	12	163
Clay, grey, and gravel, scattered	14	177
Clay, brown, hard	18	195
Clay, grey, and clam shells	12	207
Clay, grey, scattered gravel, and clam shells	25	232
Clay, grey, and little gravel	92	324
Gravel, grey, wood, and water	5	329
Gravel, grey and clay	45	374
Clay, grey, and little gravel, hard	6	380
Gravel, grey, and clay	26	406
Clay, grey, gravel, and wood	14	420
Clay, brownish-grey, and gravel	1	421
Gravel, grey, sand, and clay	22	443
Sand, gravel, grey, and saltwater	17	460

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
NH 40N/02E-02D01. Altitude 220 feet. Drilled by B & C Well Drilling Inc., 1979.		
Clay, brown, and sandy	35	35
Clay, grey, soft	8	43
Clay, grey, hard	15	58
Coarse gravel with hard clay	7	65
Sand, gravel, and clay	17	82
Sand, yellow, very fine	5	87
Sand, gravel, and clay	6	93
Hardpan	14	107
Sand, grey, fine	14	121
Clay, grey, soft	6	127
Hardpan	6	133
Sand, and gravel	2	135
Gravel, and water	4	139
Sand	1	140
NK 40N/02E-02Q01. Altitude 114 feet. Dug 1952.		
Gravel	15	15
Sand	7	22
NL 40N/02E-02Q02. Altitude 115 feet. Drilled 1982.		
Sand, dirt, and clay	23	23
NM 40N/02E-03C01. Altitude 240 feet. Drilled by B & C Well Drilling Inc., 1980.		
Soil	2	2
Clay, blue	82	84
Gravel and sand	0.5	84.5
Hardpan	6.5	91
Sand, gravel and water	10	101
NN 40N/02E-03K01. Altitude 250 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Topsoil	1	1

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, brown, and gravel	12	13
Sand, grey with seepage	5	18
Clay, grey	31	49
Clay, sandy, and grey	11	60
Clay, grey	33	93
Clay, sandy, and grey	25	118
Sand, grey, and dry	6	124
Clay, grey, and sandy	32	156
Sand, grey, and dry	14	170
Clay, grey, and wood	7	177
Clay, grey	19	196
Sand, grey, medium, and water	13	209
Clay, grey	1	210
NV 40N/02E-13H01. Altitude 103 feet. Drilled by Don Mulka, 1961.		
Clay, loam	2	2
Clay	1	3
Sand	23	26
NW 40N/02E-13J02. Altitude 100 feet. Drilled by Snowden Well Digging.		
Sand	10	10
Gravel	5	15
Sand	25	40
OC 40N/02E-14P02. Altitude 91 feet. Drilled by Snowden Well Digging, 1981.		
Sand	2	2
Sand, gravel, and clay	8	10
Sand, hard	15	25
Sand, grey, and water	17	42
OD 40N/02E-14R01. Altitude 95 feet. Drilled by Herman Ellingson, 1966.		
Topsoil, brown	2	2
Sand, grey, and gravel, small	28	30

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, blue, sand, fine at 30 (bottom of hole)		
OJ 40N/02E-15P01. Altitude 90 feet. Drilled by Levy Rice, 1946.		
Topsoil	5	5
Sand	4	9
Sand, gravel, and waterbearing	15	24
OK 40N/02E-15Q01. Altitude 90 feet. Drilled by Don Mulka, 1954.		
Clay, red	5	5
Sand	19	26
ON 40N/02E-21A01. Altitude 90 feet. Drilled by Snowden Well Digging, 1974.		
Clay loam	1	1
Clay, hard	2	3
Bog iron	1	4
Sand, hard	4	8
Sand, grey	13	21
PD 40N/02E-23D02. Altitude 90 feet. Drilled by Livermore & Son Inc., 1989.		
Topsoil	1	1
Sand, with thin clay seams and water	46	47
Sand, blue	1	48
Clay, blue	12	60
PJ 40N/02E-26A04. Altitude 60 feet. Drilled by Snowden Well Digging, 1980.		
Loam, sandy	1	1
Sand, coarse	22	23
Sand, fine	5	28

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
QA 40N/03E-02C01. Altitude 152 feet. Drilled by B & C Well Drilling, Inc., 1986.		
Topsoil, sandy	2	2
Gravel, sandy	11	13
Gravel, sandy, and water	11	24
Boulders at bottom of hole		
QB 40N/03E-02M02. Altitude 141 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1986.		
Topsoil	2	2
Gravel, dry	2	4
Gravel, sand, and water	26	30
Sand, small gravel, and water	7	37
Sand, gravel, and water	20	57
QC 40N/03E-02N01. Altitude 134 feet. Drilled by Beck & Zwicker, 1946.		
Topsoil	3	3
Gravel, coarse, and rock	17	20
QF 40N/03E-03N02. Altitude 128 feet. Drilled by Al Towe Well Digging, 1982.		
Topsoil	2	2
Clay, hard	6	8
Sand, coarse, and gravel,fine	15	23
QG 40N/03E-03R02. Altitude 135 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1986.		
Topsoil	2	2
Gravel, dry	8	10
Gravel, sand, and water	29	39
Sand, brown, and water	9	48
Sand, grey, gravel, and water	22	70
Sand, grey, trace of clay, and water	5	75
Clay, grey	2	77

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
QH 40N/03E-03R03. Altitude 135 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1988.		
Topsoil	3	3
Gravel, brown, dry	12	15
Gravel, rusty brown	19	34
Sand, brown, little gravel, and water	22	56
Sand, red, grey, and water	17	73
Clay, grey at 73 (bottom of hole)		
QQ 40N/03E-05N01. Altitude 123 feet. Drilled by America Water Well, Inc., 1984.		
Topsoil, black	1	1
Sand, brown	2	3
Sand, brown, and gravel	3	6
Sand, blue, grey, gravel, and water	12	18
QR 40N/03E-05N02. Altitude 118 feet. Drilled 1980.		
Gravel	20	20
QV 40N/03E-06M01. Altitude 123 feet. Drilled by Tilley and Hillard, 1947.		
Gravel	20	20
Sand, very fine	27	47
Clay, soft	68	115
Clay with gravel	7	122
Clay, hard	30	152
Sand and water	4	156
QW 40N/03E-06N02. Altitude 120 feet. Drilled by Snowden Well Digging, 1979.		
Loam sandy	2	2
Clay, loam	3	5
Gravel	3	8
Sand, coarse	25.6	33.6

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
RA 40N/03E-07M03. Altitude 111 feet. Drilled by Hayes Well Drilling & Pumps Inc., 1979.		
Topsoil	2	2
Sand, brown	8	10
Gravel and water	15	25
Sand, dirty grey, and little water	31	56
Clay, grey	24	80
RB 40N/03E-08J01. Altitude 113 feet. Drilled by Frank Otter, 1938.		
Loam, black	1	1
Clay	3	4
Sand, coarse	10	14
Gravel, coarse	12	26
RD 40N/03E-09A04. Altitude 123 feet. Drilled by B & K Water Wells, 1978.		
Topsoil	2	2
Clay, brown	6	8
Gravel, brown	12	20
Gravel and sand, blue	7	27
RE 40N/03E-09D01. Altitude 118 feet. Drilled by Dun Mulka, 1953.		
Loam	1	1
Clay	2	3
Sand and gravel	18	22
RF 40N/03E-09G01. Altitude 122 feet. Drilled by Livermore & Son, Inc., 1988.		
Road bed	2	2
Sand, gravel, and boulders	4	6
Sand and gravel	19	25
Sand gradually gets finer	40	65
Clay, blue and soft	5	70

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Materials	Well number	Thickness (feet)	Depth (feet below land surface)
RK	40N/03E-11E04. Altitude 130 feet.	Drilled by B & C Well Drilling, Inc., 1984.	
Gravel and sand, fine		22	22
Gravel, pea		13	35
Gravel and sand, coarse		9	44
RM	40N/03E-12H01. Altitude 100 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1982.	
Topsoil		1	1
Gravel, brown, and little clay		11	12
Gravel, brown, sand, and water		13	25
Clay, grey, and sand seepage		27	52
Clay, grey		68	120
RN	40N/03E-13N01. Altitude 85 feet.	Drilled by B & C Well Drilling, Inc., 1984.	
Clay, grey		160	160
Clay, grey, and sand		10	170
Sand, very fine, saline		5	175
RO	40N/03E-13Q01. Altitude 86 feet.	Drilled by M. Starkemburg, 1947.	
Topsoil		2	2
Clay, blue		178	180
Sand, coarse, gravel, and quicksand		45	225
RP	40N/03E-14B01. Altitude 95 feet.	Drilled by Radke Well Drilling, 1947.	
Clay, hard blue and cobbles		260	260
Sand		5	265
RU	40N/03E-16D01. Altitude 111 feet.	Drilled by Sumas Well Drill, 1963.	
Clay, red, and loam		3	3
Sand		24	27

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
SB 40N/03E-16M01. Altitude 100 feet.	Drilled 1984.	
Clay, sandy topsoil, brown	7	7
Clay, brown	3	10
Sand, brown, and gravel	3	13
Gravel, grey, sand, and water	10	23
Sand, grey, and water	36	59
Clay, grey	210	269
Clay, grey, and gravel	4	273
Clay, grey	2	275
Clay, grey, and gravel	49	324
Gravel, grey, and water	21	345
Clay, and gravel, grey	5	350
Clay, sand, occasional gravel	30	380
SC 40N/03E-16Q01. Altitude 104 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1988.	
Topsoil	1	1
Sand, dry, and gravel	15	16
Sand, brown, and water	14	30
Sand, brown, dirty, and water	8	38
Sand, fine, grey, and water	12	50
Clay, grey	4	54
SE 40N/03E-18E01. Altitude 103 feet.	Drilled by B & K Water Wells, 1979.	
Topsoil	2	2
Sand and clay	4	6
Sand, grey, and gravel	30	36
SG 40N/03E-19A01. Altitude 98 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1989.	
Topsoil	1	1
Clay, brown, and sand	9	10
Clay, grey, sand, and little gravel	4	14
Sand, grey, little gravel, and water	7	21
Sand, coarse, grey, gravel, and water	11	32
Sand and water	6	38

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, grey, sand, fine	2	40
SH 40N/03E-22C01. Altitude 55 feet. Drilled 1945.		
Gravel	5	5
Clay, grey-blue	10	15
SI 40N/03E-24E01. Altitude 75 feet. Drilled by Star Drilling Service, 1990.		
Clay, red	11	11
Clay, grey	132	149
Hardpan	1	150
Gravel	0.5	150.5
SK 40N/03E-25J01. Altitude 78 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1985.		
Topsoil	10	10
Clay, grey	7	17
Peat, dark brown	19.5	36.5
Sand and water	2	38.5
Gravel, grey, water, and clay, grey	6.5	45
SR 40N/03E-26H01. Altitude 70 feet. Drilled by Sumas Well Drill, 1954.		
Clay, loam	8	8
Sand	7	15
Gravel	9	24
SP 40N/03E-31N02. Altitude 80 feet. Drilled by Livermore & Son Inc., 1989.		
Sand, coarse	12	12
Sand, brown, and fine	32	44
Sand, blue, and fine	9	53

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials		Thickness (feet)	Depth (feet below land surface)
SS 40N/03E-32G01.	Altitude 77 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1985.	
Topsoil		2	2
Sand, brown, and dry		31	33
Gravel and sand		1	34
Clay, grey, and sandy		3	37
Clay, grey		78	115
Clay, grey, and gravel		10	125
Clay, grey, and scattered gravel		27	152
Silt, grey, fine, sand, and saltwater		51	203
Sand, fine, grey, and saltwater		102	305
Clay, grey		48	353
Sand, grey, and saltwater		7	360
Gravel, grey, and clay		42	402
Gravel and saltwater		5	407
Gravel, grey, and clay		30	437
Gravel, saltwater, and clay		5	442
SW 40N/03E-32L01.	Altitude 87 feet.	Drilled by B & K Water Well Inc., 1989.	
Topsoil		2	2
Sand, brown, and coarse		24	26
Sand, brown, and fine		8	34
Clay, brown		6	40
Sand, grey, and fine		5	45
SZ 40N/03E-32P01.	Altitude 85 feet.	Drilled by Bezona Well Service, 1989.	
Soil, brown, and sandy		2	2
Sand, grey, and coarse		23	25
Clay, blue		15	40
TA 40N/03E-32P02.	Altitude 92 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1981.	
Topsoil		2	2
Sand, brown and coarse		15	17
Sand, brown, coarse and gravel		15	32
Clay, brown		2	34

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, grey	23	57
Sand, grey	14	71
Clay, grey	123	194
Sand, grey, and water	13	207
Clay, sandy grey	12	219
Sand, grey, and water	23	242
Clay, grey, and gravel	129	371
Sand, grey, and water	2	373
Gravel, some sand, and water	4	377
Gravel and clay, grey	1	378
Gravel, sand, and water	72	450
Gravel, grey, and clay	43	493
Clay, grey	24	517
Clay, grey, and clam shells	40	557
Clay, grey, and gravel	12	569
Clay, grey	1	570
Gravel and saltwater	4	574
Clay, grey, and gravel	6	580
Granite boulder	3	583
Conglomerated gravel	117	700
TB 40N/03E-32Q01. Altitude 83 feet. Drilled by B & K Water Well Inc., 1988.		
Topsoil	2	2
Sand, grey, coarse	14	16
Clay, brown	1	17
Sand, grey, and gravel	8	25
Clay, blue at bottom of hole		
TG 40N/03E-34P01. Altitude 80 feet. Drilled by B & K Water Wells, 1988.		
Topsoil	2	2
Sand, coarse	17	19
Sand and gravel	15	34
Clay, blue at bottom of hole		
TH 40N/03E-34Q01. Altitude 80 feet. Drilled by Hayes Well Drilling & Pumps, Inc.		

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, fine to coarse	10	10
Sand and gravel, brown, fine to medium	5	15
Sand, grey, fine to medium	15	30
Silt, with sand, light grey	5	35
Clay, silty, with some gravel	100	135
Sand, very fine, and bearing water	80	215
Clay, silty, and occasional gravel	41	256
Bedrock at bottom of hole		
TJ 40N/03E-35R02. Altitude 105 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1988.		
Topsoil	3	3
Gravel, dry	32	35
Sand, medium, brown, and water	12	47
Sand, medium, grey, and water	5	52
Clay, grey at bottom of hole		
TK 40N/03E-36J01. Altitude 90 feet. Drilled 1936.		
Gravel, ashy, and grey	30	30
Subsoil, gravel, rusty, and gravel, ash-grey	3	33
TU 40N/04E-05D02. Altitude 181 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1979.		
Topsoil	5	5
Sand and little gravel	5	10
Clay, sandy, and gravel	40	50
Gravel and water	31	81
Sand, dirty, and little water	14	95
TW 40N/04E-05E02. Altitude 162 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1988.		
Topsoil	3	3
Gravel, brown, and dry	28	31
Gravel and water	9	40
Gravel, grey, sand, and water	31	71

Appendix **Table 3.** Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, grey, medium, gravel, and water	6	77
Sand, grey, medium, clay, and water at bottom of hole		
TZ 40N/04E-05N02.	Altitude 139 feet.	Drilled by B & C Well Drilling, Inc., 1979.
Gravel with cobbles, sandy	17	17
Hardpan, brown	32	49
Hardpan, softer	14	63
Gravel, coarse	10	73
Sand with gravel	7	80
Sand, coarse, with gravel	6	86
UG 40N/04E-07G01.	Altitude 110 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1988.
Sand, brown, coarse, and gravel	2	2
Sand, brown	13	15
Sand, brown, and little clay	7	22
Sand, brown	12	34
Sand, brown, and water	5	39
Clay, coarse, brown, and sand	1	40
Sand, brown, and water	10	50
Sand, brown, coarse, gravel, and water	15	65
Gravel, brown, sand, coarse, and water	13	78
UH 40N/04E-07H04.	Altitude 74 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1987.
Topsoil	4	4
Sand, brown, dry, gravel, and clay	6	10
Sand, brown, fine, and little gravel	4	14
Clay, brown	2	16
Gravel, brown, sand, and water	4	20
Sand, brown, medium, and water, dirty	16	36
Gravel, sand, and water	4	40
Clay, brown	1	41
Gravel, sand, and water	21	62
Sand, brown, and water	10	72
Sand, brown, gravel, and water	4	76
Sand, gravel, greyish, and water	6	82

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, coarse, and water	2	84
Sand, coarse, gravel, and water	6	90
Clay, grey at bottom of hole		
UI 40N/04E-08A02. Altitude 56 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1980.		
Topsoil	3	3
Sand, brown, slit, and clay	22	25
Clay, grey, and some gravel	7	32
Gravel, grey, sand, clay, and water	3	35
Gravel, grey, sand, and water	22	57
UK 40N/04E-09B01. Altitude 48 feet. Drilled by G.A. Bezona, 1962.		
Clay	10	10
Sandy muck, some water	10	20
Clay and gravel	13	33
Gravel, loose, and water	16	49
UR 40N/04E-10E02. Altitude 46 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1971.		
Loam, sandy, tan	1	1
Clay, grey	3	4
Silt, grey, and clay seepage	2	6
Clay, grey, chunks of peat and wood	12	18
Silt, grey, clay, and wood	7	25
Sand, gravel, and water	13	38
US 40N/04E-10G01. Altitude 47 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1979.		
Topsoil	3	3
Clay, sandy brown	3	6
Clay, grey	24	30
Gravel and water	15	45
Clay, grey, and gravel	10	55
Gravel and water	14	69

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials			Thickness (feet)	Depth (feet below land surface)
UU	40N/04E-11C01.	Altitude 43 feet.	Drilled by America Water Wells Inc., 1980.	
Topsoil			1	1
Sand and gravel			7	8
Sand, gravel, and water			13	21
Cemented graveled boulders at bottom of hole				
UV	40N/04E-12B01.	Altitude 50 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1980.	
Topsoil			3	3
Sand, dry, and little wood			12	15
Sand, medium, and water			3	18
Sand, grey, medium, gravel, and water			7	25
Clay, grey			20	45
Gravel, sand, and little water, dirty			3	48
Clay, grey			7	55
Gravel, sand, and water			7	62
Clay, grey			3	65
Gravel, sand, and water			1	66
Peat, clay, grey, and wood			9	75
Gravel and water			7	82
Clay, grey			8	90
Gravel, sand, and water			12	102
Sand, fine, and water			8	110
VI	40N/04E-19K01.	Altitude 70 feet.	Drilled by Dahlman Pump & Drilling, Inc., 1982.	
Topsoil			3	3
Clay, blue			32	35
Sand and gravel			15	50
Gravel and water			7	57
VO	40N/04E-22J02.	Altitude 178 feet.	Drilled by Hayes Well Drilling & Pumps, Inc., 1981.	
Topsoil			1	1
Gravel, brown, dry and sand			36	37
Gravel, brown, sand, seepage			20	57
Gravel, brown, sand, and water			12	69

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Clay, brown	2	71
Clay, grey, and soft	36.5	107.5
Sand, grey, coarse, little gravel, and water.	1	108.5
Clay, grey, and little gravel	4.5	113
Clay, grey, and soft	6	119
Gravel, sand, and water	1	120
Sand, little gravel, shells, and water	3	123
Sand, grey, and clay, soft	4	127
Clay, grey	1	128
Clay, grey, and gravel, soft	2	130
Clay, grey, and soft	7	137
Clay, grey, and gravel	7	144
Clay, and gravel, grey	11	155
Sandstone	45	200
VS 40N/04E-28D02. Altitude 130 feet. Drilled by B & C Well Drilling, Inc., 1980.		
Soil	1	1
Gravel, crusted	1	2
Gravel, dry, loose	39	41
Gravel, dirty	7	48
Hardpan	1	49
Gravel and water	19	68
Silt with sand and water	3	71
VX 40N/04E-30D01. Altitude 75 feet. Drilled by Herman Ellingson, 1962.		
Topsoil	2	2
Sand	6	8
Clay and peat	18	26
Gravel	1	27
VY 40N/04E-30E01. Altitude 75 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1980.		
Topsoil	3	3
Clay, brown	7	10
Clay, grey	5	15

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Peat and wood	5	20
Gravel, grey, and clay	5	25
Gravel, grey, and water	9	34
Clay, grey at bottom of hole		
WL 41N/02E-33J01. Altitude 250 feet. Drilled by Livermore and Son, Inc., 1989.		
Topsoil	2	2
Hardpan	6	8
Sand, gravel, and hardpan	6	14
Sand and clay, blue	47	61
Sand, fine, and water	7	68
Sand and clay, blue	6	74
Sand, gravel, and water	5	79
WN 41N/02E-35Q02. Altitude 150 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1979.		
Gravel, greyish-brown	15	15
Gravel, grey, and clay	8	23
Clay, grey, and gravel	37	60
Gravel, grey, and sand	35	95
Clay, grey, very hard	26	121
Gravel, grey, and clay	119	240
Gravel, clean, grey	2	242
Gravel, grey, and clay	18	260
Gravel, clay, grey, and wood	3	263
Gravel, grey and clay, and small layers of clay	51	314
Clay, grey, hard	17	331
Gravel, grey, and clay, dry	10	341
Gravel, brownish-grey, and clay	4	345
Gravel, grey, and clay	37	382
Clay, grey, and gravel	16	398
Gravel, grey, water wood, and clam shells	26	424
Siltstone	76	500

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
WO 41N/02E-36J01. Altitude 129 feet. Drilled by Snowden Well Digging, 1979.		
Sandy loam	2	2
Sand, and clay, hard	3	5
Gravel	10	15
Sand, layers of hard and fine silt	13	28
Clay, blue at bottom of hole		
WP 41N/02E-36K01. Altitude 129 feet. Drilled by Herman Ellingson, 1962.		
Topsoil	3	3
Gravel, water bearing	26	29
WS 41N/03E-31Q01. Altitude 136 feet. Drilled by Snowden Well Digging, 1980.		
Peat, soil	4	4
Sand and clay	3	7
Sand and gravel	26	33
WT 41N/03E-32Q01. Altitude 137 feet. Drilled by A & K Driller, 1974.		
Topsoil	1	1
Sand, coarse, and gravel	29	30
WU 41N/03E-33E01. Altitude 146 feet. Drilled by Livermore & Son, Inc., 1987.		
Topsoil	3	3
Sand and gravel, dry	13	16
Sand and gravel	5	21
Sand and water	22	43
WV 41N/03E-33G01. Altitude 141 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Topsoil, sandy, and some gravel	2	2
Sand, brown, and gravel	13	15
Gravel, brown, sand, and water	8	23

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Sand, brown, and water	62	85
Clay, grey, soft	150	235
Sand, grey, coarse, and water	18	253
Clay, grey	22	275
Sand, gravel, and saltwater	8	283
WX 41N/03E-34G01. Altitude 141 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1988.		
Topsoil	2	2
Clay, grey	1	3
Gravel, sand, and water	15	18
Sand, little gravel, and water	20	38
Sand, fine, and clay and water at bottom of hole		
WY 41N/03E-34M01. Altitude 141 feet. Drilled by Harold Zwicker, 1954.		
Clay loam	3	3
Gravel and rock	17	20
XH 41N/03E-35L01. Altitude 158 feet. Drilled by B & C Well Drilling, Inc., 1988.		
Topsoil	2	2
Sand, and gravel	25	27
XC 41N/03E-36J02. Altitude 162 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1987.		
Topsoil	1	1
Sand, brown, gravel, and wood	7	8
Gravel, brown	24	32
Gravel, brown, sand, and water	16	48
Gravel, rusty-brown, and water	11	59
Sand, greenish-grey, gravel, and water	20	79
Gravel, grey, sand, and water	13	92
Clay, grey at bottom of hole		

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
XD 41N/03E-36N01. Altitude 159 feet. Drilled by Don Mulka, 1956.		
Clay, red, loam	2	2
Gravel	24	26
XG 41N/04E-31R01. Altitude 174 feet. Drilled by Livermore and Son, Inc., 1951.		
Topsoil	3	3
Sand and gravel	35	38
Sand, fine, and water bearing	9	47
Sand and gravel, brown	13	60
Sand and gravel, blue	11	71
XI 41N/04E-32E01. Altitude 206 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1981.		
Topsoil	3	3
Sand, brown, dry, and gravel	67	70
Sand, brown, gravel, and water	10	80
Gravel, brown, sand and water	23	103
Sand, brown, gravel, and water	27	130
Sand, brown, some gravel, and water	44	174
Gravel, grey, sand, and clay	10	184
Sand, grey, very little gravel, and water	29	213
Clay, grey	21	234
Sand, grey, fine, and water	106	340
Clay, grey, with some sand	20	360
Sand, grey, medium, some clay	40	400
XJ 41N/04E-32M01. Altitude 189 feet. Drilled by Bezona Well Service, 1979.		
Gravel, silty, and topsoil	2	2
Gravel, sand, and alluvium	88	90
Gravel, coarse	5	95
XK 41N/04E-32Q01. Altitude 132 feet. Drilled 1970.		
Topsoil	6	6

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
Gravel	21	27
XL 41N/04E-32R01. Altitude 194 feet. Drilled by B & C Well Drilling, Inc., 1974.		
Topsoil	3	3
Gravel, cemented	7	10
Boulders	1	11
Gravel, cemented	12	23
Sand, with gravel	4	27
Clay, sandy	23	50
Gravel, cemented	15	65
Sand, with gravel	17	82
Sand and gravel with water	10	92
XQ 41N/04E-33H04. Altitude 50 feet. Drilled by Kimple Well Drilling, 1971.		
Peat	30	30
Gravel, clayey	5	35
Gravel with chunks of clay and water	10	45
Gravel, coarse	11	56
Sand, coarse	2	58
Gravel, coarse	10	68
XR 41N/04E-33N02. Altitude 119 feet.		
Sand, brown, fine, and traces of clay, silt and gravel	32	32
Silt and traces of sand	22	54
Sand, dark brown and grey, and little gravel	50	104
Silt, grey	4	108
Sand, grey-brown, fine	91	199
Clay, grey	1	200

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
XT 41N/04E-33N04. Altitude 87 feet.		
Sand brown, fine, and some slit, trace clay	23	23
Clay, grey, traces of fine sand, and silt	13	36
Sand, grey to brown, fine, trace clay, and little silt	6	42
Clay, grey, trace silt	12	54
Sand, grey-brown, and gravel	17.5	71.5
Clay, brown-grey, some sand	0.5	72
XW 41N/04E-36L01. Altitude 30 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1982.		
Topsoil	2	2
Gravel, small, brown	6	8
Clay, brown, and sand	4	12
Clay, grey, and some sand	6	18
Sand, grey, some gravel, and water	11	29
Clay, brown	2	31
Clay, grey	2	33
Sand, grey, some gravel, and water	4	37
Clay, grey	16	53
Sand, grey, some gravel, and water	10	63
Clay, grey, some sand, and lots of wood	5	68
Sand, grey, fine, dirty, some wood, and water	15	83
XX 41N/05E-31M01. Altitude 35 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1979.		
Topsoil	3	3
Clay, tan, sandy	5	8
Clay, grey	26	34
Sand, medium, and water	8	42
Clay, grey	10	52
Sand, gravel, and water	20	72
Clay, grey	2	74
Sand, fine, dirty, wood, and water	4	78

Appendix Table 3. Lithologic logs used in construction of hydrogeologic sections--Continued

(Mapcode) Well number Materials	Thickness (feet)	Depth (feet below land surface)
YB 41N/05E-32L02. Altitude 27 feet. Drilled by Hayes Well Drilling & Pumps, Inc., 1986.		
Topsoil	2	2
Clay, grey, and sand	23	25
Sand and water	10	35
Sand, dirty, wood, and water	7	42
Sand, dirty, fine, grey, and wood	48	90
Silt, grey, sand, clay, and wood	50	140
Clay, grey	40	180

Appendix Table 4a. Values of common constituents, concentrations of major ions, iron, and manganese
[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, not analyzed; SUMS, Sumas aquifer; EVRS, Everson-Vashon unit; VSHN, Vashon unit; BDRK, bedrock unit]

Local well number	Date	Hydro-geo-logic unit	pH (stan-dard)	Alka-linity (mg/L K as CaCO3)	Oxy-gen dis-solved (mg/L)	Hard-ness, total (mg/L as CaCO3)	Iron, dis-solved (µg/L as Fe)	Manga-nese, dis-solved (µg/L as Mn)
092G.008.1.2.2-01	10-01-91	EVRS	7.0	97	0.3	100	5	11
092G.008.1.4.2-15	10-01-91	EVRS	8.3	146	0.2	258	340	140
092G.008.2.1.1-02	10-01-91	EVRS	8.2	132	0.1	64	110	140
092G.008.2.2.1-03	10-01-91	SUMS	8.5	74	0.1	84	7	27
092G.008.2.2.3-03	10-01-91	SUMS	6.2	56	4.3	66	7	1
092G.008.2.3.3-14	10-01-91	EVRS	8.9	147	0.0	27	34	17
092G.008.2.4.1-18	10-01-91	SUMS	7.3	79	1.7	83	5	0.9
092G.008.2.4.2-14	10-01-91	EVRS	6.7	55	5.8	78	3	0.9
092G.009.1.1.1-06-25	06-13-90	SUMS	5.5	9.0	8.8	76	3	2
092G.009.1.1.1-06-35	06-13-90	SUMS	5.7	13	8.5	95	3	0.9
092G.009.1.1.1-07-55	06-13-90	SUMS	6.7	44	6.4	68	3	0.9
092G.009.1.1.1-07-75	06-13-90	SUMS	8.0	69	0.2	88	3	5
092G.009.1.1.2-11-25	06-12-90	SUMS	5.5	9.0	9.0	54	3	3
092G.009.1.1.2-11-35	06-12-90	SUMS	5.8	13	9.2	98	3	3
092G.009.1.1.2-12-55	06-12-90	SUMS	6.7	46	5.0	82	3	0.9
092G.009.1.1.2-12-75	06-12-90	SUMS	8.0	65	0.8	85	3	7
092G.009.1.1.4-17	09-30-91	SUMS	6.4	50	5.8	112	46	4
092G.009.1.1.4-18-25	06-12-90	SUMS	5.5	16	8.1	32	4	0.9
092G.009.1.1.4-18-35	06-12-90	SUMS	5.7	19	7.6	35	3	0.9
092G.009.1.1.4-19-55	06-12-90	SUMS	6.4	48	6.0	61	3	0.9
092G.009.1.1.4-19-75	06-12-90	SUMS	8.1	56	1.0	91	3	28
092G.009.1.2.4-31	09-30-91	EVRS	6.4	47	6.4	94	22	0.9
092G.009.1.3.4-26	09-30-91	SUMS	6.0	27	6.4	45	22	7
092G.009.2.1.2-19	10-02-91	SUMS	6.5	50	4.5	92	3	380
092G.009.2.1.4-26	10-02-91	SUMS	8.0	94	2.8	144	12	7
092G.009.2.2.3-11	10-01-91	SUMS	6.8	17	<1	232	34,000	970
39N/02E-01P02	08-29-90	SUMS	6.6	15	--	53	6	4
39N/02E-10F01	08-28-90	SUMS	7.6	36	2.3	85	150	230
39N/02E-11B01	04-23-91	SUMS	6.1	13	2.2	40	13	66
39N/02E-12K03	08-29-90	SUMS	7.0	26	--	41	5	8
39N/02E-13B01	04-26-91	SUMS	7.2	88	5.7	109	5,300	380
39N/02E-14M01	08-28-90	SUMS	6.8	45	<0.1	69	170	66
39N/02E-22D02	04-25-91	SUMS	8.4	83	1.3	111	87	200
39N/02E-24C02	04-26-91	SUMS	6.2	24	3.2	54	960	63

Appendix Table 4b. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Nitrate plus nitrite dissolved (mg/L as N)	Sulfate dissolved (mg/L as SO4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg.L as Si)	Local well number
8.0	1.7	22	11	1.0	14	4.9	0.1	17	092G.008.1.2.2-01
43	12	36	41	0.05	110	620	0.2	25	092G.008.1.4.2-15
34	4.4	15	6.5	0.05	0.2	4.3	0.2	31	092G.008.2.1.1-02
8.8	2.8	24	5.9	3.6	15	2.2	0.1	18	092G.008.2.2.1-03
5.9	2.2	18	5.3	4.2	5.5	5.8	0.2	20	092G.008.2.2.3-03
57	5.3	4	4.3	0.05	6.1	2.4	0.2	19	092G.008.2.3.3-14
5.9	1.4	20	8.2	8.1	10	2.7	0.1	21	092G.008.2.4.1-18
4.7	1.0	20	7.0	8.4	2.9	6.8	0.1	23	092G.008.2.4.2-14
4.4	5.6	23	4.5	18	7.4	8.5	0.1	11	092G.009.1.1.1-06
5.5	2.0	29	5.6	21	8.1	10	0.1	16	092G.009.1.1.1-06
3.8	0.9	19	5.2	6.9	5.7	0.3	0.1	20	092G.009.1.1.1-07
4.8	1.6	27	5.0	1.2	16	0.5	0.1	16	092G.009.1.1.1-07
4.7	0.7	16	3.6	11	12	5.8	0.2	12	092G.009.1.1.2-11
6.1	0.8	30	5.7	19	14	12	<0.1	16	092G.009.1.1.2-11
4.6	1.0	24	5.5	2.7	9.3	6.9	0.1	19	092G.009.1.1.2-12
7.2	1.4	26	5.0	2.0	20	8.5	<0.2	17	092G.009.1.1.2-12
6.7	1.2	32	7.9	16	9.7	8.5	0.1	22	092G.009.1.1.4-17
3.2	0.6	10	1.8	5.9	2.3	2.7	0.1	15	092G.009.1.1.4-18
3.1	0.5	11	1.9	5.5	2.1	2.9	0.1	16	092G.009.1.1.4-18
3.3	0.7	17	4.6	4.6	3.0	0.4	0.1	22	092G.009.1.1.4-19
4.6	2.4	29	4.7	5.0	23	1.0	0.1	8.7	092G.009.1.1.4-19
6.6	1.0	27	6.5	9.9	11	10	0.1	23	092G.009.1.2.4-31
7.0	0.7	14	2.5	4.9	10	6.4	0.1	16	092G.009.1.3.4-26
5.4	1.4	25	7.4	9.1	15	5.8	0.4	16	092G.009.2.1.2-98
6.3	2.1	44	8.5	6.9	31	8.1	0.3	16	092G.009.2.1.4-98
34	5.4	52	25	0.06	10	210	<0.1	49	092G.009.2.2.3-11
11	4.4	13	5.2	9.3	23	16.8	<0.1	17	39N/02E-01P02
8.4	1.5	25	5.7	4.9	31	15	0.4	24	39N/02E-10F01
5.4	0.7	11	3.1	3.3	16	8.9	<0.1	16	39N/02E-11B01
6.0	9.4	9.9	4.1	4.5	16	6.0	<0.1	21	39N/02E-12K03
10	1.6	28	9.5	0.1	34	12	<0.1	26	39N/02E-13B01
7.9	1.0	15	7.7	3.7	25	13	<0.1	26	39N/02E-14M01
22	1.8	29	9.4	0.05	43	27	<0.1	22	39N/02E-22D02
6.4	0.9	13	5.4	2.6	19	14	<0.1	20	39N/02E-24C02

Appendix Table 4a. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Local well number	Date	Hydro-geo-logic unit	pH (stan-dard)	Alka-linity (mg/L K as CaCO3)	Oxy-gen dis-solved (mg/L)	Hard-ness, total (mg/L as CaCO3)	Iron, dis-solved (µg/L as Fe)	Manga-nese, dis-solved (µg/L as Mn)
39N/02E-26H01	04-23-91	SUMS	6.7	73	7.1	117	3	0.9
39N/02E-27F03	08-28-90	SUMS	7.4	48	2.2	83	26	5
39N/02E-27Q04	07-10-91	SUMS	6.6	36	3.2	56	4	8
39N/03E-01C01	04-22-91	SUMS	6.7	45	1.2	68	54	69
39N/03E-02B02	08-28-90	SUMS	7.4	60	0.2	84	120	97
39N/03E-07K02	04-26-91	SUMS	6.5	28	6.6	141	10	28
39N/03E-08C02	08-30-90	SUMS	6.7	26	--	71	11	0.9
39N/03E-13E01	04-23-91	BDRK	8.6	179	0.1	26	170	13
39N/03E-16F02	04-30-91	SUMS	6.6	31	0.1	42	100	16
39N/03E-17R03	04-23-91	SUMS	8.0	120	0.3	225	360	380
39N/03E-19N01	04-23-91	EVRS	7.9	133	0.6	121	3	4
39N/03E-21K01	04-24-91	EVRS	8.8	414	0.1	54	150	16
39N/03E-24B01	04-26-91	SUMS	6.3	31	7.2	27	19	1
39N/03E-26D01	04-23-91	EVRS	7.1	166	<0.1	109	160	360
39N/03E-26J01	04-25-91	BDRK	7.7	214	<0.1	195	1,500	110
39N/03E-28F01	04-24-91	EVRS	8.5	212	<0.1	145	260	50
39N/03E-32J01	04-25-91	EVRS	7.9	211	<0.1	154	580	260
39N/03E-33R01	04-24-91	BDRK	8.5	606	<0.1	12	48	6
39N/03E-34N01	04-25-91	SUMS	6.6	118	<0.1	129	93	380
39N/03E-35L01	04-24-91	EVRS	8.5	229	0.1	68	80	72
39N/04E-03P01	08-31-90	VSHN	7.5	57	<0.1	156	190	90
39N/04E-10M01	04-27-91	VSHN	8.6	95	0.4	170	80	20
39N/04E-16F01	04-25-91	SUMS	6.6	51	3.2	61	15	50
39N/04E-16H01	04-25-91	VSHN	6.5	71	6.8	90	11	0.9
39N/04E-16Q02	04-24-91	SUMS	6.5	49	4.1	69	30	0.9
39N/04E-18M01	04-23-91	BDRK	8.2	143	0.1	31	15	99
39N/04E-19M01	04-25-91	BDRK	8.4	376	<0.1	14	5	11
39N/04E-20H01	04-24-91	SUMS	6.4	39	2.7	46	73	2
39N/04E-22L01	04-23-91	SUMS	6.6	268	0.1	319	7	690
39N/04E-28F01	04-26-91	SUMS	6.2	39	0.8	44	94	3
39N/04E-30D01	04-26-91	EVRS	8.4	300	0.1	65	61	87
39N/04E-32A01	04-26-91	EVRS	8.9	444	0.2	10	180	11
39N/04E-32N01	04-24-91	EVRS	9.0	392	0.3	12	75	6
39N/04E-33E01	04-26-91	EVRS	8.8	409	1.0	12	73	4
40N/02E-03C01	04-30-91	EVRS	8.0	203	<0.1	53	570	270

Appendix Table 4b. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Nitrate plus nitrite dissolved (mg/L as N)	Sulfate dissolved (mg/L as SO4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg.L as Si)	Local well number
7.4	0.9	24	14	12	10	10	<0.1	25	39N/02E-26H01
15	1.1	17	9.9	12	19	16	0.1	28	39N/02E-27F03
15	1.1	15	4.6	5.8	15	13	0.1	17	39N/02E-27Q04
24	1.8	17	6.3	0.37	9.7	54	<0.1	21	39N/03E-01C01
24	2.3	22	7.1	0.2	16	49	0.3	23	39N/03E-02B02
8.0	1.7	32	15	19	27	13	<0.1	20	39N/03E-07K02
6.6	1.1	16	7.7	0.1	3.9	7.2	<0.1	21	39N/03E-08C02
220	0.9	9.9	0.2	0.05	1.3	230	0.5	11	39N/03E-13E01
4.7	0.8	9.4	4.7	1.2	19	3.3	0.2	24	39N/03E-16F02
13	2.0	64	16	1.4	79	34	<0.1	30	39N/03E-17R03
15	2.6	32	10	1.2	12	7.8	<0.1	19	39N/03E-19N01
240	10	6	9.6	0.05	170	23	0.3	19	39N/03E-21K01
3.3	0.5	7.1	2.3	0.4	1.4	1.4	<0.1	17	39N/03E-24B01
33	3.3	24	12	0.05	2.6	7.5	<0.1	20	39N/03E-26D01
760	5.3	61	9.7	0.05	1.6	1,300	0.3	9.9	39N/03E-26J01
390	12	22	22	0.1	2.2	610	0.2	16	39N/03E-28F01
39	3.5	37	15	0.05	0.1	30	0.2	27	39N/03E-32J01
380	1.6	4	0.7	0.05	0.1	220	0.5	7.6	39N/03E-33R01
4.8	0.8	36	9.7	0.05	17	3.2	<0.1	13	39N/03E-34N01
98	4.9	16	6.9	0.05	0.2	55	0.5	21	39N/03E-35L01
400	4.7	46	10	0.1	1.0	689	0.5	18	39N/04E-03P01
370	3.1	42	16	0.05	0.1	650	0.3	15	39N/04E-10M01
3.4	1.1	13	7.1	1.5	11	3.2	<0.1	15	39N/04E-16F01
6.2	1.3	13	14	5.0	9.1	7.8	<0.1	21	39N/04E-16H01
5.3	1.0	9.5	11	3.6	7.2	5.6	0.1	24	39N/04E-16Q02
67	0.8	11	0.9	0.05	0.4	28	0.3	13	39N/04E-18M01
210	1.2	4.6	0.6	0.05	79	20	0.4	9.2	39N/04E-19M01
3.6	0.7	11	4.7	0.7	5.8	3.7	<0.1	14	39N/04E-20H01
33	2.7	44	51	15	23	40	<0.1	33	39N/04E-22L01
6.6	0.9	10	4.8	1.2	8.0	5.0	<0.1	15	39N/04E-28F01
220	5.9	14	7.4	0.1	1.1	170	0.5	22	39N/04E-30D01
230	3.5	2.6	0.9	0.05	0.1	74	1.1	16	39N/04E-32A01
200	3.8	2.3	1.7	0.05	0.1	59	0.6	15	39N/04E-32N01
210	3.6	2.0	1.7	0.05	0.1	70	1.0	16	39N/04E-33E01
70	4.2	11	6.2	0.05	0.1	5.2	0.6	28	40N/02E-03C01

Appendix Table 4a. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Local well number	Date	Hydrogeologic unit	pH (standard)	Alkalinity (mg/L K as CaCO3)	Oxygen dissolved (mg/L)	Hardness, total (mg/L as CaCO3)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
40N/02E-10N02	08-21-91	SUMS	6.5	216	0.0	229	8,200	1,100
40N/02E-13J04	07-19-91	SUMS	6.3	1.0	--	99	24,000	430
40N/02E-13J07	07-19-91	SUMS	7.3	451	0.2	48	1,600	45
40N/02E-14P02	04-30-91	SUMS	6.1	20	8.8	110	30	3
40N/02E-15J01	04-29-91	SUMS	6.5	54	0.4	95	5,700	870
40N/02E-15P01	08-21-91	SUMS	6.1	23	3.8	41	27	47
40N/02E-21R01	04-30-91	SUMS	5.7	9	7.7	105	26	10
40N/02E-23D01	04-30-91	SUMS	5.8	30	3.4	73	26	23
40N/02E-26A03	10-04-91	SUMS	6.7	48	6.8	98	28	66
40N/02E-27B01	08-30-90	SUMS	6.5	17	--	85	6	0.9
40N/02E-33B02	10-02-91	SUMS	6.4	27	9.4	62	12	5
40N/03E-03B01	08-30-90	SUMS	6.5	19	--	56	38	4
40N/03E-03R02	05-02-91	SUMS	7.0	48	5.3	113	6	31
40N/03E-05L01	08-14-91	SUMS	6.6	559	0.2	395	36,000	3,500
40N/03E-05M05	08-14-91	SUMS	6.1	26	--	112	58	12
40N/03E-05N02	08-29-90	SUMS	6.0	10	--	49	1,600	58
40N/03E-07A02	05-01-91	SUMS	5.9	19	4.0	65	15	33
40N/03E-10K01	05-02-91	SUMS	6.2	54	3.4	111	27	1
40N/03E-11E04	05-02-91	SUMS	6.4	37	6.9	81	17	3
40N/03E-16A02	08-27-90	SUMS	6.5	30	8.5	70	7	0.9
40N/03E-16K01	05-01-91	SUMS	6.3	22	2.5	64	50	93
40N/03E-19A01	10-04-91	SUMS	6.6	48	0	64	13,000	800
40N/03E-24E01	10-02-91	EVRS	8.0	83	--	1,008	10	200
40N/03E-31L01	05-01-91	SUMS	6.8	27	8.5	58	8	0.9
40N/03E-31P03	04-26-91	SUMS	6.5	35	7.7	100	58	0.9
40N/03E-32M01	08-29-90	SUMS	7.1	62	--	51	8	5
40N/03E-36Q01	04-30-91	SUMS	6.2	44	5.3	66	4	2
40N/04E-01K02	10-04-91	SUMS	6.9	134	3.4	100	14,000	450
40N/04E-05N02	05-02-91	SUMS	7.9	103	4.3	122	7	1
40N/04E-05P01	05-02-91	SUMS	6.5	43	7.6	80	12	1
40N/04E-05P02	08-29-90	SUMS	6.5	57	--	106	12	0.9
40N/04E-09B01	02-21-91	SUMS	7.0	109	<0.1	101	8,400	265
40N/04E-09B01	05-03-91	SUMS	7.0	109	--	0	8,400	265
40N/04E-09N03	08-28-90	SUMS	7.2	179	<0.1	162	11,000	560
40N/04E-17G01	10-03-91	SUMS	6.7	106	4.5	139	2,700	320

Appendix Table 4b. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Nitrate plus nitrite dissolved (mg/L as N)	Sulfate dissolved (mg/L as SO4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg.L as Si)	Local well number
18	16	49	26	1.4	34	43	0.1	27	40N/02E-10N02
6.2	0.7	24	9.6	0.05	120	6.0	<0.1	35	40N/02E-13J04
50	110	13	3.9	0.05	2.6	49	<0.1	28	40N/02E-13J07
4.3	0.9	33	6.7	16	25	8.9	<0.1	18	40N/02E-14P02
10	14	23	9.2	0.2	84	8.3	<0.1	19	40N/02E-15J01
4.5	16	11	3.4	1.4	31	5.4	0.1	9.9	40N/02E-15P01
7.7	12	33	5.6	20	25	17	<0.1	11	40N/02E-21R01
5.9	1.0	22	4.5	4.0	30	9.0	0.1	15	40N/02E-23D01
18	6.9	28	7.0	13	32	11	<0.1	15	40N/02E-26A03
5.7	1.3	25	5.6	11	26	9.1	<0.1	17	40N/02E-27B01
14	6.6	18	4.3	1.8	20	14	0.1	17	40N/02E-33B02
3.6	0.7	16	4.1	7.8	13	7.8	<0.1	15	40N/03E-03B01
5.4	1.3	34	6.9	12	20	11	<0.1	16	40N/03E-03R02
61	50	94	39	0.05	22	58	0.1	17	40N/03E-05L01
11	6.6	35	6.0	18	38	15	<0.1	11	40N/03E-05M05
3.2	0.8	16	2.4	1.3	31	10	<0.1	13	40N/03E-05N02
5.8	9.9	19	4.4	11	26	4.9	<0.1	14	40N/03E-07A02
5.6	4.0	31	8.3	7.6	27	12	<0.1	18	40N/03E-10K01
4.7	0.7	22	6.4	1.5	11	7.9	0.1	20	40N/03E-11E04
4.4	0.9	17	6.8	7.4	24	14	<0.1	16	40N/03E-16A02
4.2	1.2	15	6.5	3.7	28	7.4	<0.1	17	40N/03E-16K01
5.5	0.5	18	4.7	0.05	34	10	0.1	31	40N/03E-19A01
1,800	44	140	160	0.05	620	2,800	0.4	13	40N/03E-24E01
4.7	0.7	14	5.7	7.2	4.7	8.7	<0.1	22	40N/03E-31L01
7.8	1.5	33	9.0	19	12	11	<0.1	21	40N/03E-31P03
6.0	0.9	12	5.1	11	3.2	8.5	<0.1	21	40N/03E-32M01
18	1.1	18	5.2	2.3	8.1	33	<0.1	20	40N/03E-36Q01
12	2.1	14	16	0.05	0.3	10	<0.1	53	40N/04E-01K02
3.6	1.1	36	7.9	2.3	11	6.1	0.1	23	40N/04E-05N02
5.9	2.0	21	6.9	11	8.3	6.3	<0.1	20	40N/04E-05P01
6.5	1.1	27	9.4	12	5.7	13	0.2	27	40N/04E-05P02
7.2	2.1	11	19	0.05	1.0	11	0.1	49	40N/04E-09B01
7.2	2.1	11	19	0.05	1.0	11	0.2	49	40N/04E-09B01
9.0	2.5	17	29	0.1	1.4	19	0.2	49	40N/04E-09N03
7.6	3.2	18	23	0.06	8.7	16	<0.1	45	40N/04E-17G01

Appendix Table 4a. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Local well number	Date	Hydro- geo- logic unit	pH (stan- dard)	Alka- linity (mg/L K as CaCO3)	Oxy- gen dis- solved (mg/L)	Hard- ness, total (mg/L as CaCO3)	Iron, dis- solved (µg/L as Fe)	Manga- nese, dis- solved (µg/L as Mn)
40N/04E-20F01	08-30-90	SUMS	6.9	112	<0.1	132	3,800	140
40N/04E-22G01	05-02-91	SUMS	6.4	30	10.7	39	29	7
40N/04E-22J01	05-02-91	SUMS	6.3	27	7.8	31	40	4
40N/04E-22R01	05-03-91	VSHN	8.3	81	0.1	98	29	20
40N/04E-29H02	05-03-91	SUMS	6.7	54	<0.1	37	6,300	170
40N/04E-30G01	10-03-91	SUMS	7.2	192	3.1	178	5,100	800
40N/04E-31R02	10-04-91	SUMS	7.0	184	2.6	184	5,300	890
40N/05E-06K01	07-03-91	SUMS	6.9	144	<0.1	156	5	34
41N/02E-33J01	04-29-91	EVRS	8.9	196	0.2	12	48	8
41N/03E-32Q01	05-01-91	SUMS	5.6	17	4.6	210	8	15
41N/03E-34M01	05-01-91	SUMS	6.0	17	5.4	146	32	110
41N/03E-34Q01	05-02-91	SUMS	8.4	66	0.2	90	78	170
41N/03E-35L01	05-01-91	SUMS	6.0	22	9.0	117	46	8
41N/03E-36J01	05-02-91	SUMS	5.7	14	6.9	40	13	6
41N/03E-36J02	05-02-91	SUMS	6.6	63	0.2	53	11,000	200
41N/04E-31J02	08-31-90	SUMS	6.7	44	--	94	29	5
41N/04E-32Q01	04-30-91	SUMS	6.6	53	7.8	118	9	2
41N/04E-32R01	05-01-91	SUMS	7.2	64	4.3	130	12	1
41N/04E-33H01S	05-01-91	SUMS	8.0	76	2.6	117	10	1
41N/04E-33H04	05-01-91	SUMS	8.2	82	0.8	122	3	1
41N/04E-33N04	07-20-91	SUMS	7.5	70	5.3	141	4	0.9

Appendix Table 4b. Values of common constituents, concentrations of major ions, iron, and manganese--Continued

Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Nitrate plus nitrite dissolved (mg/L as N)	Sulfate dissolved (mg/L as SO4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg.L as Si)	Local well number
9.3	2.8	15	23	0.1	31	12	0.2	40	40N/04E-20F01
4.4	0.6	9.5	3.7	3.7	3.5	2.8	<0.1	18	40N/04E-22G01
3.8	0.6	6.5	3.8	2.4	3.6	1.9	<0.1	14	40N/04E-22J01
3.4	1.2	28	7.0	0.05	21	1.8	<0.1	16	40N/04E-22R01
5.4	0.6	9	3.6	0.05	7.8	7.9	<0.1	28	40N/04E-29H02
18	4.6	37	21	0.05	0.1	28	0.4	38	40N/04E-30G01
8.4	2.6	26	29	0.1	14	19	<0.1	46	40N/04E-31R02
6.7	1.5	6.5	34	0.05	14	11	0.1	34	40N/05E-06K01
110	2.9	2.6	1.5	0.05	8.1	39	0.5	16	41N/02E-33J01
11	3.4	66	11	43	26	15	<0.1	10	41N/03E-32Q01
6.5	9.6	39	12	20	66	9.5	<0.1	15	41N/03E-34M01
3.2	1.3	27	5.7	0.05	24	5.0	<0.1	17	41N/03E-34Q01
5.4	4.1	34	8.0	21	19	9.4	<0.1	14	41N/03E-35L01
4.2	1.7	12	2.6	7.3	5.2	4.0	<0.1	9.3	41N/03E-36J01
3.9	0.6	15	3.8	0.05	5.8	4.9	<0.1	25	41N/03E-36J02
5.2	1.1	28	6.0	13	12	6.5	0.2	24	41N/04E-31J02
5.6	0.9	31	9.9	16	8.1	9.1	0.1	23	41N/04E-32Q01
4.9	1.2	38	8.7	15	17	9.9	<0.1	19	41N/04E-32R01
4.9	1.4	35	7.4	5.8	21	7.8	<0.1	16	41N/04E-33H01S
6.1	1.7	37	7.3	5.6	24	8.2	<0.1	15	41N/04E-33H04
5.3	1.3	42	8.9	15	15	10	<0.1	19	41N/04E-33N04

Appendix Table 5. Concentration of trace elements in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada

[µg/L, micrograms per liter; <, less than; --, not analyzed; SUMS, Sumas aquifer; EVRS, Everson-Vashon unit; VSHN, Vashon unit; Codes: BDRK, bedrock unit; USGS, U.S. Geological Survey; BCME, British Columbia Ministry of Environment]

Local well number	Date	Hydro-geo-logic unit code	Agency ana-lyzing sample (code number)	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Beryl-lium, dis-solved (µg/L as Be)	Boron, dis-solved (µg/L as B)	Cad-mium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)
39N/02E-01P02	08-29-90	SUMS	USGS	<1	41	--	--	<1	<1
39N/02E-10F01	08-28-90	SUMS	USGS	<1	38	--	--	<1	<1
39N/02E-12K03	08-29-90	SUMS	USGS	<1	20	--	--	<1	<1
39N/02E-14M01	08-28-90	SUMS	USGS	1	54	--	--	<1	<1
	08-28-90	--	USGS	1	54	--	--	<1	<1
39N/02E-27F03	08-28-90	SUMS	USGS	<1	10	--	--	<1	<1
39N/03E-02B02	08-28-90	SUMS	USGS	1	55	--	--	<1	<1
39N/03E-08C02	08-30-90	SUMS	USGS	<1	10	--	--	<1	<1
39N/03E-13E01	04-23-91	BDRK	USGS	--	93	<0.5	310	<1	<5
39N/03E-26J01	04-25-91	BDRK	USGS	--	1,100	<2	60	<3	<20
39N/04E-03P01	08-31-90	VSHN	USGS	6	200	--	--	<1	<1
39N/04E-19M01	04-25-91	BDRK	USGS	--	46	<0.5	--	1	<5
39N/04E-30D01	04-26-91	EVRS	USGS	--	44	<0.5	--	<1	<5
40N/02E-27B01	08-30-90	EVRS	USGS	<1	4	--	--	<1	<1
40N/03E-03B01	08-30-90	SUMS	USGS	<1	9	--	--	<1	<1
40N/03E-05N02	08-29-90	SUMS	USGS	<1	6	--	--	<1	<1
40N/03E-16A02	08-27-90	SUMS	USGS	<1	6	--	--	<1	<1
40N/03E-32M01	08-29-90	SUMS	USGS	<1	5	--	--	<1	<1
40N/04E-05P02	08-29-90	SUMS	USGS	<1	13	--	--	<1	2
40N/04E-09N03	08-28-90	SUMS	USGS	<1	390	--	--	3	<1
40N/04E-20F01	08-30-90	SUMS	USGS	<1	76	--	--	<1	<1
41N/04E-31J02	08-31-90	SUMS	USGS	<1	7	--	--	<1	<1
41N/04E-32Q01	04-30-91	SUMS	USGS	--	8	<0.5	9.9	<1	<5
41N/04E-33H04	05-01-91	SUMS	USGS	--	20	<0.5	9.9	<1	<5
092G.008.2.2.2-15	03-04-87	SUMS	BCME	<1	10	--	--	<10	<10
092G.008.2.4.4-11	03-04-87	SUMS	BCME	<1	60	--	--	<10	<10
092G.009.1.1.1-06-25	01-30-92	SUMS	BCME	<1	50	<1	28	<2	<2
092G.009.1.1.1-06-35	01-30-92	SUMS	BCME	<1	10	<1	19	<2	<2
092G.009.1.1.1-07-55	01-30-92	SUMS	BCME	<1	10 **	<1	8	<2	<2
092G.009.1.1.1-07-75	01-30-92	SUMS	BCME	3	13	<1	<8	<2	<2
092G.009.1.1.2-11-25	01-29-92	SUMS	BCME	<1	6	<1	21	<2	<2
092G.009.1.1.2-11-35	01-29-92	SUMS	BCME	<1	6	<1	28	<2	<2
092G.009.1.1.2-12-55	01-29-92	SUMS	BCME	<1	6	<1	9	<2	<2
092G.009.1.1.2-12-75	01-29-92	SUMS	BCME	2	11	<1	9	<2	<2
092G.009.1.1.2-13	01-30-92	SUMS	BCME	--	<10	--	--	<10	<10
092G.009.1.1.4-18-25	01-30-92	SUMS	BCME	<1	5	<1	<8	<2	<2
092G.009.1.1.4-18-35	01-30-92	SUMS	BCME	<1	3	<1	<8	<2	<2
092G.009.1.1.4-19-55	01-30-92	SUMS	BCME	<1	4	<1	<8	<2	<2
092G.009.1.1.4-19-75	01-30-92	SUMS	BCME	1	15	<1	<8	<2	<2
092G.009.1.2.3-10	10-27-88	SUMS	BCME	<1	10	--	--	<10	<10
092G.009.1.3.3-08	09-28-88	SUMS	BCME	<1	40	--	--	<10	<10
092G.009.2.1.1-37	07-29-84	SUMS	BCME	<250 *	--	--	--	<10	<10
092G.009.2.1.2-24	07-29-84	SUMS	BCME	<250 *	--	--	--	<10	<10
092G.009.2.1.3-47	10-20-88	SUMS	BCME	<1	80	--	--	<10	<10
092G.009.2.1.4-20	10-20-88	SUMS	BCME	<1	<10	--	--	<10	<10
092G.009.2.1.4-23	10-20-88	SUMS	BCME	<1	<10	--	--	<10	<10

Appendix Table 5. Concentration of trace elements in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Mercury, dissolved (µg/L as Hg)	Molybdenum dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Strontium dissolved (µg/L as Sr)	Vanadium dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
--	40	<1	--	<0.1	--	--	<1	<1	--	--	6
--	2	<1	--	<0.1	--	--	<1	<1	--	--	43
--	4	<1	--	<0.1	--	--	<1	<1	--	--	10
--	2	<1	--	<0.1	--	--	<1	<1	--	--	170
--	2	<1	--	<0.1	--	--	<1	1	--	--	160
--	11	<1	--	<0.1	--	--	<1	1	--	--	7
--	15	<1	--	<0.1	--	--	<1	<1	--	--	46
--	10	<1	--	<0.1	--	--	<1	<1	--	--	10
<3	190	<10	<4	--	<10	<10	--	<1	270	<6	130
<9	<30	<30	18	--	<30	<30	--	<3	1,700	<18	150
--	1	<1	--	<0.1	--	--	<1	<1	--	--	180
<3	<10	<10	<4	--	40	<10	--	2	240	<6	85
<3	<10	<10	<4	--	20	<10	--	<1	230	<6	7
--	160	<1	--	<0.1	--	--	<1	<1	--	--	11
--	13	<1	--	<0.1	--	--	<1	<1	--	--	240
--	3	<1	--	<0.1	--	--	1	1	--	--	26
--	34	1	--	<0.1	--	--	<1	1	--	--	7
--	28	<1	--	<0.1	--	--	<1	<1	--	--	36
--	6	<1	--	<0.1	--	--	<1	2	--	--	18
--	2	1	--	<0.1	--	--	<1	1	--	--	48
--	1	<1	--	<0.1	--	--	<1	1	--	--	45
--	68	<1	--	<0.1	--	--	<1	1	--	--	68
<3	20	<10	<4	--	<10	<10	--	<1	120	<6	14
<3	<10	<10	4	--	<10	<10	--	<1	120	<6	<3
<100	50	<100	--	--	<10	<50	--	--	--	<10	20
<100	<10	<100	--	--	<10	<50	--	--	--	<10	20
3	4	<20	--	--	<4	<8	<30	<10	120	<3	20 **
<3	<2	<20	--	--	<4	<8	<30	<10	150	<3	25
<3	3	<20	--	--	<4	<8	<30	<10	85	<3	32
<3	2	<20	--	--	<4	<8	<30	<10	63	5	16
<3	2	<20	--	--	<4	<8	<30	<10	79	<3	14
<3	3	<20	--	--	<4	<8	<30	<10	110	<3	41
<3	6 **	<20	--	--	<4	<8	<30	<10	76	3	19 **
<3	6 **	<20	--	--	<4	<8	<30	<10	68	6	14
<100	<10	<100	--	--	<10	<50	--	--	--	<10	110
<3	4	<20	--	--	<4	<8	<30	<10	50	<3	12 **
<3	2	<20	--	--	<4	<8	<30	<10	49	<3	17 **
<3	1	<20	--	--	<4	<8	<30	<10	50	<3	24 **
<3	1	<20	--	--	<4	<8	<30	<10	64	<3	34
<100	<10	<100	--	--	<10	<50	--	--	--	<10	30
<100	<10	<100	--	--	10	<50	--	--	--	<10	100
<100	<10	<100	--	--	<10	<50	--	--	--	<10	<10
<100	<10	<100	--	--	<10	<50	--	--	--	<10	<10
<100	20	<100	--	--	<10	<50	--	--	--	<10	130
<100	90	<100	--	--	<10	<50	--	--	--	<10	140
<100	20	<100	--	--	<10	<50	--	--	--	<10	90

* Data not included in determining range of arsenic concentration.

** Analytical report indicates suspected contamination.

Appendix Table 6. Total recoverable concentrations of pesticides in selected well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada

[µg/L, micrograms per liter; <, less than; --, not analyzed]

		Triazines and other nitrogen containing herbicides					
Local well number	Date	Alachlor (µg/L)	Ametryn (µg/L)	Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Metribuzin (µg/L)
39N/02E-01P02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-10F01	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-12K03	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-14M01	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-26H01	04-23-91	<0.2	<0.1	<0.1	<0.2	<0.2	<0.1
39N/02E-27F03	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/03E-02B02	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/03E-08C02	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/02E-27B01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-03B01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-05N02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-11E04	05-02-91	<0.2	<0.1	<0.1	<0.2	<0.2	<0.1
40N/03E-16A02	08-27-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-31P03	04-26-91	<0.2	<0.1	<0.1	<0.2	<0.2	<0.1
40N/03E-32M01	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-05P02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-09N03	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-20F01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
41N/03E-32Q01	05-01-91	<0.2	<0.1	0.1	<0.2	<0.2	<0.1
41N/03E-35L01	05-01-91	<0.2	<0.1	<0.1	<0.2	<0.2	<0.1
41N/04E-31J02	08-31-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.2-11-25	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.4-18-20	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.4-18-35	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Appendix Table 6. Total recoverable concentrations of pesticides in selected well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Prometone (µg/L)	Prometryn (µg/L)	Propazine (µg/L)	Simazine (µg/L)	Simetryn (µg/L)	Trifluralin (µg/L)
39N/02E-01P02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-10F01	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-12K03	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-14M01	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-26H01	04-23-91	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
39N/02E-27F03	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/03E-02B02	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
39N/03E-08C02	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/02E-27B01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-03B01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-05N02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-11E04	05-02-91	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-16A02	08-27-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-31P03	04-26-91	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
40N/03E-32M01	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-05P02	08-29-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-09N03	08-28-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
40N/04E-20F01	08-30-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
41N/03E-32Q01	05-01-91	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
41N/03E-35L01	05-01-91	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
41N/04E-31J02	08-31-90	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.2-11-25	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.4-18-20	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0926.009.1.1.4-18-35	04-17-91	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Appendix Table 6. Total recoverable concentrations of pesticides in selected well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

		Carbamate insecticides and metablites			
Local well number	Date	Aldicarb (µg/L)	Aldicarb sulfone (µg/L)	Aldicarb sulfoxide (µg/L)	Carbaryl (µg/L)
39N/02E-01P02	08-29-90	<0.5	<0.5	<0.5	<0.5
39N/02E-10F01	08-28-90	<0.5	<0.5	<0.5	<0.5
39N/02E-12K03	08-29-90	<0.5	<0.5	<0.5	<0.5
39N/02E-14M01	08-28-90	<0.5	<0.5	<0.5	<0.5
	08-28-90	<0.5	<0.5	<0.5	--
39N/02E-26H01	04-23-91	<0.5	<0.5	<0.5	<0.5
39N/02E-27F03	08-28-90	<0.5	<0.5	<0.5	<0.5
39N/03E-02B02	08-28-90	<0.5	<0.5	<0.5	<0.5
39N/03E-08C02	08-30-90	<0.5	<0.5	<0.5	<0.5
	08-30-90	<0.5	<0.5	<0.5	<0.5
40N/02E-27B01	08-30-90	<0.5	<0.5	<0.5	<0.5
	08-30-90	<0.5	<0.5	<0.5	<0.5
40N/03E-03B01	08-30-90	<0.5	<0.5	<0.5	<0.5
40N/03E-05N02	08-29-90	<0.5	<0.5	<0.5	<0.5
40N/03E-11E04	05-02-91	<0.5	<0.5	<0.5	<0.5
40N/03E-16A02	08-27-90	<0.5	<0.5	<0.5	<0.5
40N/03E-31P03	04-26-91	<0.5	<0.5	<0.5	<0.5
40N/03E-32M01	08-29-90	<0.5	<0.5	<0.5	<0.5
40N/04E-05P02	08-29-90	<0.5	<0.5	<0.5	<0.5
40N/04E-09N03	08-28-90	<0.5	<0.5	<0.5	<0.5
40N/04E-20F01	08-30-90	<0.5	<0.5	<0.5	<0.5
41N/03E-32Q01	05-01-91	<0.5	<0.5	<0.5	<0.5
41N/03E-35L01	05-01-91	<0.5	<0.5	<0.5	<0.5
41N/04E-31J02	08-31-90	<0.5	<0.5	<0.5	<0.5
0926.009.1.1.2-11-25	04-17-91	<0.5	<0.5	<0.5	<0.5
0926.009.1.1.4-18-20	04-17-91	<0.5	<0.5	<0.5	<0.5
0926.009.1.1.4-18-35	04-17-91	<0.5	<0.5	<0.5	<0.5

Appendix Table 6. Total recoverable concentrations of pesticides in selected well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Carbofuran (µg/L)	3-Hydroxy carbofuran (µg/L)	Methomyl (µg/L)	1-Naphthol (µg/L)	Oxamyl (µg/L)	Propham (µg/L)
39N/02E-01P02	08-29-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/02E-10F01	08-28-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/02E-12K03	08-29-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/02E-14M01	08-28-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	08-28-90	<0.5	<0.5	--	<0.5	<0.5	--
39N/02E-26H01	04-23-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/02E-27F03	08-28-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/03E-02B02	08-28-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
39N/03E-08C02	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/02E-27B01	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-03B01	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-05N02	08-29-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-11E04	05-02-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-16A02	08-27-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-31P03	04-26-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/03E-32M01	08-29-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/04E-05P02	08-29-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/04E-09N03	08-28-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40N/04E-20F01	08-30-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
41N/03E-32Q01	05-01-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
41N/03E-35L01	05-01-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
41N/04E-31J02	08-31-90	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
0926.009.1.1.2-11-25	04-17-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
0926.009.1.1.4-18-20	04-17-91	<0.5	<0.5	<0.5	<0.5	0.5	<0.5
0926.009.1.1.4-18-35	04-17-91	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix Table 7. Concentrations of volatile organic compounds in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada

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

Local well number	Date	Chloro- methane total (µg/L)	Di- chloro- methane total (µg/L)	Tri- chloro- methane total (µg/L)	Tetra- chloro- methane total (µg/L)	Bromo- methane total (µg/L)	Di- bromo- methane total (µg/L)	Tri- bromo- methane total (µg/L)	Bromo- di- chloro- methane total (µg/L)
39N/02E-01P02	08-29-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	04-25-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-10F01	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-12K03	08-29-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-14M01	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-26H01	04-23-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-27F03	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-02B02	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-08C02	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/02E-27B01	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-03B01	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-05N02	08-29-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-11E04	05-02-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-16A02	08-27-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-31P03	04-26-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-32M01	08-29-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-05P02	08-29-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-09N03	08-28-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-20F01	08-30-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-32Q01	05-01-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-35L01	05-01-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/04E-31J02	08-31-90	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.2-11-25	04-17-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-20	04-17-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-35	04-17-91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix Table 7. Concentrations of volatile organic compounds in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Di-bromo-chloro-methane total (µg/L)	Tri-chloro-fluoro-methane total (µg/L)	Di-chloro-di-fluoro-methane total (µg/L)	Chloro-ethane total (µg/L)	1,1-Di-chloro-ethane total (µg/L)	1,2-Di-chloro-ethane total (µg/L)	1,1,1-Tri-chloro-ethane total (µg/L)	1,1,2-Tri-chloro-ethane total (µg/L)	1,1,2-Tetra-chloro-ethane total (µg/L)
39N/02E-01P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-10F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-12K03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-14M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-26H01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-27F03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-02B02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-08C02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/02E-27B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-03B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-05N02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-11E04	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-16A02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-31P03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-32M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-05P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-09N03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-20F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-32Q01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-35L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/04E-31J02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.2-11-25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-20	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-35	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix Table 7. Concentrations of volatile organic compounds in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	1,1,2,2-Tetrachloroethane total (µg/L)	1,2-Dibromoethane total (µg/L)	Vinyl chloride total (µg/L)	1,1-Dichloroethene total (µg/L)	cis 1,2-Dichloroethene total (µg/L)	Trichloroethene total (µg/L)	Tetrachloroethene total (µg/L)	1,2-Dichloropropane total (µg/L)	1,3-Dichloropropane total (µg/L)
39N/02E-01P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.6	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	2.8	<0.2
39N/02E-10F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-12K03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-14M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-26H01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-27F03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-02B02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-08C02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/02E-27B01	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	5.6	0.2
	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	5.6	0.2
40N/03E-03B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-05N02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-11E04	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-16A02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-31P03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-32M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-05P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-09N03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-20F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-32Q01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-35L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/04E-31J02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.2-11-25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-20	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-35	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix Table 7. Concentrations of volatile organic compounds in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	2,2-Dichloropropane total (µg/L)	1,2-Dibromo-3-chloropropane total (µg/L)	1,2,3-Trichlororpropane total (µg/L)	1,1-Dichloropropene total (µg/L)	cis 1,3-Dichloropropene total (µg/L)	trans 1,3-Dichloropropene total (µg/L)	Benzene total (µg/L)	Chlorobenzene total (µg/L)	1,2-DiChlorobenzene total (µg/L)	1,3-Dichlorobenzene total (µg/L)
39N/02E-01P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-10F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-12K03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-14M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-26H01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-27F03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-02B02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-08C02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/02E-27B01	<0.2	<0.2	1.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	1.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-03B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-05N02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-11E04	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-16A02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-31P03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-32M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-05P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-09N03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-20F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-32Q01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-35L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/04E-31J02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.2-11-25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-20	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-35	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix Table 7. Concentrations of volatile organic compounds in well water samples from portions of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	1,4-Di-chloro-benzene total (µg/L)	Bromo-benzene total (µg/L)	Toluene total (µg/L)	2-Chloro-toluene total (µg/L)	4-Chloro-toluene total (µg/L)	Di-methyl-benzene total (µg/L)	Ethyl-benzene total (µg/L)	Ethenyl-benzene total (µg/L)
39N/02E-01P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-10F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-12K03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-14M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-26H01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/02E-27F03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-02B02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
39N/03E-08C02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/02E-27B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-03B01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-05N02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-11E04	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-16A02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-31P03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/03E-32M01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-05P02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-09N03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
40N/04E-20F01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-32Q01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/03E-35L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
41N/04E-31J02	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.2-11-25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-20	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
0926.009.1.1.4-18-35	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada

[mg/L, milligrams per liter; --, no data; <, less than]

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
092G.008.1.2.2-01	10-01-91	--	<0.01	--	<0.01	--	<0.0	--	0.9	1.0
092G.008.1.4.2-15	10-01-91	--	0.56	--	<0.01	--	0.6	--	--	<0.05
092G.008.2.1.1-02	10-01-91	--	0.55	--	<0.01	--	0.6	--	--	<0.05
092G.008.2.2.1-03	10-01-91	--	<0.01	--	0.37	--	--	--	3.6	3.6
092G.008.2.2.3-03	10-01-91	--	<0.01	--	<0.01	--	<0.0	--	4.2	4.2
092G.008.2.3.3-14	10-01-91	--	0.07	--	<0.01	--	--	--	--	<0.05
092G.008.2.4.1-18	10-01-91	--	0.01	--	<0.01	--	<0.0	--	8.1	8.1
092G.008.2.4.2-14	10-01-91	--	<0.01	--	<0.01	--	<0.0	--	8.4	8.4
092G.009.1.1.1-06-20	12-11-91	--	--	0.01	--	0.01	--	<0.2	20	--
	12-15-92	--	--	<0.01	--	0.01	--	--	15	--
092G.009.1.1.1-06-35	12-11-91	--	--	<0.01	--	<0.01	--	<0.2	19	--
092G.009.1.1.1-07-55	12-11-91	--	--	0.02	--	0.01	--	<0.2	10	--
	12-15-92	--	--	<0.01	--	0.01	--	--	11	--
092G.009.1.1.1-07-75	12-11-91	--	--	<0.01	--	0.24	--	<0.2	3.3	--
	12-15-92	--	--	<0.01	--	0.25	--	--	3.9	--
092G.009.1.1.2-11-25	12-11-91	--	--	0.02	--	<0.01	--	<0.2	6.9	--
	12-15-92	--	--	<0.01	--	0.02	--	--	9.6	--
092G.009.1.1.2-11-35	12-11-91	--	--	<0.01	--	<0.01	--	<0.2	13	--
	12-15-92	--	--	<0.01	--	0.02	--	--	16	--
092G.009.1.1.2-12-55	12-11-91	--	--	<0.01	--	<0.01	--	<0.2	8.8	--
	12-15-92	--	--	<0.01	--	<0.01	--	--	7.2	--
092G.009.1.1.2-12-75	12-11-91	--	--	<0.01	--	0.19	--	<0.2	3.8	--
	12-15-92	--	--	<0.01	--	0.26	--	--	3.5	--
092G.009.1.1.4-17	09-30-91	--	<0.01	--	<0.01	--	<0.0	--	16	16
092G.009.1.1.4-18-25	12-10-91	--	--	<0.01	--	<0.01	--	<0.2	3.3	--
092G.009.1.1.4-18-35	12-10-91	--	--	<0.01	--	<0.01	--	<0.2	4.8	--
092G.009.1.1.4-19-55	12-10-91	--	--	<0.01	--	0.66	--	<0.2	6.8	--
092G.009.1.1.4-19-75	12-10-91	--	--	0.01	--	0.01	--	<0.2	5.3	--
092G.009.1.2.4-31	09-30-91	--	<0.01	--	<0.01	--	<0.0	--	9.9	9.9
092G.009.1.3.4-26	09-30-91	--	<0.01	--	<0.01	--	<0.0	--	4.9	4.9
092G.009.2.1.2-19	10-02-91	--	<0.01	--	<0.01	--	<0.0	--	9.1	9.1
092G.009.2.1.4-26	10-02-91	--	<0.01	--	0.09	--	<0.0	--	6.9	6.9
092G.009.2.2.3-11	10-01-91	--	1.40	--	<0.01	--	1.5	--	0.06	0.06
39N/02E-01P02	08-29-90	--	<0.01	--	<0.01	--	0.3	--	9.3	9.3
	10-18-90	--	--	0.04	--	<0.01	--	--	14	--
	11-14-90	0.56	--	0.04	--	<0.01	--	0.6	9.5	--
	12-18-90	--	--	0.02	--	<0.01	--	--	6.1	--
	03-13-91	0.48	--	0.02	--	<0.01	--	0.5	7.6	--
	04-25-91	0.30	--	<0.01	--	<0.01	--	0.3	6.5	--
	05-21-91	--	--	<0.01	--	0.01	--	--	5.4	--
	06-26-91	0.69	--	0.01	--	<0.01	--	0.7	9.9	--
	07-18-91	--	--	0.03	--	0.01	--	--	9.6	--
	08-23-91	0.48	--	0.02	--	<0.01	--	0.5	7.9	--
	09-25-91	--	--	0.03	--	0.01	--	--	7.9	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
	10-23-91	--	--	0.03	--	0.01	--	<0.2	8.4	--
39N/02E-10F01	08-28-90	--	0.02	--	<0.01	--	0.6	--	4.9	4.9
	10-16-90	--	--	0.05	--	<0.01	--	--	3.7	--
	11-14-90	--	--	0.04	--	<0.01	--	<0.2	1.6	--
	12-18-90	--	--	0.02	--	<0.01	--	--	8.6	--
	01-16-91	0.80	--	<0.01	--	<0.01	--	0.8	15	--
	02-20-91	--	--	<0.01	--	<0.01	--	--	12	--
	03-13-91	0.48	--	0.02	--	<0.01	--	0.5	9.8	--
	03-13-91	0.38	--	0.02	--	<0.01	--	0.4	9.9	--
	04-25-91	0.59	0.02	0.01	<0.01	<0.01	0.5	0.6	8.2	8.2
	05-21-91	--	--	<0.01	--	<0.01	--	--	12	--
	06-26-91	0.79	--	0.01	--	<0.01	--	0.8	11	--
	07-18-91	--	--	0.04	--	<0.01	--	--	8.4	--
	08-23-91	0.58	--	0.02	--	<0.01	--	0.6	6.3	--
	09-25-91	--	--	0.03	--	0.01	--	--	3.7	--
	10-23-91	--	--	0.02	--	<0.01	--	<0.2	3.0	--
39N/02E-11B01	04-23-91	--	--	0.01	--	<0.01	--	<0.2	3.3	--
39N/02E-12K03	08-29-90	--	0.07	--	<0.01	--	0.6	--	4.5	4.5
39N/02E-13B01	04-26-91	--	0.06	--	<0.01	--	0.2	--	0.13	0.13
39N/02E-14L01	04-25-91	--	0.04	--	0.02	--	<0.2	--	0.63	0.63
39N/02E-14M01	08-28-90	--	<0.01	--	<0.01	--	0.5	--	3.7	3.7
	08-28-90	--	0.01	--	<0.01	--	0.2	--	3.7	3.7
39N/02E-16H03	04-25-91	--	<0.01	--	<0.01	--	<0.2	--	0.83	0.83
39N/02E-22D02	04-25-91	--	0.03	--	<0.01	--	<0.2	--	--	<0.05
39N/02E-24C02	04-26-91	--	0.02	--	<0.01	--	0.3	--	2.6	2.6
39N/02E-24R02	04-24-91	--	<0.01	--	<0.01	--	0.6	--	5.2	5.2
39N/02E-26H01	04-23-91	0.59	--	0.01	--	0.01	--	0.6	12	--
39N/02E-27F03	08-28-90	--	0.03	--	<0.01	--	0.4	--	12	12
	10-18-90	--	--	0.04	--	<0.01	--	--	12	--
	11-14-90	0.36	--	0.04	--	<0.01	--	0.4	12	--
	12-18-90	--	--	0.02	--	<0.01	--	--	13	--
	01-16-91	1.1	--	<0.01	--	<0.01	--	1.1	13	--
	01-16-91	1.0	--	<0.01	--	<0.01	--	1.0	13	--
	02-20-91	--	--	<0.01	--	<0.01	--	--	13	--
	03-14-91	0.47	--	0.03	--	0.03	--	0.5	14	--
	04-25-91	0.68	--	0.02	--	<0.01	--	0.7	14	--
	05-21-91	--	--	<0.01	--	<0.01	--	--	13	--
	06-26-91	0.80	--	<0.01	--	<0.01	--	0.8	13	--
	07-17-91	--	--	0.04	--	0.01	--	--	12	--
	08-23-91	0.89	--	0.01	--	<0.01	--	0.9	11	--
	09-25-91	--	--	0.04	--	0.02	--	--	11	--
	10-23-91	--	--	0.02	--	<0.01	--	<0.2	11	--
39N/02E-27F04	04-24-91	--	--	0.01	--	0.01	--	<0.2	2.6	--
39N/02E-27J01	04-24-91	0.39	--	0.01	--	<0.01	--	0.4	14	--
39N/02E-27Q04	07-10-91	--	<0.01	--	<0.01	--	0.6	--	5.8	5.8

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
39N/02E-28J03	04-25-91	--	<0.01	--	<0.01	--	<0.2	--	1.4	1.4
39N/03E-01C01	10-18-90	--	--	0.05	--	<0.01	--	--	0.40	--
	11-15-90	--	--	0.05	--	<0.01	--	<0.2	0.30	--
	12-17-90	--	--	0.04	--	<0.01	--	--	0.30	--
	02-20-91	--	--	0.01	--	<0.01	--	--	0.30	--
	03-13-91	--	--	0.04	--	<0.01	--	<0.2	0.29	--
	04-22-91	--	--	0.01	--	<0.01	--	<0.2	0.37	--
	05-22-91	--	--	0.01	--	<0.01	--	--	0.31	--
	06-25-91	--	--	0.02	--	<0.01	--	<0.2	0.28	--
	07-17-91	--	--	0.05	--	<0.01	--	--	0.26	--
	08-22-91	0.28	--	0.02	--	<0.01	--	0.3	0.28	--
	09-26-91	--	--	0.03	--	<0.01	--	--	0.27	--
	10-23-91	--	--	0.04	--	0.01	--	<0.2	0.33	--
	12-12-91	--	--	0.02	--	<0.01	--	<0.2	0.30	--
39N/03E-02B02	08-28-90	--	0.05	--	<0.01	--	0.3	--	0.20	0.20
39N/03E-05L02	04-23-91	0.20	--	<0.01	--	0.01	--	0.2	4.6	--
39N/03E-07K02	04-26-91	--	<0.01	--	<0.01	--	0.9	--	19	19
39N/03E-08C02	08-30-90	--	<0.01	--	<0.01	--	1.6	--	--	<0.10
39N/03E-10L01	10-16-90	--	--	0.35	--	0.01	--	--	0.30	--
	11-15-90	0.32	--	0.38	--	0.02	--	0.7	0.70	--
	11-16-90	0.34	--	0.36	--	0.02	--	0.7	0.70	--
	12-17-90	--	--	0.16	--	<0.01	--	--	2.6	--
	02-21-91	--	--	0.15	--	<0.01	--	--	2.8	--
	04-29-91	0.31	--	0.19	--	<0.01	--	0.5	2.5	--
	05-22-91	--	--	0.22	--	0.01	--	--	1.9	--
	06-25-91	0.27	--	0.33	--	<0.01	--	0.6	0.97	--
	07-17-91	--	--	0.32	--	0.02	--	--	1.4	--
	08-23-91	0.30	--	0.30	--	<0.01	--	0.6	1.8	--
	09-26-91	--	--	0.35	--	0.01	--	--	0.34	--
	10-23-91	0.13	--	0.37	--	0.02	--	0.5	0.14	--
39N/03E-11M01	08-21-91	--	0.02	--	<0.01	--	0.7	--	--	<0.05
39N/03E-13E01	04-23-91	0.37	--	0.13	--	0.01	--	0.5	<0.05	--
39N/03E-15C02	08-20-91	--	<0.01	--	<0.01	--	<0.2	--	--	<0.05
39N/03E-16F02	04-30-91	--	0.01	--	0.01	--	<0.2	--	1.2	1.2
39N/03E-17R03	04-23-91	--	--	<0.01	--	<0.01	--	<0.2	1.4	--
39N/03E-19N01	10-16-90	--	--	0.04	--	<0.01	--	--	1.4	--
	11-16-90	--	--	0.04	--	<0.01	--	<0.2	1.4	--
	01-19-91	--	--	<0.01	--	<0.01	--	<0.2	1.3	--
	02-20-91	--	--	<0.01	--	<0.01	--	--	1.3	--
	03-13-91	--	--	0.02	--	0.01	--	<0.2	1.3	--
	04-23-91	--	--	0.01	--	<0.01	--	<0.2	<0.05	--
	05-21-91	--	--	<0.01	--	<0.01	--	--	1.1	--
	08-23-91	--	--	0.01	--	<0.01	--	<0.2	1.1	--
	09-26-91	--	--	0.01	--	<0.01	--	--	1.1	--
	10-23-91	--	--	0.03	--	0.01	--	<0.2	1.3	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
	12-12-91	--	--	<0.01	--	0.01	--	<0.2	1.4	--
39N/03E-20F02	08-20-91	--	<0.01	--	<0.01	--	<0.2	--	2.7	2.7
39N/03E-21K01	04-24-91	--	0.02	--	<0.01	--	<0.2	--	--	<0.05
39N/03E-23J01	04-26-91	--	0.80	--	<0.01	--	1.0	--	0.16	0.16
39N/03E-24B01	04-26-91	--	<0.01	--	<0.01	--	<0.2	--	0.38	0.38
39N/03E-26D01	04-23-91	--	--	0.28	--	0.01	--	<0.2	<0.05	--
39N/03E-26J01	04-25-91	--	2.0	--	<0.01	--	2.4	--	--	<0.05
39N/03E-26P02	10-18-90	--	--	0.81	--	<0.01	--	--	<0.10	--
	11-16-90	0.30	--	0.80	--	<0.01	--	1.1	<0.10	--
	12-18-90	--	--	0.79	--	<0.01	--	--	<0.10	--
	03-13-91	0.17	--	0.73	--	0.02	--	0.9	<0.05	--
	04-22-91	0.03	--	0.77	--	0.02	--	0.8	<0.05	--
	05-22-91	--	--	0.73	--	<0.01	--	--	<0.05	--
	06-26-91	0.29	--	0.71	--	<0.01	--	1.0	<0.05	--
	07-17-91	--	--	0.74	--	<0.01	--	--	<0.05	--
	08-23-91	0.19	--	0.71	--	<0.01	--	0.9	<0.05	--
	09-26-91	--	--	0.75	--	<0.01	--	--	<0.05	--
	10-23-91	0.11	--	0.79	--	0.01	--	0.9	<0.05	--
39N/03E-28R01	08-20-91	--	0.96	--	<0.01	--	1.3	--	--	<0.05
39N/03E-29C01	04-25-91	--	<0.01	--	0.01	--	<0.2	--	--	<0.05
39N/03E-31R02	04-26-91	--	0.62	--	<0.01	--	0.8	--	0.17	0.17
39N/03E-32J01	04-25-91	--	0.23	--	<0.01	--	0.4	--	--	<0.05
39N/03E-33R01	04-24-91	0.70	--	0.20	--	<0.01	--	0.9	<0.05	--
39N/03E-34N01	04-25-91	--	0.02	--	<0.01	--	0.2	--	--	<0.05
39N/03E-35L01	04-24-91	0.09	--	0.41	--	0.01	--	0.5	<0.05	--
39N/03E-36P01	04-24-91	0.11	--	0.29	--	0.01	--	0.4	<0.05	--
39N/04E-03P01	10-16-90	--	--	0.23	--	<0.01	--	--	<0.10	--
	01-17-91	--	--	0.19	--	<0.01	--	<0.2	<0.10	--
	02-19-91	--	--	0.20	--	<0.01	--	--	<0.10	--
	02-19-91	--	--	0.20	--	0.01	--	--	<0.10	--
	04-24-91	0.99	--	0.21	--	0.01	--	1.2	<0.05	--
	05-22-91	--	--	0.19	--	<0.01	--	--	<0.05	--
	06-25-91	0.10	--	0.20	--	<0.01	--	0.3	<0.05	--
	07-17-91	--	--	0.23	--	0.01	--	--	<0.05	--
	08-22-91	--	--	0.02	--	<0.01	--	<0.2	<0.05	--
	09-25-91	--	--	0.21	--	<0.01	--	--	<0.05	--
	10-23-91	--	--	0.03	--	<0.01	--	<0.2	0.15	--
	12-13-91	--	--	0.02	--	<0.01	--	--	<0.05	--
39N/04E-10M01	04-27-91	--	0.25	--	<0.01	--	0.4	--	--	<0.05
39N/04E-16F01	04-25-91	--	<0.01	--	<0.01	--	<0.2	--	1.5	1.5
39N/04E-16H01	04-25-91	--	<0.01	--	<0.01	--	0.4	--	5.0	5.0
39N/04E-16Q02	04-24-91	--	<0.01	--	<0.01	--	0.3	--	3.6	3.6
39N/04E-18M01	04-23-91	--	--	0.14	--	<0.01	--	<0.2	<0.05	--
39N/04E-19M01	04-25-91	--	0.33	--	<0.01	--	0.4	--	--	<0.05
39N/04E-20H01	04-24-91	--	--	<0.01	--	<0.01	--	<0.2	0.70	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
39N/04E-22L01	04-23-91	0.50	--	<0.01	--	0.03	--	0.5	15	--
39N/04E-28F01	04-26-91	--	<0.01	--	<0.01	--	0.2	--	1.2	1.2
39N/04E-30D01	04-26-91	--	0.45	--	<0.01	--	0.9	--	--	--
39N/04E-32A01	04-26-91	--	0.40	--	<0.01	--	0.6	--	--	<0.05
39N/04E-32N01	04-24-91	0.15	--	0.35	--	0.01	--	0.5	<0.05	--
39N/04E-33E01	04-26-91	--	0.28	--	<0.01	--	0.5	--	--	<0.05
40N/02E-02D01	08-21-91	--	0.05	--	<0.01	--	0.4	--	--	<0.05
40N/02E-03C01	11-16-90	0.08	--	0.32	--	<0.01	--	0.4	<0.10	--
	02-21-91	--	--	0.30	--	<0.01	--	--	<0.10	--
	03-14-91	0.08	--	0.32	--	<0.01	--	0.4	0.05	--
	03-14-91	0.08	--	0.32	--	<0.01	--	0.4	<0.05	--
	04-30-91	--	0.30	--	<0.01	--	0.3	--	--	<0.05
	05-21-91	--	--	0.31	--	0.01	--	--	<0.05	--
	06-25-91	0.15	--	0.25	--	<0.01	--	0.4	<0.05	--
	07-17-91	--	--	0.32	--	0.01	--	--	<0.05	--
	08-22-91	0.14	--	0.26	--	<0.01	--	0.4	<0.05	--
	09-25-91	--	--	0.31	--	<0.01	--	--	<0.05	--
	10-24-91	0.05	--	0.35	--	<0.01	--	0.4	0.14	--
	12-12-91	0.0	--	0.30	--	0.01	--	0.3	<0.05	--
40N/02E-04A02	04-26-91	--	0.14	--	<0.01	--	0.4	--	--	<0.05
40N/02E-10N02	08-21-91	0.30	2.2	2.1	0.01	<0.01	2.7	2.4	1.4	1.4
40N/02E-12C01	08-22-91	--	0.24	--	<0.01	--	0.5	--	--	<0.05
40N/02E-13J04	07-19-91	--	0.22	--	<0.01	--	0.3	--	--	<0.05
40N/02E-13J05	08-13-91	4.0	--	46	--	<0.01	--	50	<0.05	--
40N/02E-13J07	07-19-91	--	63	--	0.02	--	63	--	--	<0.05
40N/02E-14P02	04-30-91	--	<0.01	--	<0.01	--	1.4	--	16	16
	08-20-91	--	--	<0.01	--	<0.01	--	--	13	--
40N/02E-15A02	08-21-91	--	--	0.03	--	0.02	--	--	3.2	--
40N/02E-15C01	09-05-91	--	--	0.04	--	<0.01	--	--	0.12	--
40N/02E-15H02	08-21-91	--	--	<0.01	--	<0.01	--	--	3.2	--
40N/02E-15H03	09-05-91	--	--	0.12	--	<0.01	--	--	0.07	--
40N/02E-15J01	04-29-91	--	0.28	--	<0.01	--	0.5	--	0.21	0.21
40N/02E-15P01	08-21-91	--	0.02	--	<0.01	--	0.2	--	1.4	1.4
40N/02E-15R03	08-21-91	--	--	<0.01	--	<0.01	--	--	8.2	--
40N/02E-16B02	04-27-91	--	<0.01	--	<0.01	--	0.6	--	6.4	6.4
40N/02E-21D01	08-20-91	--	--	0.04	--	<0.01	--	--	0.59	--
40N/02E-21J05	08-21-91	--	--	<0.01	--	<0.01	--	--	4.8	--
40N/02E-21N02	08-22-91	--	--	0.04	--	0.02	--	--	8.2	--
40N/02E-21R01	04-30-91	--	<0.01	--	<0.01	--	0.8	--	20	20
40N/02E-21R03	08-23-91	--	--	<0.01	--	<0.01	--	--	22	--
40N/02E-22E02	08-21-91	--	--	<0.01	--	<0.01	--	--	4.8	--
40N/02E-22N02	08-22-91	--	--	<0.01	--	<0.01	--	--	13	--
40N/02E-22N07	08-22-91	--	--	<0.01	--	<0.01	--	--	5.0	--
40N/02E-22R02	04-29-91	--	<0.01	--	<0.01	--	<0.2	--	2.8	2.8
40N/02E-23A03	08-20-91	--	--	<0.01	--	<0.01	--	--	6.7	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
40N/02E-23B02	08-21-91	--	--	<0.01	--	<0.01	--	--	11	--
40N/02E-23D01	04-30-91	--	<0.01	--	0.05	--	0.4	--	4.0	4.0
40N/02E-23D04	08-22-91	--	--	0.03	--	<0.01	--	--	13	--
40N/02E-23N01	04-27-91	--	0.13	--	<0.01	--	0.4	--	1.5	1.5
40N/02E-23P01	08-22-91	--	--	<0.01	--	<0.01	--	--	20	--
40N/02E-26A03	10-04-91	--	<0.01	--	<0.01	--	<0.0	--	13	13
40N/02E-26B02	08-22-91	--	--	<0.01	--	<0.01	--	--	7.6	--
40N/02E-26C03	09-05-91	--	--	0.02	--	0.02	--	--	2.2	--
40N/02E-26C04	08-22-91	--	--	<0.01	--	<0.01	--	--	4.0	--
40N/02E-26D02	09-05-91	--	--	0.03	--	0.02	--	--	5.6	--
40N/02E-27B01	08-30-90	--	<0.01	--	<0.01	--	0.3	--	11	11
	10-17-90	--	--	0.04	--	<0.01	--	--	12	--
	11-14-90	0.67	--	0.03	--	<0.01	--	0.7	11	--
	12-18-90	--	--	0.02	--	<0.01	--	--	10	--
	02-20-91	--	--	<0.01	--	<0.01	--	--	7.4	--
	02-20-91	--	--	<0.01	--	<0.01	--	--	7.5	--
	03-14-91	0.28	--	0.02	--	<0.01	--	0.3	6.3	-
	04-24-91	0.19	--	0.01	--	<0.01	--	0.2	6.6	--
	05-21-91	--	--	0.01	--	<0.01	--	--	7.9	--
	06-26-91	0.70	--	<0.01	--	<0.01	--	0.7	8.1	--
	07-18-91	--	--	0.03	--	<0.01	--	--	9.2	--
	08-14-91	--	--	0.09	--	<0.01	--	--	9.2	--
	09-25-91	--	--	0.02	--	0.01	--	--	9.2	--
40N/02E-27C01	08-22-91	--	--	<0.01	--	<0.01	--	--	7.8	--
40N/02E-27D02	08-22-91	--	--	<0.01	--	<0.01	--	--	7.2	--
40N/02E-27N02	04-30-91	--	<0.01	--	<0.01	--	0.8	--	14	14
	08-21-91	--	<0.01	--	<0.01	--	0.6	--	9.0	9.0
40N/02E-28G01	08-23-91	--	--	<0.01	--	<0.01	--	--	7.4	--
40N/02E-33B02	10-02-91	--	<0.01	--	<0.01	--	<0.0	--	1.8	1.8
40N/03E-02B01	05-02-91	--	0.02	--	<0.01	--	0.4	--	9.0	9.0
40N/03E-03A02	05-01-91	--	0.01	--	<0.01	--	0.7	--	9.9	9.9
40N/03E-03B01	08-30-90	--	0.01	--	<0.01	--	0.5	--	7.8	7.8
	10-18-90	--	--	0.04	--	<0.01	--	--	6.3	--
	11-14-90	0.46	--	0.04	--	<0.01	--	0.5	7.0	--
	12-18-90	--	--	0.02	--	<0.01	--	--	6.7	--
	02-20-91	--	--	0.03	--	<0.01	--	--	7.4	--
	03-14-91	0.50	--	<0.01	--	<0.01	--	0.5	8.2	--
	04-23-91	0.38	--	0.02	--	<0.01	--	0.4	10	--
	05-21-91	--	--	0.04	--	0.01	--	--	11	--
	06-25-91	0.60	--	<0.01	--	<0.01	--	0.6	10	--
	07-17-91	--	--	0.04	--	0.01	--	--	10	--
	08-21-91	0.56	--	0.04	--	<0.01	--	0.6	9.3	--
	09-25-91	--	--	0.03	--	<0.01	--	--	6.2	--
	10-24-91	--	--	0.02	--	<0.01	--	<0.2	5.8	--
	12-13-91	--	--	0.01	--	<0.01	--	--	6.1	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
40N/03E-03R02	05-02-91	--	0.02	--	0.05	--	0.7	--	12	12
40N/03E-05L01	08-14-91	3.0	34	34	<0.01	<0.01	35	37	0.05	<0.05
40N/03E-05M05	08-14-91	0.52	--	0.08	--	<0.01	--	0.6	18	--
40N/03E-05N02	08-29-90	--	0.03	--	<0.01	--	0.3	--	1.3	1.3
40N/03E-07A02	05-01-91	--	<0.01	--	<0.01	--	1.2	--	11	11
40N/03E-09G01	05-02-91	--	0.07	--	<0.01	--	<0.2	--	--	<0.05
	08-21-91	--	0.03	--	<0.01	--	<0.2	--	--	<0.05
40N/03E-10C02	05-03-91	0.48	--	0.02	--	0.01	--	0.5	6.2	--
40N/03E-10K01	05-02-91	--	0.02	--	<0.01	--	0.4	--	7.6	7.6
40N/03E-10R02	05-01-91	--	0.02	--	<0.01	--	<0.2	--	1.4	1.4
40N/03E-11E04	05-02-91	--	0.01	--	<0.01	--	<0.2	--	1.5	1.5
40N/03E-16A02	08-27-90	--	0.03	--	<0.01	--	0.4	--	7.4	7.4
	10-17-90	--	--	0.04	--	<0.01	--	--	8.3	--
	11-14-90	0.46	--	0.04	--	<0.01	--	0.5	8.3	--
	12-17-90	--	--	0.02	--	<0.01	--	--	8.2	--
	02-21-91	--	--	<0.01	--	<0.01	--	--	6.5	--
	03-14-91	0.20	--	<0.01	--	<0.01	--	0.2	6.4	--
	04-23-91	0.40	--	<0.01	--	<0.01	--	0.4	12	--
	05-21-91	--	--	<0.01	--	<0.01	--	--	14	--
	06-25-91	0.70	--	<0.01	--	<0.01	--	0.7	15	--
	07-17-91	--	--	0.03	--	0.01	--	--	13	--
	08-22-91	0.59	--	0.01	--	<0.01	--	0.6	14	--
	09-26-91	--	--	0.01	--	<0.01	--	--	16	--
40N/03E-16F01	05-01-91	--	0.07	--	0.01	--	<0.2	--	0.35	0.35
40N/03E-16K01	05-01-91	--	<0.01	--	<0.01	--	0.5	--	3.7	3.7
40N/03E-19A01	10-04-91	--	0.10	--	<0.01	--	<0.0	--	--	<0.05
40N/03E-24E01	10-02-91	--	1.2	--	<0.01	--	1.3	--	0.06	0.06
40N/03E-25F01	08-21-91	--	0.41	--	0.01	--	1.0	--	1.2	1.2
40N/03E-31L01	05-01-91	--	<0.01	--	<0.01	--	0.5	--	7.2	7.2
40N/03E-31P03	04-26-91	--	<0.01	--	<0.01	--	0.8	--	19	19
	12-13-91	--	--	<0.01	--	<0.01	--	<0.2	14	--
40N/03E-32L01	04-25-91	--	<0.01	--	<0.01	--	0.6	--	12	12
40N/03E-32M01	08-29-90	--	0.02	--	<0.01	--	0.4	--	11	11
	10-17-90	--	--	0.04	--	<0.01	--	--	11	--
	11-16-90	0.67	--	0.03	--	<0.01	--	0.7	11	--
	12-17-90	--	--	0.02	--	<0.01	--	--	8.9	--
	01-19-91	0.60	--	<0.01	--	0.01	--	0.6	11	--
	02-21-91	--	--	<0.01	--	0.02	--	--	11	--
	03-13-91	0.78	--	0.02	--	<0.01	--	0.8	12	--
	04-24-91	0.59	--	0.01	--	0.01	--	0.6	13	--
	05-21-91	--	--	<0.01	--	0.02	--	--	11	--
	06-25-91	0.70	--	<0.01	--	<0.01	--	0.7	10	--
	07-18-91	--	--	0.03	--	0.01	--	--	12	--
	08-23-91	0.49	--	0.01	--	<0.01	--	0.5	12	--
	09-26-91	--	--	<0.01	--	<0.01	--	--	12	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
	12-13-91	--	--	<0.01	--	0.01	--	--	10	--
40N/03E-32Q01	04-25-91	--	0.01	--	<0.01	--	<0.2	--	2.8	2.8
40N/03E-33J02	04-26-91	--	0.25	--	<0.01	--	0.3	--	--	<0.05
40N/03E-36Q01	04-30-91	--	<0.01	--	<0.01	--	<0.2	--	2.3	2.3
40N/04E-01K02	10-04-91	--	0.55	--	<0.01	--	0.8	--	--	<0.05
40N/04E-05N02	05-02-91	--	0.01	--	<0.01	--	<0.2	--	2.3	2.3
40N/04E-05P01	05-02-91	--	0.02	--	0.01	--	0.7	--	11	11
40N/04E-05P02	08-29-90	--	<0.01	--	<0.01	--	0.5	--	12	12
40N/04E-09B01	02-21-91	--	--	<0.01	--	<0.01	--	--	<0.05	--
	05-03-91	--	0.26	--	0.02	--	0.5	--	--	<0.05
	01-15-92	0.0	--	0.20	--	<0.01	--	0.2	<0.05	--
40N/04E-09N03	08-28-90	--	0.25	--	<0.01	--	0.3	--	--	<0.10
40N/04E-17G01	10-03-91	--	0.14	--	<0.01	--	0.3	--	0.06	0.06
40N/04E-20F01	08-30-90	--	0.05	--	<0.01	--	0.3	--	--	<0.10
	11-15-90	--	--	0.06	--	<0.01	--	<0.2	0.70	--
	12-17-90	--	--	0.03	--	<0.01	--	--	1.5	--
	02-19-91	--	--	0.02	--	0.01	--	--	1.5	--
	03-14-91	--	--	0.03	--	<0.01	--	<0.2	0.80	--
	04-23-91	0.37	--	0.03	--	0.01	--	0.4	0.62	--
	05-22-91	--	--	0.04	--	0.01	--	--	0.36	--
	08-22-91	0.15	--	0.05	--	<0.01	--	0.2	0.14	--
	09-25-91	--	--	0.06	--	0.01	--	--	0.13	--
	10-23-91	--	--	0.06	--	0.01	--	<0.2	0.22	--
	12-13-91	--	--	0.03	--	0.01	--	--	0.45	--
40N/04E-22G01	05-02-91	--	0.02	--	<0.01	--	0.3	--	3.7	3.7
40N/04E-22J01	05-02-91	--	0.19	--	<0.01	--	<0.2	--	2.4	2.4
40N/04E-22R01	05-03-91	--	0.03	--	0.01	--	<0.2	--	--	<0.05
40N/04E-29H02	05-03-91	--	0.22	--	0.02	--	0.3	--	--	<0.05
40N/04E-30G01	09-05-91	--	--	0.70	--	0.03	--	--	<0.05	--
	10-03-91	--	0.59	--	<0.01	--	0.7	--	--	<0.05
40N/04E-31R02	09-05-91	--	--	0.20	--	<0.01	--	--	<0.05	--
	10-04-91	--	0.19	--	<0.01	--	0.3	--	0.14	0.14
40N/04E-34P01	08-21-91	--	<0.01	--	<0.01	--	<0.2	--	1.0	1.0
40N/05E-06K01	07-03-91	--	0.04	--	<0.01	--	0.2	--	--	<0.05
41N/02E-33J01	04-29-91	--	0.16	--	<0.01	--	0.3	--	--	<0.05
41N/02E-35P01	04-30-91	--	0.09	--	<0.01	--	<0.2	--	--	<0.05
41N/03E-32Q01	05-01-91	--	0.05	--	0.01	--	0.7	--	43	43
41N/03E-34M01	05-01-91	--	<0.01	--	<0.01	--	1.1	--	20	20
41N/03E-34Q01	05-02-91	--	0.02	--	0.01	--	<0.2	--	--	<0.05
41N/03E-35L01	05-01-91	--	0.18	--	<0.01	--	0.7	--	21	21
41N/03E-36J01	05-02-91	--	0.01	--	<0.01	--	0.4	--	7.3	7.3
41N/03E-36J02	05-02-91	--	0.08	--	<0.01	--	<0.2	--	--	<0.05
41N/04E-31J02	08-31-90	--	<0.01	--	<0.01	--	0.5	--	13	13
	10-18-90	--	--	0.04	--	<0.01	--	--	14	--
	11-14-90	0.45	--	0.05	--	<0.01	--	0.5	2.9	--

Appendix Table 8. Concentrations of selected nitrogen species in ground water of the Lynden-Everson-Nooksack-Sumas study area, Whatcom County, Wash., and British Columbia, Canada--Continued

Local well number	Date	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)
	12-18-90	--	--	0.03	--	<0.01	--	--	13	--
41N/04E-31J02	01-17-91	0.60	--	<0.01	--	<0.01	--	0.6	13	--
	02-19-91	--	--	0.01	--	<0.01	--	--	11	--
	03-14-91	0.50	--	<0.01	--	0.01	--	0.5	10	--
	04-23-91	--	--	0.02	--	<0.01	--	<0.2	8.1	--
	05-21-91	--	--	<0.01	--	<0.01	--	--	8.6	--
	06-25-91	0.80	--	<0.01	--	<0.01	--	0.8	10	--
	07-17-91	--	--	0.04	--	0.01	--	--	11	--
	08-22-91	0.58	--	0.02	--	<0.01	--	0.6	13	--
	09-25-91	--	--	<0.01	--	<0.01	--	--	13	--
41N/04E-31R02	05-02-91	--	0.02	--	<0.01	--	0.3	--	8.6	8.6
41N/04E-32Q01	04-30-91	--	<0.01	--	<0.01	--	1.1	--	16	16
41N/04E-32R01	05-01-91	--	0.03	--	0.01	--	0.8	--	15	15
41N/04E-33H01S	05-01-91	--	0.02	--	<0.01	--	0.4	--	5.8	5.8
	01-14-92	--	--	<0.01	--	<0.01	--	<0.2	6.3	--
41N/04E-33H04	05-01-91	--	0.02	--	0.01	--	0.4	--	5.6	5.6
	01-14-92	--	--	<0.01	--	<0.01	--	<0.2	5.4	--
41N/04E-33N04	07-20-91	--	0.03	--	0.02	--	0.7	--	15	15

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