Geohydrology and Ground-Water Quality of East King County, Washington

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4082

Prepared in cooperation with
SEATTLE-KING COUNTY
DEPARTMENT OF PUBLIC HEALTH

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

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By G. L. Turney, S. C. Kahle, and N. P. Dion

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
gallon (gal)	0.003785	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature: Air temperatures are given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$°C = 5/9\ (°F-32)$$

Following convention, water temperatures are given in degrees Celsius, which can be converted to degrees Fahrenheit by the following equation:

$$°F = 1.8\ (°C) + 32$$

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

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ABSTRACT

East King County is a rapidly growing 250-square-mile area east of Seattle in western Washington. Because of the rapid growth, the demand for good-quality ground water is increasing. The major source of ground water is a sequence of unconsolidated deposits of both glacial and nonglacial origin that is as much as 1,200 feet thick and blankets Tertiary bedrock. A map of surficial exposures of those deposits and 12 geohydrologic sections were constructed from existing maps and from information on more than 600 inventoried wells and springs. Ten geohydrologic units were delineated, 4 of which are the major aquifers in the study area: the Quaternary alluvium, the Vashon recessional outwash, the Vashon advance outwash, and the upper coarse-grained unit.

Precipitation averages an estimated 57 inches per year over the study area, of which 31 inches, or 413,000 acre-feet, enters the ground-water system as recharge. Ground water generally flows to the Snoqualmie River, then northward along the Snoqualmie River Valley, which bisects the study area from south to north. Some ground water flows to Lake Sammamish, which forms part of the western boundary of the study area. An estimated 98,500 acre-feet of ground water discharges to the Snoqualmie River or Lake Sammamish each year. Another 9,540 acre-feet discharges to springs, and 4,270 acre-feet is withdrawn from wells. Most of the remaining 300,700 acre-feet of recharge flows as ground water to the north or west, out of the study area.

A total of 9,560 acre-feet of water from wells and springs was put to beneficial use during the year 1990. Approximately 4,460 acre-feet was used for public supplies, and 3,010 acre-feet was used for aquaculture (fish farming). Much of the remainder was used for domestic supplies, crop irrigation, and dairy cattle.

The chemical quality of the ground water was typical for western Washington, based on samples collected from 124 wells and springs. All of these samples were analyzed for concentrations of common ions and trace elements. The median dissolved-solids concentration was 115 milligrams per liter, and 95 percent of the water samples were classified as soft or moderately hard. The median nitrate concentration was 0.07 milligram per liter, and no widespread contribution from agriculture or septic tanks was apparent.

Water-quality problems in east King County, when present, were commonly due to natural causes. Iron and manganese concentrations were as large as 14,000 and 920 micrograms per liter (µg/L), respectively, but this is typical of western Washington ground waters. Arsenic was present in 64 percent of the samples, and 15 percent had concentrations of 20 µg/L or greater. Also, radon was present at levels exceeding the proposed maximum contaminant level of 300 picocuries per liter in 29 percent of the 17 samples analyzed for radon.

Samples from selected wells were analyzed for concentrations of pesticides and volatile organic compounds. The pesticide dicamba was present at a concentration of 0.01 µg/L in samples from 3 of 12 selected wells, and the pesticide 2,4-D was present at a concentration of

0.02 µg/L in one sample from a fourth well. No volatile organic compounds were detected in any samples collected from 11 selected wells.

INTRODUCTION

The demand for water in east King County has steadily increased over the past 20 years because of rapid growth in population and residential development. In one part of the study area, the Sammamish Plateau, the population increased by more than 150 percent from 1980 to 1990. Nevertheless, much of east King County remains undeveloped, and projected population growth rates are high. Also, the area is often considered for sources of water to supply other areas of the county. The demand for water in the area is, therefore, likely to increase in the future. Ground-water resources in east King County are already relied upon for most public supply, domestic, and agricultural uses, and undoubtedly will be developed further to help meet this future demand. Surface water is used for some industrial and agricultural purposes, but many surface-water bodies are closed to further appropriations.

The importance of ground water in east King County has led State and local officials to recognize the need for ground-water resource management that addresses several concerns:

(1) The potential for further ground-water development;

(2) the degree, if any, of existing ground-water contamination;

(3) the potential for future ground-water contamination; and

(4) the effects of ground-water development on ground-water and surface-water resources.

Accordingly, the Seattle-King County Department of Public Health (SKCHD) designated a 250-mi^2 area of east King County as a Ground-Water Management Area (GWMA) under the State GWMA program. The GWMA program, which is administered by the Washington State Department of Ecology (Ecology), calls for a description of the physical and chemical characteristics of the ground-water system (Washington State Department of Ecology, 1988). To address this need, in 1990 the U.S. Geological Survey (USGS) entered into a cooperative agreement with the SKCHD to conduct a 2-year study of the ground-water system in east King County. The study had the following objectives:

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

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

(3) evaluate the potential for ground-water development on the basis of aquifer characteristics, ground-water interaction with surface water, and ground-water recharge; and

(4) determine what additional data are needed to further quantify ground-water availability.

Purpose and Scope

The purpose of this report is to summarize the findings of the study described above. The report includes descriptions of the areal geometry of the aquifers, ground-water flow system, water use, ground-water level fluctuations, and water-quality characteristics of the principal geohydrologic units.

The area actually studied comprises 259 mi^2, which is slightly larger than the designated GWMA (figs. 1 and 2). This is because data from a few wells outside the GWMA boundary were used in constructing some of the geohydrologic and water-table maps. Except where noted, results presented and mapped in this report are for the study area and may be considered the same for the GWMA. The most significant exceptions are some components of the water budget calculations, specifically rainfall, recharge, and water use, which are area-dependent and were calculated for the GWMA alone. Population figures are also for only the GWMA, except where noted.

Description of the Study Area

The study area and GWMA are referred to as east King County, but they are actually located in north-central King County. This reference is traditional and stems from the study area's location east of the Seattle-Bellevue urban area (fig. 1). The study-area boundary follows the King County-Snohomish County line (figs. 1 and 2) on the north. On the west, it roughly follows the Snoqualmie River drainage divide, then turns westward to the east shore of Lake Sammamish. The boundary follows the east shore of the lake then turns eastward to and continues along the Snoqualmie River drainage divide, which

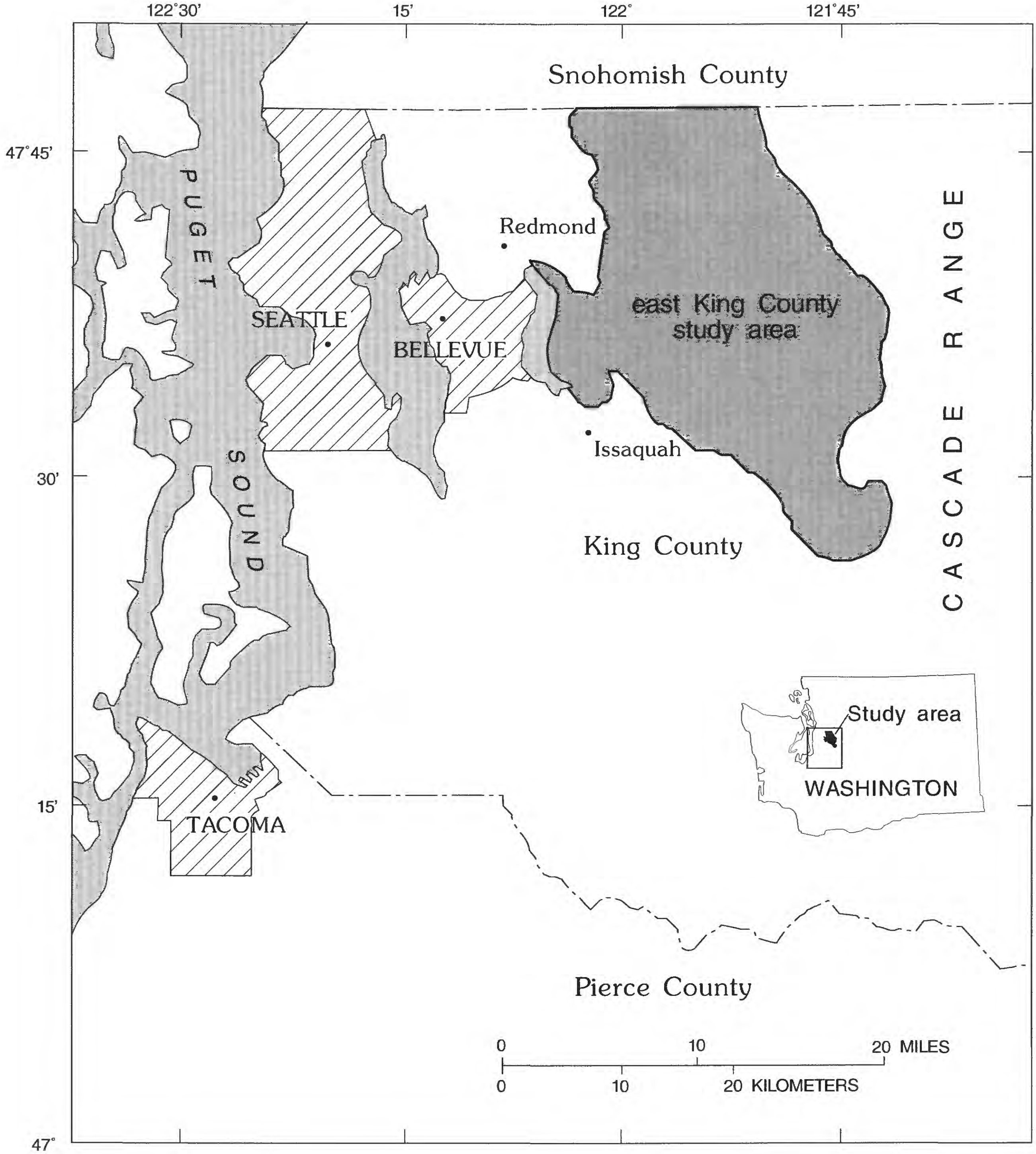


Figure 1.--Location of the east King County study area.

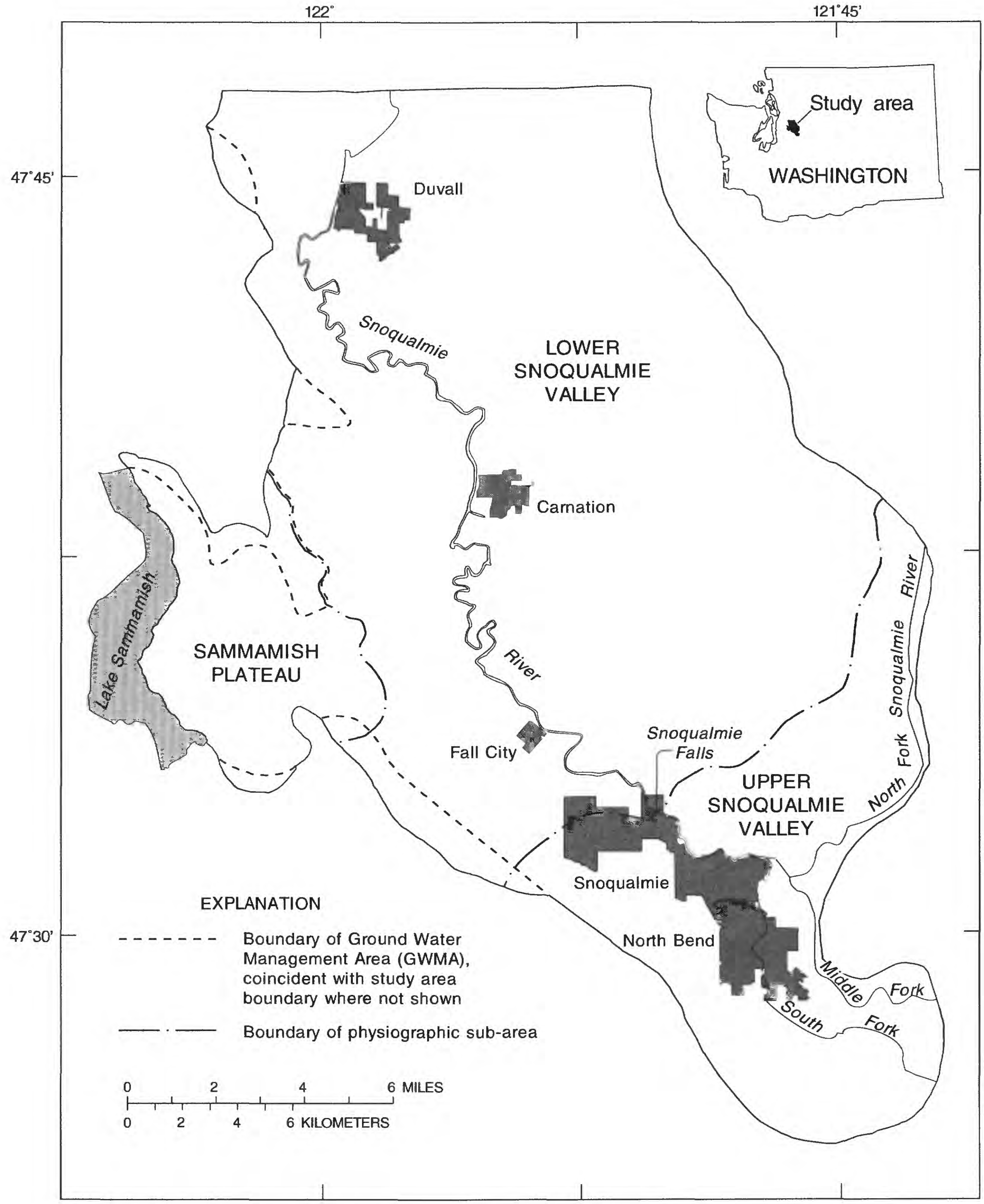


Figure 2.--East King County study area and three physiographic sub-areas.

defines the southwestern study boundary. The eastern boundary follows the base of the foothills of the Cascade Range.

The topographic surface of the study area resulted from erosion and deposition during and since the last glaciation (approximately 15,000 years ago). The Snoqualmie River flows generally from south to north, creating an alluvial valley approximately 1 mile wide that bisects the study area (fig. 2). About one third of the way into the study area from the south, the river drops some 270 feet over Snoqualmie Falls. Above the falls the altitude of the valley floor ranges from 400 to 600 feet and below the falls it ranges from 30 to 130 feet. West of the river is a glacial-drift-covered plateau that has moderate relief and ranges from 200 to 400 feet in altitude. Southwest and east of the river valley are hills of consolidated bedrock thinly mantled with glacial drift; these hills have considerably more relief than the rest of the study area. Some of this relief is due in part to incisions from tributaries to the Snoqualmie River, and the altitudes of the hills generally range from 500 to more than 1,000 ft.

Physiographically, the study area is divided into three sub-areas (fig. 2). The Sammamish Plateau consists of the western drift-covered plateau. The upper Snoqualmie Valley is the part of the study area generally upstream (south) of Snoqualmie Falls. The lower Snoqualmie Valley is the area downstream of the falls, less the Sammamish Plateau.

All of the study area except the Sammamish Plateau is drained by the Snoqualmie River. Three separate tributaries, the North, Middle, and South Forks of the Snoqualmie River, converge about 3 miles upstream of Snoqualmie Falls to form the main stem of the river. The Tolt and Raging Rivers also are tributaries to the Snoqualmie River, along with several smaller streams including Cherry, Harris, Griffin, and Patterson Creeks (plate 1). The Sammamish Plateau drains to Lake Sammamish by several small unnamed creeks. The major lakes in the study area include Ames, Beaver, Joy, Langlois, Margaret, and Pine (plate 1) and are described by Bortleson and others (1976).

The climate of the study area is characterized by warm, dry summers and cool, wet winters. Moist air masses reaching the area originate over the Pacific Ocean, and this maritime air moderates temperatures in both winter and summer (Phillips, 1960). Prevailing winds are from the south or southwest in fall and winter, gradually shifting to the northwest or north in late spring and summer.

The mean annual air temperature at the National Weather Service station at Snoqualmie Falls is 50°F, and July is usually the warmest month (mean monthly temperature of 63°F) and January the coldest (mean monthly temperature of 38°F) (fig. 3). Afternoon temperatures are usually in the 70's in summer and from the upper 30's to lower 40's in winter (National Oceanic and Atmospheric Administration, 1982).

During the wet season (winter), rainfall is usually of light to moderate intensity and continuous over an extended period of time. The mean annual precipitation for the study area is about 57 in., but ranges from less than 45 in. in the northwestern part of the study area to more than 90 in. in the southeastern part of the study area (fig. 3). The areas of greater precipitation result from the lifting and cooling of moist maritime air by relatively high landforms. The mean annual precipitation at Snoqualmie Falls is just over 61 in. (National Oceanic and Atmospheric Administration, 1982). In an average year, July has the least precipitation (1.4 in.) at Snoqualmie Falls and December has the greatest (9.5 in.). Seventy-two percent of the precipitation at Snoqualmie Falls falls in the 6-month period October to March. Most of the winter precipitation is rain. Total rainfall for the three driest months (June, July, and August) is 10 percent of the annual total. Precipitation at Snoqualmie Falls in 1990 was 81 in. (much larger than normal) and in 1991 it was 58 in. (slightly below normal). The monthly variability is apparent in figure 3.

The type of native vegetation varies according to soil type. Poorly drained fine-grained soils support mostly firs, cedars, alders, and maples. Beneath these trees is an understory of huckleberry, Oregon grape, salal, and ferns. On well-drained soils, underlain by coarse-grained outwash or alluvium, the vegetation usually consists of wild grasses, Scotch broom, and isolated patches of firs and oaks.

The estimated 1990 population of the GWMA, which encompasses the incorporated cities of Duvall, Carnation, Snoqualmie, and North Bend, was about 56,500 (King County Parks, Planning, and Resources Department, 1991). However, only about 14 percent of the population resided within the boundaries of those four cities. The population of King County's East Sammamish and Snoqualmie Valley Planning Areas, which have approximately the same boundary as the study area, more than tripled from 1970 to 1990 and is projected to double from 1990 to 2020 (fig. 4, King County Parks, Planning, and Resources Department, 1991). Most of the growth is in the East Sammamish Planning Area, where the

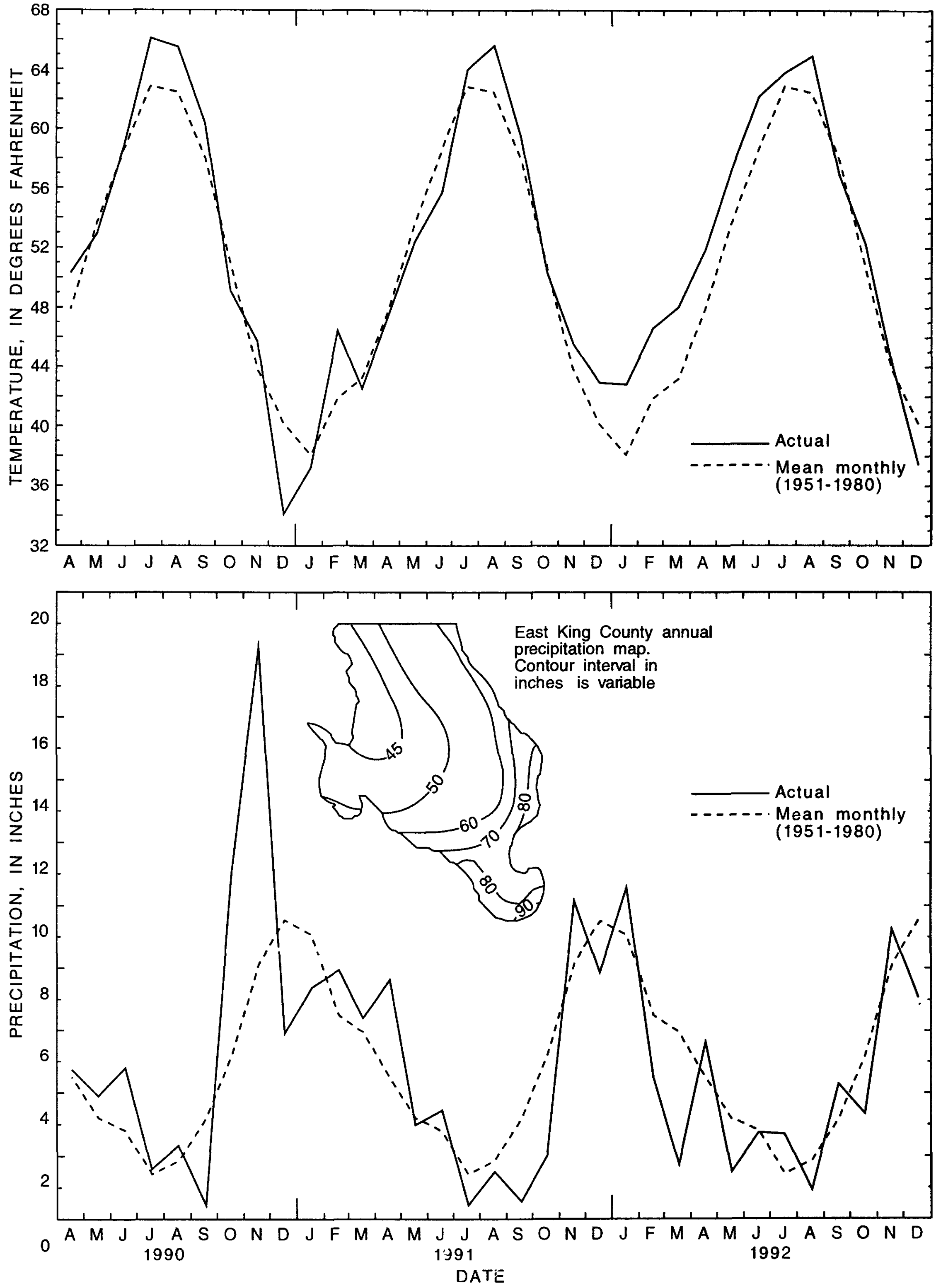


Figure 3.--Observed and mean monthly climatic conditions at Snoqualmie Falls, and precipitation map of east King County. (Observed values are from National Weather Service records; mean monthly values are from National Atmospheric and Oceanic Administration, 1982.)

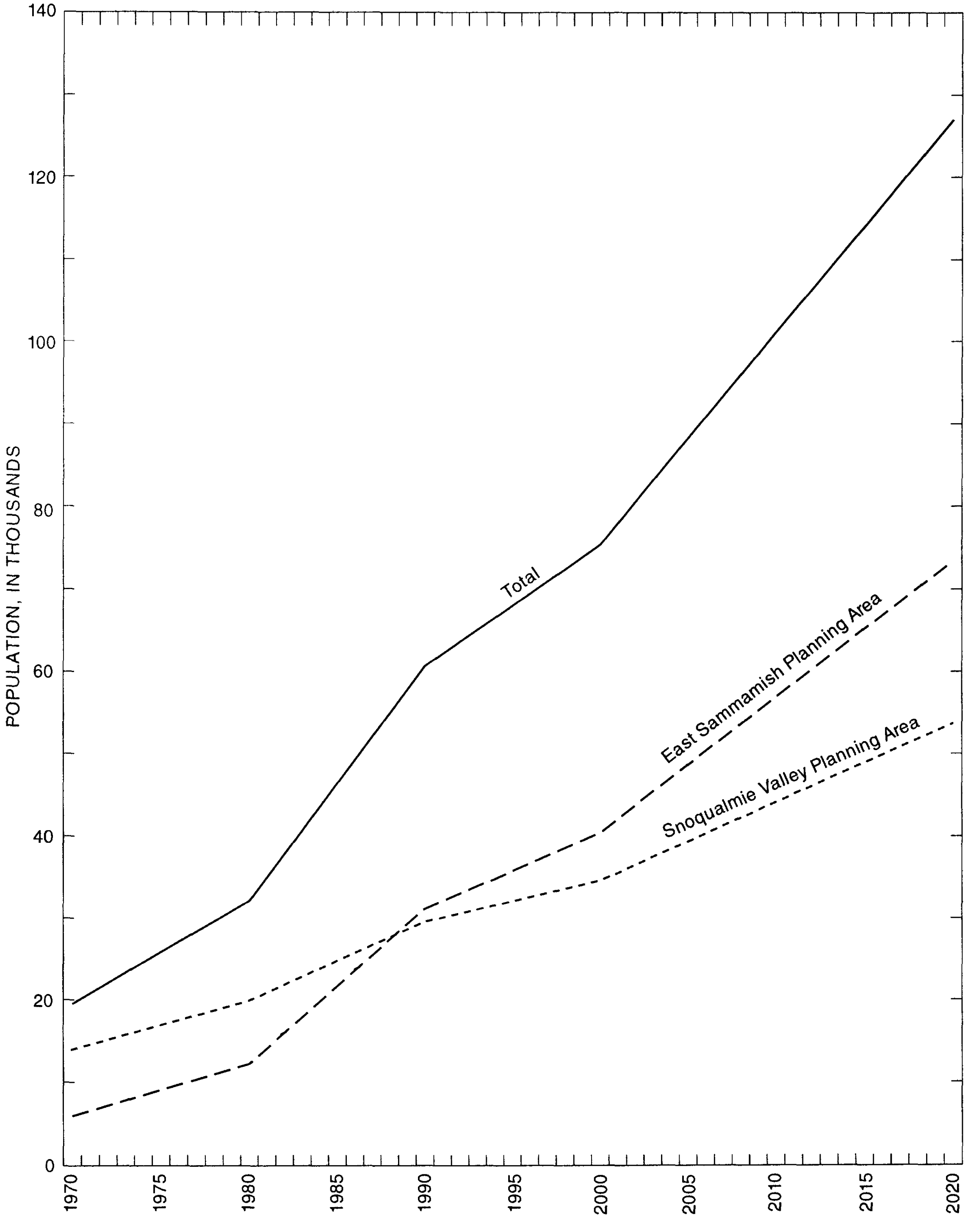


Figure 4.--Population trends for East Sammamish and Snoqualmie Valley Planning Areas. (Data from King County Parks, Planning, and Resource Department, 1991).

population increased over 150 percent from 1980 to 1990. As a result, the Sammamish Plateau is more suburban in nature than is the rest of the study area.

Much of the population, especially in the Sammamish Plateau, is employed in Redmond, Issaquah, or in the Seattle-Bellevue metropolitan area to the west (fig. 1). There is also commercial employment throughout the study area. In the Snoqualmie River Valley, there are some agricultural activities, the largest of which is dairy farming. Other agricultural activities include berry farms, nurseries, tree farms, and a few crops. Timber production and processing was historically a major employer and it is still significant in some communities.

Well-Numbering System

In Washington, wells are assigned numbers that identify their location within a township, range, section, and 40-acre tract. For example, well number 25N/06E-12H02 (fig. 5) indicates that the well is in township 25 North (25N) and range 6 East (6E) of the Willamette base line and meridian. The numbers immediately following the hyphen indicate the section (12) within the township; the letter following the section gives the 40-acre tract of the section, according to the schematic shown on figure 5. The two digit sequence number (02) following the letter indicates that the well was the second one inventoried by

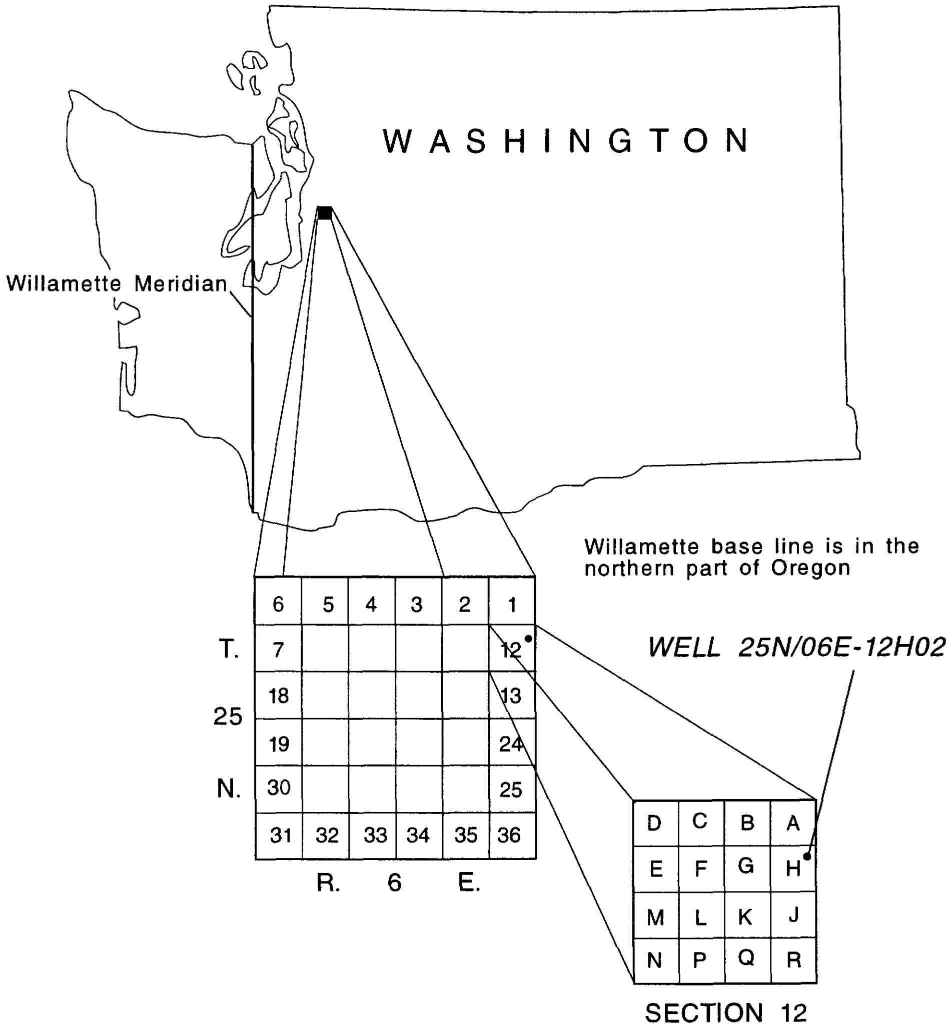


FIGURE 5.--The well-numbering system in the State of Washington.

USGS personnel in that 40-acre tract. In some plates of this report, wells are identified individually by only the section and 40-acre tract, such as 12H02, and township and range are shown as a grid. Well numbers with a P1 or P2 following the sequence number designate a piezometer, or monitoring well, and those with a D1 (or D2) following the sequence number indicate the well has been deepened once (or twice). An S following the sequence number indicates the site is a spring, rather than a well.

Acknowledgments

The authors acknowledge the cooperation of the many well owners and tenants who supplied information and allowed access to their wells and land during the field work, and the owners and managers of various water systems and companies who supplied well and water-use data. Two drillers, T. L. Cannon and H. O. Meyer, were also of assistance in providing and clarifying well logs and records.

STUDY METHODS

The approach and study methods used to describe the ground-water system in east King County are discussed in this section. The data collected and the rationale for collecting the data are also discussed. Assumptions made in collecting and interpreting the data are presented as necessary.

Approach

The following steps were taken to achieve the study objectives.

(1) A surficial geology map of exposures of the geologic units was made for the study area.

(2) Geohydrologic sections showing the altitude and thickness of the identified lithologies were constructed along selected lines throughout the study area.

(3) The surficial geology map and the geohydrologic sections were used to identify and describe the major geohydrologic units in the Quaternary sediments.

(4) The areal extent and the altitude of the top of each major geohydrologic unit was mapped.

(5) The range of hydraulic conductivities of each geohydrologic unit was estimated.

(6) The quantity of ground-water recharge derived from precipitation was estimated and mapped.

(7) The ground-water flow system was described on maps showing the configuration of the potentiometric surface and the implied horizontal direction of water movement in each major aquifer.

(8) The annual quantity of ground water withdrawn was estimated and its use described.

(9) A comprehensive water budget was estimated.

(10) The overall significant chemical characteristics of the ground water were described and mapped.

(11) Areas or points of detected water-quality problems were identified.

(12) Deficiencies in the existing data were identified and possible sampling programs to obtain the necessary data were briefly described.

Only data either readily available or collectable were used--that is, no test drilling or borehole geophysical logging was conducted for this study. Also, because of the size of the study area and the heterogeneity of the subsurface deposits, a regional perspective was used to characterize and describe the individual geohydrologic units and the water movement and quality in each unit.

Geohydrologic Methods

The bulk of the data used in this study came from information on a total of 604 wells (plate 1) that were inventoried in the field during 1990 and 1991. An attempt was made to inventory an average of three wells per section (1 square mile) or a total of approximately 750 wells. Because the eastern part of the study area contains no wells, the total number of wells inventoried (604) falls short of this planned number (750). However, the well density in the rest of the study area is approximately three per section.

The wells to be inventoried were selected on the basis of several criteria. First, only wells having a Washington State Water Well Report, or equivalent, were selected. The report contains information on the owner, construction, lithology, and testing of the well, and in most cases is the only way the USGS and other agencies are aware of the well's existence. Second, wells were selected to provide an even areal coverage of the study area. Also, wells of various depths and lithologies were selected. Where possible, wells with detailed well logs and smaller screened intervals were selected. Finally, ease of access was considered. In many instances, only one or two wells in a given section were available to inventory. However, where several wells were available, field personnel were given the option to inventory the most readily available well. As a result, one well may have been inventoried instead of another because of something as simple as the owner being at home. The 604 inventoried wells represent only about 20 percent of the total number of wells estimated to be in the study area at the time of the inventory.

Six springs were inventoried (plate 1) to help estimate ground-water discharge. The primary criterion for inventorying a spring was that it was present on USGS topographic maps, and all of these were inventoried. Other springs were also inventoried if they were identified in the field or during discussions with water purveyors. It should be recognized that there are hundreds of small springs and seeps in the study area, most of which would be difficult to locate and measure.

The well and spring inventory process began with locating the site in the field. Latitude, longitude, and land-surface altitude of the site were then determined from 1:24,000 scale topographic quadrangle maps. Finally, the water level was measured where possible. The information obtained during the inventory, along with information from the water well report, was then entered into the USGS National Water Information System (NWIS) data base. Data pertaining to the inventoried wells and springs are presented in Appendix A.

Information used to map the surficial geology of the study area was obtained from maps published by Tabor and others, 1982; Frizzell and others, 1984; Minard, 1985; Minard and Booth, 1988; Booth, 1990; and Booth and Minard, 1992. Field observations by project personnel at road and stream cuts provided additional information concerning geomorphic features and shallow geologic conditions.

The surficial geology map and subsurface lithologic information from water well reports were used to construct geohydrologic sections and maps of the geohydrologic units. Twelve sections were constructed using data from 120 wells. The sections were oriented both east-west and north-south across the study area, and were correlated to define the major geohydrologic units. After the sections were correlated, the data from the sections were extrapolated and used in conjunction with the data from the remaining wells to construct maps showing the areal extent and the altitude of the tops of the upper six units. Few wells were deep enough to extend into the deeper geohydrologic units, so those units were not mapped. All wells determined to be completed in a single geohydrologic unit were assigned a unit designation.

The estimates of recharge to the ground-water system from precipitation were based on the results of precipitation-runoff studies in King County. Because the methods used in making the estimates are complex and involve much interpretation, they are described in greater detail in the section on recharge (p. 27).

The ground-water flow system is depicted in part on maps showing the potentiometric surfaces of four major aquifers. The maps were based on water levels measured in more than 340 wells at the time of inventory. (Water levels were measured in more than 475 inventoried wells, but only 340 were completed in the four major aquifers.) An additional 40 water levels reported by drillers of inventoried wells were used as needed to corroborate or refine the contours. The number and distribution of water-level measurements in the major aquifers were considered adequate to map and contour the respective potentiometric surfaces. The number of water-level measurements in other, less-widely used units was more limited, and thus the potentiometric surfaces for those units could not be mapped. Vertical flow directions were determined by comparing water levels in closely spaced wells finished at significantly different altitudes, and by comparing the maps of the potentiometric surfaces for the major aquifers.

For a network of 42 wells, water levels were measured monthly from May 1991 to December 1992 in order to track seasonal water-level variations. The 42 wells were selected from the inventoried wells, taking care to preserve the areal and vertical distribution. In some cases, wells relatively close to each other but with different depths were selected. The selected wells were then reviewed to verify that all of the major geohydrologic units were represented. If continued access to a well was thought to be a potential problem, it was replaced by another well with similar characteristics prior to beginning the monthly measurements.

Estimates of the horizontal hydraulic conductivity for each aquifer were based on specific-capacity data. Only data from wells with complete specific-capacity information (discharge rate, time, draw-down, well-construction data, and geologic log) were used. 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 (a section of a well in bedrock with no casing or screen), the modified Theis equation (Ferris and others, 1962) was used to first estimate transmissivity values. This equation is

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

where

T = transmissivity of the geohydrologic unit, in ft^2/day;

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

s = drawdown in the well, in feet;

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

r = radius of the well, in feet; and

S = storage coefficient, a dimensionless decimal.

The equation was solved for transmissivity using Newton's iterative method (Carnahan and others, 1969). The transmissivity was then used in the following equation to calculate horizontal hydraulic conductivity:

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

where

K_h = horizontal hydraulic conductivity of the geohydrologic unit, in ft/day;

T = transmissivity, as calculated above; and

b = thickness of the geohydrologic unit, in feet, approximated by the length of the open interval as described in the water well report.

The use of the open interval to approximate the aquifer thickness assumes that the wells are open through the entire thickness of the aquifer, which was almost never the case. Nevertheless, this assumption is necessary because the equations as derived assume only horizontal flow (vertical flow is nonexistent, or at least insignificant) and in a homogeneous aquifer, horizontal flow alone can be measured only if a well penetrates the entire aquifer thickness. However, in heterogeneous glacial aquifers, such as those in east King County, vertical flow is likely to be insignificant compared to horizontal flow because the layering of the aquifer materials leads to horizontal hydraulic conductivities that are generally much larger than vertical hydraulic conductivities. Thus, although the wells are rarely open through the entire aquifer thickness, the assumption that they are is reasonable for glacial aquifers.

A third 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

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

where

K_h = horizontal hydraulic conductivity of the geohydrologic unit, in ft/day;

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

s = drawdown in the well, in feet; and

r = radius of the well, in feet.

Equation 3 is based on the assumption that ground water can flow equally in all directions, and specifically that horizontal and vertical hydraulic conductivities are equal. As discussed above, this is not likely to be true for glacial aquifers. However, the errors associated with violating this assumption are likely to be less than those resulting from using equations 1 and 2 for open-ended wells. In fact, hydraulic conductivities were calculated with both methods for open-ended wells, and the values calculated with equation 3 more closely resembled the hydraulic conductivities calculated for the screened wells in a given geohydrologic unit.

Water-use data estimated for this study were for the year 1990. Most of the data were obtained by telephone canvassing of the major water users in the study area. Data also were collected from Ecology, Washington Department of Health (WDOH), USGS, and reports from utilities and other agencies.

At the time of the water-use canvass, public water systems in Washington were divided into four classes (Washington State Department of Social and Health Services, 1983).

Class 1 systems had 100 or more permanent services (a physical connection designed to serve a single family) or served a transitory population of 1,000 or more people on any one day;

Class 2 systems had 10 to 99 permanent services or served a transitory population of 300 to 999 people on any one day;

Class 3 systems served a transitory population of 25 to 299 people on any one day; and

Class 4 systems had 2 to 9 permanent services or served a transitory population of less than 25 people per day.

Data for Class 1 and 2 systems were obtained by direct contact, either by telephone or letter, with each system manager or representative. Withdrawals for most Class 1 and some Class 2 systems were metered, and in those cases actual pumpage data were used. For systems that were not metered, estimates of withdrawals were made with the following formula:

$$W = CPU \times 365 \qquad (4)$$

where

W = annual system withdrawal;
C = number of connections;
P = average number of persons per connection; and
U = daily water use per person.

For unmetered systems, system managers knew the number of connections and could usually provide estimates of the other two figures (P and U). If the managers could not estimate these numbers, values of 2.5 persons per connection and 110 gal of daily water use per person were used. These numbers are based on typical averages for public supply systems in Washington (R. C. Lane, U.S. Geological Survey, written commun., 1992). For purposes of this study, persons served by the dozens of Class 3 and 4 systems were considered to be supplied by privately owned wells.

Annual ground-water withdrawals from privately owned wells for domestic use were calculated by first determining the population of the study area whose homes were supplied water by Class 1 or 2 public water systems (48,100) and subtracting that number from the total population of the area (56,500). The difference (8,400) was then multiplied by a per capita rate of 110 gal/day and by 365 days.

Ground-water withdrawals for agricultural activities were based on the operators' estimates. If estimates were unknown or uncertain, withdrawals were calculated by one of the following methods. For crop irrigation, one of two methods was used: (1) The pumping capacity of the irrigation well was multiplied by the owner's estimate of the duration of pumping; or (2) a uniform application rate of 1.5 acre-ft of water per acre per year (irrigation season) was multiplied by the estimate of irrigated acreage. To determine livestock consumption, the number of head in a herd was multiplied by the estimated daily consumption per head and the number of days of consumption. For example, dairy cattle (the livestock using the most water) were each estimated to consume 30 gallons of water per day, or about 11,000 gal/yr. Information about irrigated acreage and herd size was obtained by telephone and personal contact with farmers identified either by USGS personnel during the well-inventory process or by personnel of the U.S. Department of Agriculture Soil Conservation Service.

Ground-water withdrawals from private wells for commercial, industrial, and institutional purposes are referred to as self-supplied. They were estimated on the basis of telephone canvassing of water users identified during the well inventory, by SKCHD personnel, and by publications such as the telephone directory. Because of the large number of small commercial businesses in the study area, the canvass of this category is most likely incomplete, but the omissions are likely insignificant.

Water-Quality Methods

The sampling and analytical methods used in the water-quality phase of this study follow guidelines presented in various U.S. Geological Survey Techniques of Water-Resources Investigations (Wood, 1981; Friedman and Erdmann, 1982; Wershaw and others, 1987; Britton and Greeson, 1988; and Fishman and Friedman, 1989) and where applicable, guidelines for GWMA studies as presented by Carey (1986). This section presents an overview of selected methods.

Water samples were collected from 121 wells and 3 springs (plate 2) during July and August 1991. All samples were analyzed for concentrations of major ions, alkalinity, silica, nitrate, iron, manganese, and selected trace elements. The trace-element analytes were arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc. In addition, field measurements of temperature, specific conductance, pH, and dissolved-oxygen concentration were made at all sites. Samples from all but three wells also were analyzed for concentrations of fecal-coliform and fecal-streptococci bacteria. A subset of 11 samples, taken mostly from wells situated in more populated areas, was analyzed for concentrations of volatile organic compounds. Another subset of 12 samples collected from wells in agricultural areas was analyzed for concentrations of selected pesticides. The volatile organic compound and pesticide analytes are presented later in this report. A subset of 19 samples from wells in areas without sewers was analyzed for concentrations of boron, dissolved organic carbon (DOC), and methylene blue active substances (MBAS, or detergents). Finally, samples from 17 randomly selected wells were analyzed for concentrations of radon. All water-quality data that resulted from this study are presented in Appendix B.

All the wells sampled in this study had been inventoried and field-located, as previously described, prior to sampling. Most of the wells selected for sampling were used for domestic or, to a lesser extent, municipal purposes; a few were used for agricultural, industrial, or commercial purposes. The sampled wells were selected to provide a broad geographic coverage and a representation of the major geohydrologic units. The number of wells selected for sampling within each of the geohydrologic units was approximately proportional to the total number of wells inventoried in each unit. Wells open to more than one geohydrologic unit were not sampled. If a selected well could not be sampled for any reason, a substitute well was selected using the same criteria; care was taken to preserve the original well distribution, both areally and geohydrologically. Areas of potential ground-water-quality problems, such as elevated nitrate concentrations or the presence of pesticides, were also considered in the well-selection process. Although an effort was made to sample wells that might be representative of widespread water-quality problems, because of the regional nature of this study no attempt was made to sample wells affected by known small-scale or point-source problems. Wells from which samples were analyzed for concentrations of volatile organic compounds, pesticides, and septage-related compounds were selected mostly on the basis of the predominant land use in the general vicinity of each well. A map of potential sources of water-quality problems, including land fills, dairy farms, berry farms, and underground storage tanks, was also used to guide the well selection by identifying areas where point-source problems may be dense enough to result in regional problems.

Water samples usually were collected from a hose bib in the well distribution system as close to the wellhead as possible. All samples were collected at a point ahead of any water treatment, such as chlorination, fluoridation, or softening. Where feasible, samples were collected upstream of any holding tank. Sample water was directed from the hose bib through nylon tubing to a flow-directing stainless-steel manifold mounted in a mobile water-quality laboratory; a diagram of the system is shown on figure 6. At a flow chamber, temperature, pH, specific conductance, and dissolved-oxygen concentration were monitored continuously. Once these readings were constant for 10 minutes (indicating that the water was being drawn from the aquifer), raw and filtered samples were collected from the appropriate manifold outlet. Raw samples to be analyzed for concentrations of organic compounds and bacteria were collected last, directly from the hose bib.

After collection, samples were treated and preserved according to standard USGS procedures (Pritt and Jones, 1989). Samples requiring laboratory analysis were sent to the laboratory by first-class mail on the next work day. All sampling equipment was rinsed and cleaned as appropriate before subsequent samples were collected.

Field determinations of temperature, pH, and specific conductance were made on-site with meters, using methods outlined by Wood (1981). Dissolved-oxygen concentrations also were determined onsite with a meter, but concentrations of 1.0 mg/L (milligram per liter) or less were verified onsite with a Rhodazine-D colorimetric method (White and others, 1990) developed by Chemetrics, Inc. Alkalinity was determined in the field for samples with a dissolved-oxygen concentration of 1.0 mg/L or less and an iron concentration of 800 µg/L (micrograms per liter) or greater. The iron concentration was estimated in the field with a colorimetric method developed by Chemetrics. Only eight samples met the criteria for determining a field alkalinity, but the differences between the laboratory and field alkalinity determinations did not affect the statistical analyses or interpretations of alkalinity. The field alkalinity results are therefore presented only in Appendix B and are not discussed in the text. A detailed comparison of the laboratory and field alkalinity determinations is discussed in Appendix C. Samples were also analyzed in the field for concentrations of fecal-coliform and fecal-streptococci bacteria by membrane filtration methods outlined by Britton and Greeson (1988).

Laboratory analyses were done by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. Dissolved concentrations were determined for all inorganic constituents and total concentrations were determined for all organic compounds except dissolved organic carbon and the triazine herbicides. The triazine herbicide concentrations were reported as dissolved because the

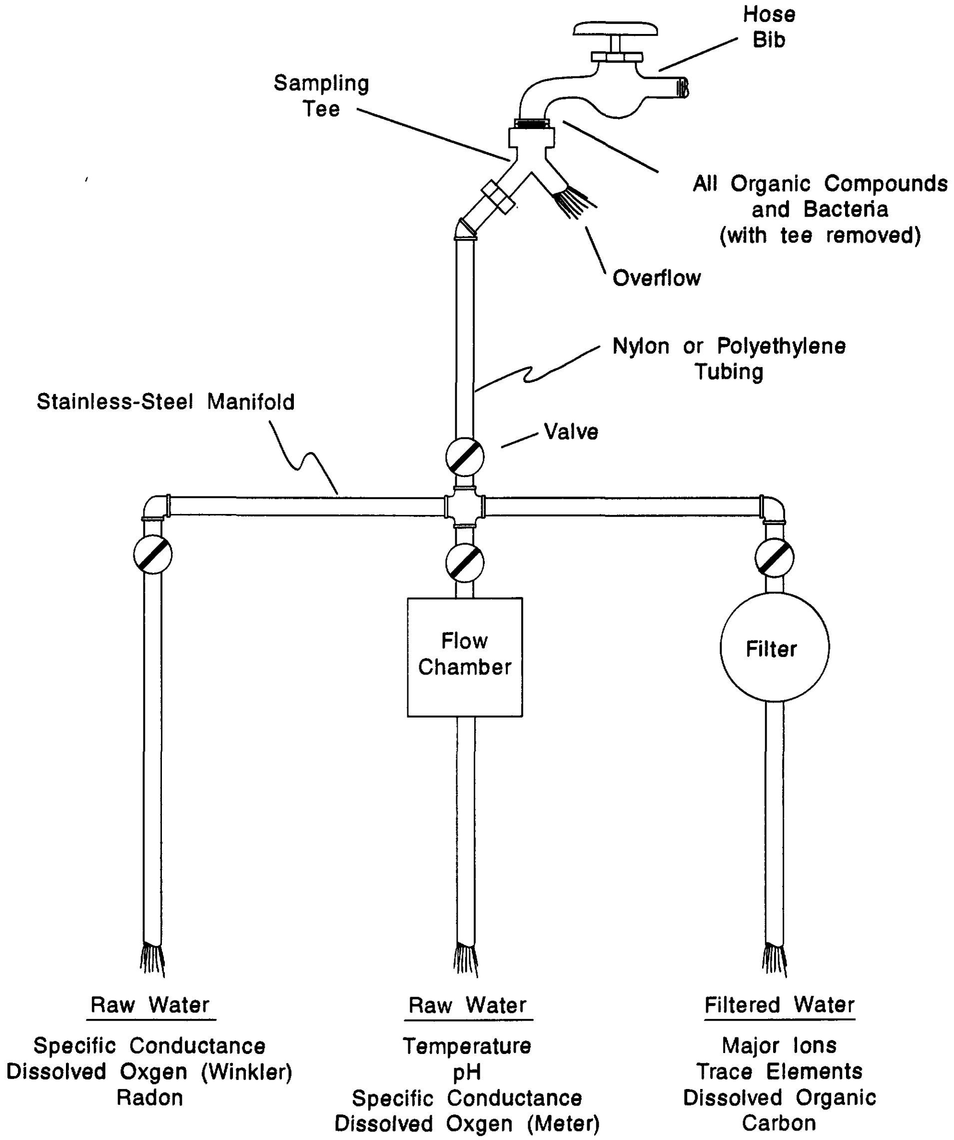


Figure 6.--Ground-water sampling system.

analytical procedure called for filtering the samples in the laboratory. Analytical procedures used at the NWQL are described by Fishman and Friedman (1989) and Wershaw and others (1987).

As part of the study's quality-assurance program, the accuracy of field measurements of pH and specific conductance was ensured by daily calibration of meters with known standards. Dissolved-oxygen meters were also calibrated daily using the water-saturated air technique. Field analyses of bacteria concentrations were performed in duplicate for 1 in every 15 wells sampled.

Samples for analysis by the NWQL were collected in duplicate on a random basis. One duplicate sample was collected for every 15 wells sampled for major ion and trace element analysis, and 1 duplicate sample was collected for every 10 wells sampled for volatile organic compound or pesticide analysis. Blank samples of deionized water were prepared at the same frequencies. Duplicates and blanks were processed in the same manner as ordinary ground-water samples and were submitted to the laboratory disguised as ordinary ground-water samples.

Because standards for most inorganic constituents are inserted routinely as blind samples into the sample stream at the NWQL, no standards or spiked samples were submitted from the field to the laboratory. At the NWQL appropriate standards were spiked into each sample for organic analysis to determine the percentage of constituent recovered.

Standard quality-assurance procedures were used at the NWQL. The resulting data were reviewed by laboratory personnel, then released to the local USGS district office in Tacoma, Wash., by electronic data transfer. The laboratory data were reviewed further by district and project personnel in consideration of the geohydrologic setting. Computer programs and statistical techniques were used to assist in all stages of the reviews. Additional details of laboratory quality-assurance procedures and data review are discussed in the project quality-assurance plan by G. L. Turney (U.S. Geological Survey, written commun., 1991) and in a general plan by Friedman and Erdmann (1982). The quality-assurance data for this project are assessed in Appendix C of this report.

GEOHYDROLOGY

The basic principles of ground-water occurrence are described in this section, followed by descriptions of the geology and ground-water flow system in east King County. The quantity of ground water used for beneficial purposes, a water budget, and water-level fluctuations are also discussed. Most of the material that follows applies specifically to east King County, but the reader is referred to Freeze and Cherry (1979) or Heath (1983) for more comprehensive discussions of general ground-water occurrence.

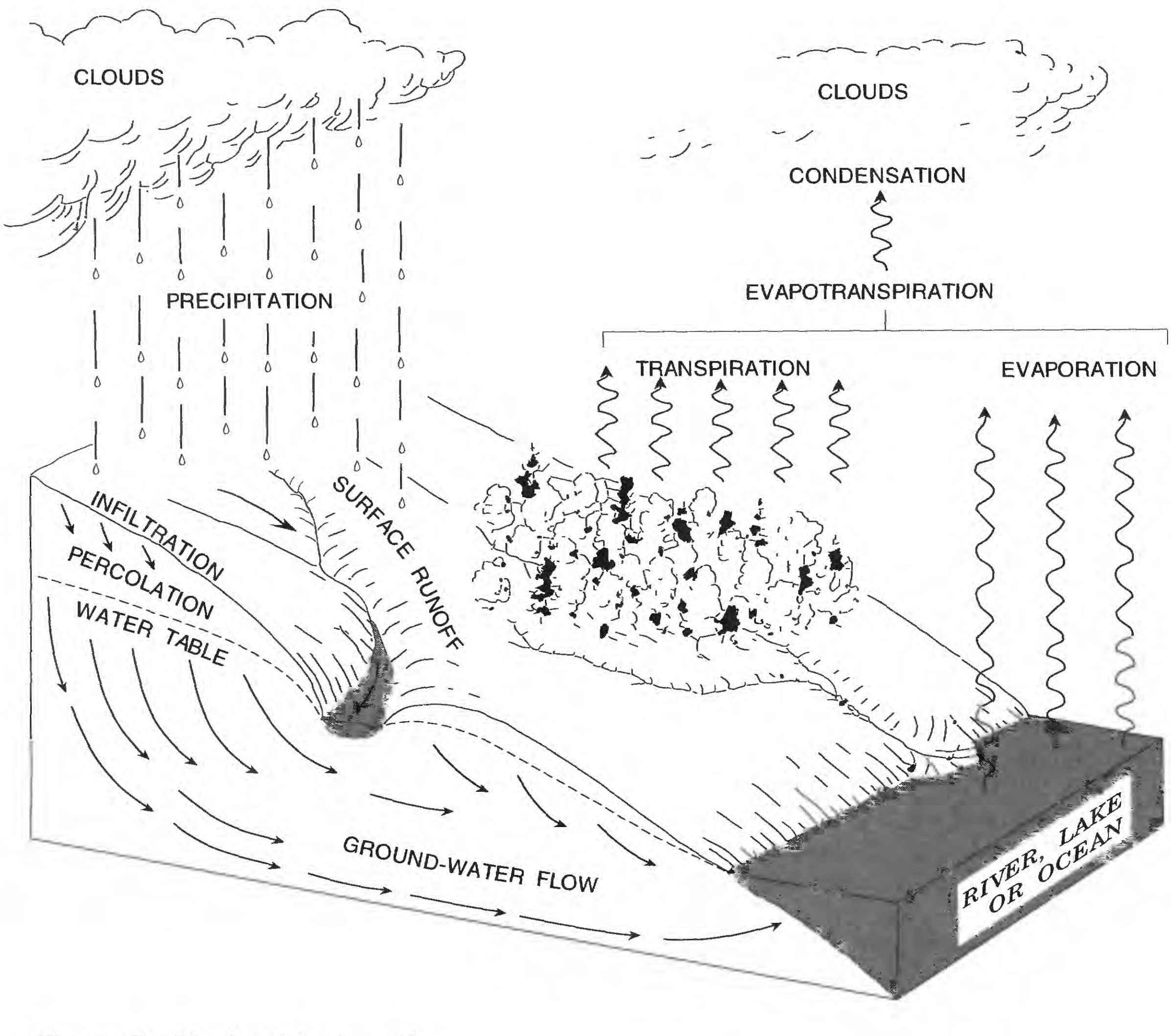


Figure 7.--The hydrologic cycle.

The Hydrologic Cycle

Water circulates continually between the ocean, the atmosphere, and the Earth's surface in a process known as the hydrologic cycle (fig. 7, see page 15). Precipitation, as rain or snow, is the source of all fresh ground water. Once on the land surface, some of the precipitation runs off to streams and lakes, some infiltrates the ground, and some is evaporated back to the atmosphere from the soil and from freewater surfaces such as ponds and lakes. Some of the water entering the soil is drawn up by plant roots and returns to the atmosphere by transpiration from leaves; the combination of evaporation and transpiration is called evapotranspiration. Most of the remaining water that enters the ground continues to percolate downward to the water table, becoming recharge to the ground water. Some of this ground water eventually returns to the land surface by seepage to springs, lakes, and streams, and some discharges directly to the sea. From the sea and other surface-water bodies, water is evaporated back to the atmosphere, where it forms clouds and, eventually, precipitation.

Ground-Water Occurrence

The occurrence of ground water varies greatly, and is largely dependent on a geohydrologic unit's permeability, or its ability to transmit water. In unconsolidated materials, such as clay, sand, or gravel, water moves through pore spaces separating the individual particles. Because these pore spaces are for the most part interconnected, there is relatively free movement of water within the deposits. Water moves more easily, however, through the larger pore spaces within deposits of well-sorted coarse sand and gravel than through the smaller pore spaces in clay, silt, and poorly sorted till. Therefore, sands and gravels are more permeable than clays, silts, and tills. In consolidated material such as granite or basalt, the principal movement of water is through interconnected joints, fractures, and faults, and permeability is highly variable.

Water-saturated geologic units can be classified either as aquifers or as confining (or semiconfining) beds. An aquifer is a geologic unit that is at least partly saturated and is sufficiently permeable to yield water in significant

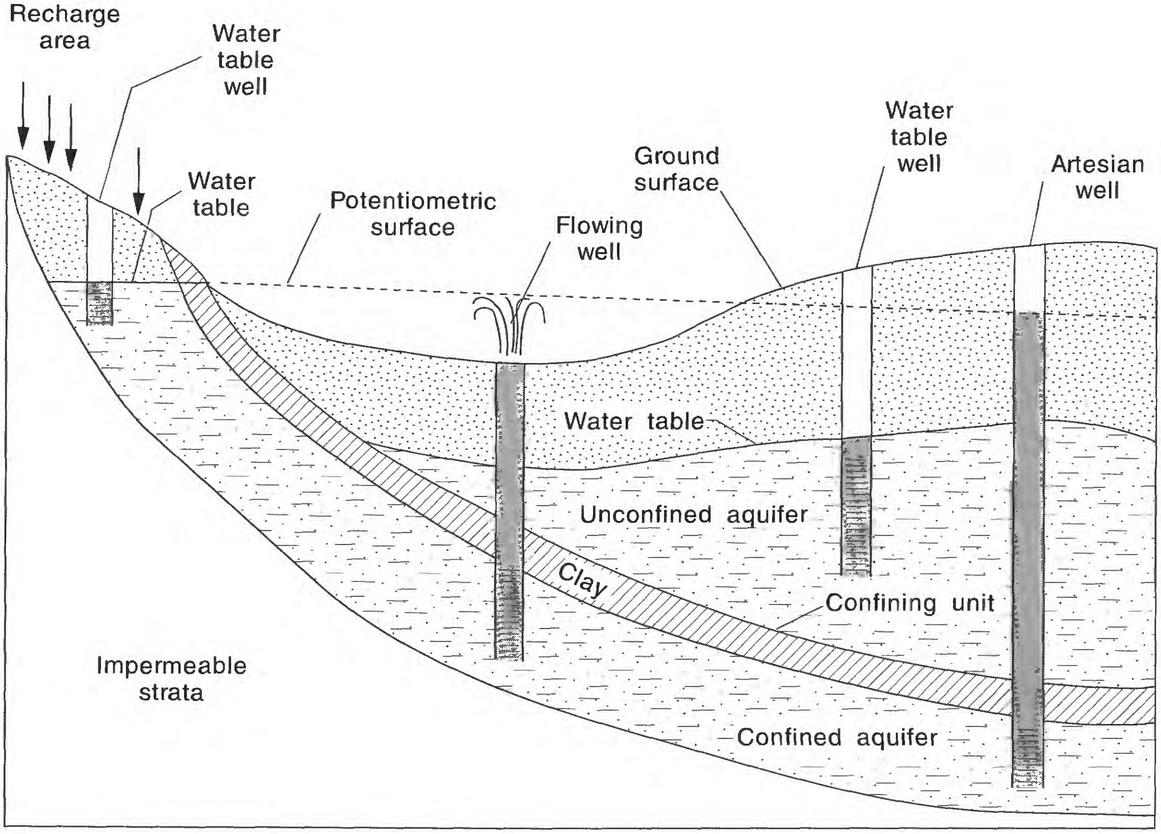


Figure 8.--Features of unconfined and confined ground-water systems. (Modified from Todd, 1980.)

quantities to a well or spring (Freeze and Cherry, 1979). A confining bed is a geologic unit having a much lower permeability than that of adjacent aquifers, thus restricting the movement of ground water into, or out of, those aquifers.

Ground water in aquifers can be present under two different conditions. Where water only partly fills an aquifer (fig. 8), the water table (the upper surface of the saturated zone) is free to rise and fall with changes in recharge and discharge. The position of the water table is determined by measuring water levels in shallow wells. In this situation, the ground water is considered to be unconfined or under "water table" conditions. Where water completely fills an aquifer that is overlain and underlain by a confining bed, ground water is considered to be confined or "artesian". In wells that tap a confined aquifer (fig. 8), water rises to a height corresponding to the hydraulic head of the confined ground water at that point. If the head is sufficient to raise the water above land surface, the well will flow and is called a flowing artesian well. A map of the heads in a confined aquifer defines the potentiometric surface, which is analogous to the water table in an unconfined aquifer. Unlike a water table, the potentiometric surface is higher in elevation than the top of the aquifer. The potentiometric surface does, however, fluctuate in response to changing recharge-discharge relations.

Flowing wells can also be constructed in aquifers without confining layers. The idealized ground-water flow pattern beneath an area of uniformly permeable material, as modified from Hubbert (1940), is shown on figure 9. In the figure, the approximate flow paths of water are shown by dashed lines with arrows; the dotted lines, which intersect the flow lines, are lines of equal potential or head. Deeper cased wells finished in recharge areas, where ground water generally moves downward, receive water under lower head than do shallower wells at the same location. Conversely, deeper cased wells located in discharge areas, where ground

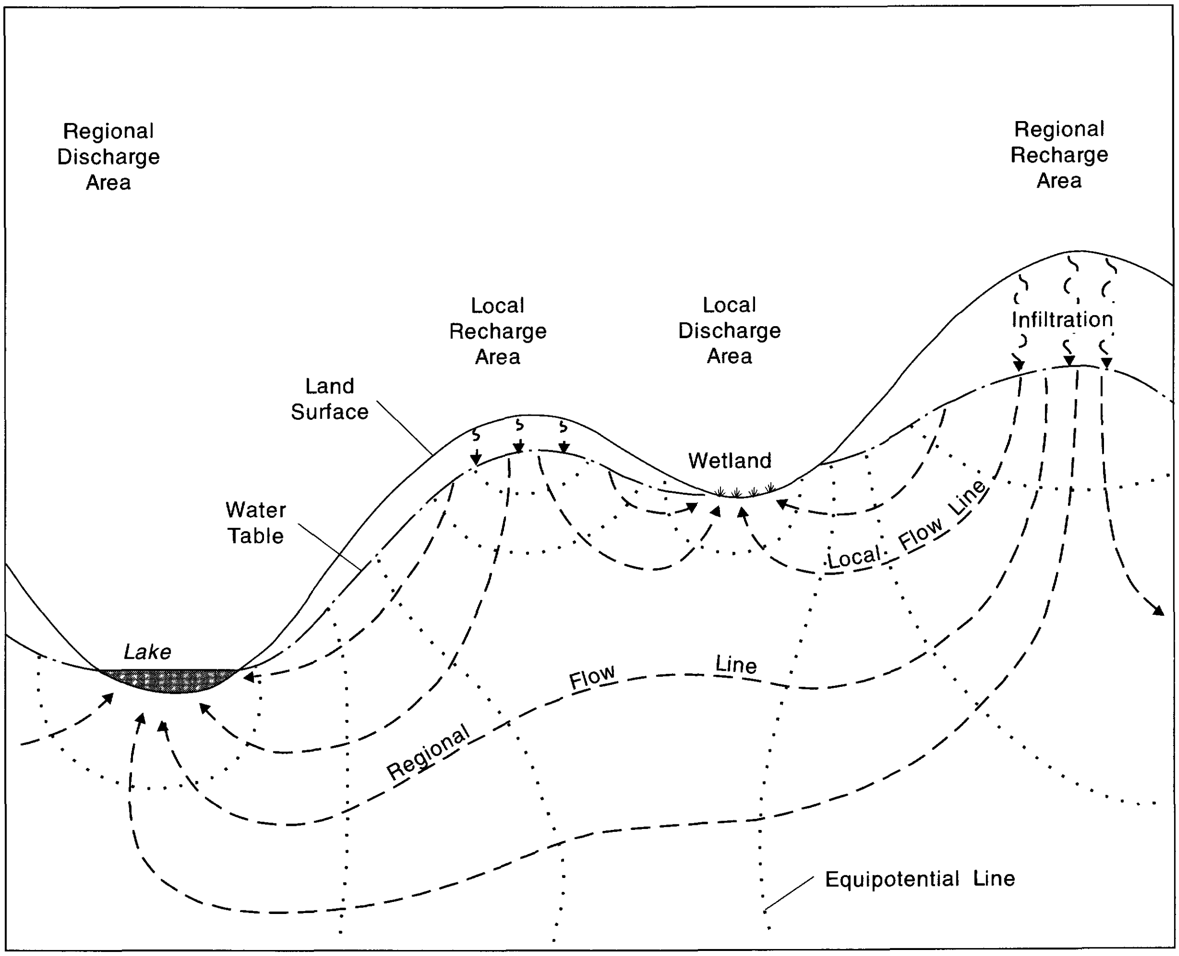


Figure 9.--Idealized ground-water flow beneath an area of uniformly permeable material. (Modified from Hubbert, 1940.)

water generally moves upward, receive water under higher head than do shallower wells at the same location. If the heads are sufficiently high, the wells will flow. The primary control on the occurrence of flowing wells is not structure or stratigraphy, but topography (Freeze and Cherry, 1979).

Ground-water flow systems are commonly divided into local and regional systems (Tóth, 1963; Freeze and Cherry, 1979). Local flow systems (fig. 9) have short flow paths, involve shallow aquifers, and are controlled chiefly by local topography. In contrast, regional flow systems have long flow paths, involve deep aquifers, and are controlled chiefly by large-scale topographic features. A third kind of flow system, termed intermediate, commonly exists between the two extremes. In reality, the three flow systems are continuous rather than discrete.

The occurrence of ground water is also important in defining geohydrologic units. Geohydrologic units are identified by considering the hydrologic properties of the initially defined geologic units. Thus, geologic units are categorized as aquifers or confining units and become geohydrologic units. Although geologic and geohydrologic units are often the same, differences arise when two geologic units directly above one another have similar hydrologic properties and are combined to form one geohydrologic unit, or when one geologic unit varies greatly in hydrologic properties (usually from top to bottom) and is split into two or more geohydrologic units. An example is the combining of glacial outwash units and overlying alluvial units into one geohydrologic unit. Identifying the distinctions between geologic and geohydrologic units is useful in the study of east King County.

Geologic Framework

Many studies have contributed to our current understanding of the geologic framework of the study area. Detailed descriptions of geologic conditions in the study area, and the Puget Sound Lowland in general, are provided in Willis (1898), Bretz (1913), Mackin (1941), Liesch and others (1963), Crandell and others (1958, 1965), Crandell, 1965, Richardson and others (1968), Livingston (1971), Hall and Othberg (1974), Thorson (1980), Gower and others (1985), Blunt and others (1987), and Booth (1990). The summary that follows is taken from the work of Liesch and others (1963) and Booth (1990); the reader is referred to those two publications for additional information concerning the geology of east King County.

Continental glacial ice originating in British Columbia invaded the Puget Sound Lowland, within which the study area lies, several times during the Pleistocene Epoch (10,000 to 1,600,000 years before present). Referred to as the Puget Lobe, this ice was part of the Cordilleran ice sheet of northwestern North America. The extent of the ice was limited geographically by the mountains and hills that surround the lowland. Within the study area the Cascade Range foothills limited the easternmost extent of the Puget Lobe. Repeated episodes of ice advance and retreat, called glaciations, resulted in thick accumulations of glacial and interglacial deposits throughout the region. These deposits consist of unconsolidated gravel, sand, silt, clay, and peat. The identification of deposits of successive glaciations in the Puget Sound region is difficult because each glaciation eroded and disturbed the deposits from previous glaciations. Therefore our knowledge of all but the last major glaciation is limited.

This most recent glaciation, referred to as the Vashon Stade of the Fraser Glaciation, began about 15,000 years ago when the ice slowly advanced southward, blanketing the entire Puget Sound Lowland. Evidence of this glaciation is apparent throughout the lowland in the form of topographic features as well as deposits called glacial drift. Although valley glaciers extended westward from the Cascade Range foothills at the same time as the continental ice, those in the study area did not extend down the valleys far enough to merge with the continental ice during this last glaciation.

As the Vashon Glacier advanced southward, rivers such as the Snoqualmie River that originally flowed northward were either diverted southward or dammed. Blocked drainages often resulted in extensive lakes fed by the rivers and the advancing glacier itself. Such lakes eventually breeched or overtopped their enclosing basins. The Vashon Glacier remained at its maximum extent for a relatively short period. As the climate warmed, beginning about 13,500 years ago, the glacier began to melt faster than it advanced, beginning the process of retreating. As the glacier retreated northward, the drainage to the north across the Puget Sound Lowland to the Strait of Juan de Fuca eventually was re-established. The Snoqualmie River, having regained its northerly course, subsequently formed a valley-wide floodplain graded to present-day sea level.

As a result of the Vashon and previous glaciations, much of the study area is covered by unconsolidated deposits that are of both glacial and nonglacial origin. These deposits tend to be heterogeneous and may be discontinuous in places. The variable topographic relief of the study area further contributes to the complexity of the deposits. Beneath these unconsolidated deposits, which are as much as 1,200 feet thick, are Tertiary and pre-Tertiary consolidated rocks, which are referred to in this report as bedrock. The various types of bedrock were not differentiated in this study. The surficial extent of the geologic units is shown on plate 1.

The youngest geologic units in the study area are Qb, bog deposits, and Qal, alluvium. The bog deposits, which cover less than 1 percent of the study area (plate 1), consist of alluvium and peat that have accumulated in poorly drained depressions on the present-day land surface. Because Qb has such small exposures, it is considered geohydrologically insignificant for this study. Qal consists mostly of the extensive deposits of the Snoqualmie River and its tributary streams and covers about 19 percent of the study area. Smaller amounts of alluvial fan deposits and landslide material are included in the unit. The Snoqualmie River alluvium consists of sand, silt, and clay downstream from Snoqualmie Falls, and sand and gravel upstream from the falls. Alluvium in tributary streams generally consists of sand, gravel, and silt.

The youngest glacial unit in the study area is Qvr, the Vashon recessional outwash. About 22 percent of the study area is covered with Qvr. Qvr consists of moderately to well-sorted sand and gravel laid down by streams emanating from the receding Vashon Glacier. Included in this unit are ice-contact deposits that accumulated along the margin of the ice in the eastern part of the study area. Associated with the recessional outwash but mapped as a separate unit is Qvrl, a fine-grained deposit of ice-dammed lakes. Qvrl covers about 1 percent of the study area and is found in limited exposures along the margins of the Snoqualmie River and Patterson Creek Valleys. Lithologically, Qvrl contains much more silt and clay than does Qvr.

Glacial till, often referred to as hardpan or boulder clay, consists of a compact, unsorted mixture of sand, gravel, and boulders in a matrix of silt and clay. Vashon till, designated Qvt, owes its compact nature to the fact that it was laid down beneath the heavy mass of the advancing Vashon Glacier. Vashon till is exposed at land surface over about 40 percent of the study area (see plate 1).

As the Vashon Glacier advanced southward, large quantities of stratified sand and gravel were deposited by meltwaters at the front and sides of the ice mass. These deposits, the Vashon advance outwash, are designated Qva and typically consist of well-bedded gravelly sand to fine-grained sand. The unit is exposed in the bluffs along the margins of the Snoqualmie River and tributary valleys (plate 1). These surficial exposures cover only 3 percent of the study area.

Beneath Qva is an extensive fine-grained assemblage of laminated clayey silt to clay with minor lenses of sand, gravel, peat, and wood. This unit, referred to as the transitional beds (Qtb), was deposited in standing water ponded by the advancing Vashon Glacier. Surficial exposures of the unit, located mostly on the walls of the Snoqualmie Valley west of Duvall and Snoqualmie, cover about 1 percent of the study area.

The oldest unconsolidated deposits mapped in the study area are referred to as pre-Fraser deposits (Qpf). These include any unconsolidated material, regardless of origin, that was deposited prior to the Fraser Glaciation. Surficial exposures of this unit are limited to less than 1 percent of the study area, and consist of either interglacial sand and gravel deposited by rivers between ice advances, or clay-rich till from earlier ice advances.

Most of the consolidated rocks that make up the bedrock (Br) consist of andesite with minor amounts of basalt and diorite. However, sandstone, siltstone, and conglomerate are predominant southwest of the Snoqualmie River. Bedrock is exposed in about 13 percent of the study area, mostly in the east and southwest (plate 1). Drillers' logs indicate that the bedrock surface forms a southeast-to-northwest-trending structural trough beneath the low-lying areas occupied by the Snoqualmie River Valley. The bedrock outcrop at Snoqualmie Falls represents a structural high that interrupts the otherwise continuous trough.

Principal Geohydrologic Units

The geologic units described previously were differentiated into aquifers and confining beds based on lithologic and well-yield data from the 604 wells inventoried in the study (Appendix A). The aquifers and confining beds thus defined are referred to as geohydrologic units because the differentiation takes into account both the geologic and hydrologic characteristics of the unit. However, the heterogeneity of the units can result in local variations in hydrologic characteristics. For example, a glacial aquifer may be composed predominantly of sand and (or) gravel, but on a small scale it also may contain relatively thin and discontinuous lenses of clay or silt. Conversely, a confining layer, composed predominantly of silt and (or) clay, also may contain local lenses of sand or gravel. As a consequence, the general occurrence and movement of ground water may be influenced locally by these small-scale variations in lithology.

The geohydrologic units defined in the subsurface were related to the surficial geologic map (plate 1) in order to place the subsurface units in their proper stratigraphic position. An examination of the geohydrologic sections (plate 1) indicates that there is a great deal of variation in the thickness of individual units, and that not all units are necessarily present at any one location.

Ten geohydrologic units were identified, as shown in figure 10, and they are listed here, in order of increasing geologic age:

(1) Alluvium (Qal);

(2) Vashon recessional outwash (Qvr);

(3) Vashon till (Qvt);

(4) Vashon advance outwash (Qva);

(5) Upper fine-grained unit (Q(A)f);

(6) Upper coarse-grained unit (Q(A)c);

(7) Lower fine-grained unit (Q(B)f);

(8) Lower coarse-grained unit (Q(B)c);

(9) Deepest unconsolidated and undifferentiated deposits (Q(C)); and

(10) Bedrock (Br).

Previously accepted and published nomenclature associated with the alluvium and Vashon Drift was used for the upper four geohydrologic units--Qal, Qvr, Qvt, and Qva. These geohydrologic units also correlated identically with the geologic units identified in the previous sections. Names that refer to grain size and relative stratigraphic position were used to refer to older unconsolidated geohydrologic units that are, in effect, subdivisions of the previously discussed geologic units. For example, Q(A)c is the upper (A) coarse-grained (c) geohydrologic unit in the Quaternary (Q) geologic units. The extent and altitude of the tops of the youngest six of these units are shown on plate 2. The remaining units are not shown because of a lack of data. The limited surficial extent of bog deposits precluded them from being recognized as a separate geohydrologic unit. However, the bog deposits can perch or confine ground water locally.

The relative importance of each of the geohydrologic units as a source of ground water can be determined from a graph of the number of study wells finished in each of them (fig. 11). The resulting information indicates that Qal, Qvr, Qva, Q(A)c, and Br are the principal sources of water for existing wells in east King County, but that usable quantities of ground water also can be obtained from Qvt, Q(A)f, Q(B)f, and Q(B)c. Qvt, Q(A)f, and Q(B)f generally act as confining beds, but some wells in these otherwise poorly permeable deposits produce water from thin, local lenses of sand or gravel. Because none of the study wells is finished in unit Q(C), the potential of the unit as a source of ground water is unknown. Although Q(C) is deep and probably of limited extent, it could provide usable quantities of water given the coarse nature of the deposits.

The Quaternary alluvium, Qal, is present mostly in the floor of the Snoqualmie River Valley and its tributaries (plate 2). An average thickness of 100 feet and a maximum thickness of 250 feet in the upper Snoqualmie River Valley is shown on the geohydrologic sections (plate 1). However, the thickness of the Qal is difficult to determine because most wells do not penetrate the entire unit. Furthermore, Qal commonly overlies older but lithologically similar deposits. The altitude of the top of the unit ranges from less than 40 feet near the King County-Snohomish County boundary to 800 feet in the uppermost reaches of the Snoqualmie River tributaries (plate 2). Qal is a highly productive aquifer, especially upstream of Snoqualmie Falls in and around the town of North Bend. Most of the 107 inventoried wells that tap this unit are located in this upper valley, where the North, Middle, and South Forks of the Snoqualmie River converge. Wells that tap Qal either downstream from the falls, in landslide deposits, or in alluvial fans have yields that tend to be smaller and somewhat less predictable than the wells in the upper valley. Wells that are on the lower valley floor are also subject to periodic flooding of the Snoqualmie River, so there are far fewer of them.

Qvr, the Vashon recessional outwash, is present in a large part of the study area (plate 2). However, Qvr is noticeably absent beneath the Snoqualmie Valley floor. A typical thickness of the unit is 60 ft, but as shown on the geohydrologic sections (plate 1), the unit can vary from a veneer overlying till to an accumulation greater than 300 ft. The altitude of the top of the unit varies from slightly less than 100 feet along the flanks of the Snoqualmie River Valley downstream from Snoqualmie Falls to 1,200 feet in the upper Snoqualmie River Valley. This coarse-grained unit can be a productive aquifer in places where relatively thick sequences of sand and gravel

Period	Epoch	Geohydrologic unit		Geohydrologic unit label	Typical thickness (feet)	Lithologic characteristics	Hydrologic characterisics
Quaternary	Holocene	Alluvium		Qal	100	Unit consists primarily of Snoqualmie River alluvium; sand and gravel upstream of Snoqualmie Falls; sand, silt, and clay downstream. Unit includes tributary stream, landslide, and alluvial fan deposits.	Highly productive unconfined aquifer upstream of Snoqualmie Falls. Unit becomes less permeable and apparently less productive downstream.
	Pleistocene	Vashon Drift of the Fraser Glaciation	Recessional outwash, ice-contact deposits, and ice-dammed lake deposits	Qvr	60	Moderately to well-sorted sand and gravel. Unit includes poorly sorted ice-contact deposits and fine-grained ice-dammed lake deposits.	An aquifer where saturated. Ground water is mostly unconfined. Perched conditions occur locally.
			Till	Qvt	70	Compact, unsorted sand, gravel, and boulders in a matrix of silt and clay. Some lenses of sand and gravel.	Confining bed, but can yield usable quantities of water.
			Advance outwash	Qva	200	Well-bedded gravelly sand to fine-grained sand.	Principal aquifer in terms of use. Ground water mostly confined.
		Upper fine-grained unit including transitional beds and minor till		Q(A)f	250	Laminated clayey silt to clay with minor lenses of sand, gravel, peat, and wood. Local occurrences of till at base of unit.	Confining bed, but can yield usable quantities of water.
		Upper coarse-grained unit consisting of intraglacial deposits		Q(A)c	140	Strongly oxidized sand and gravel.	Principal aquifer in terms of use. Ground water is confined.
		Lower fine-grained unit		Q(B)f	Unknown	Clay, silt, and till with some sand and gravel.	Confining bed, but can yield usable quantities of water. Tapped by few wells.
		Lower coarse-grained unit		Q(B)c	Unknown	Sand and gravel with minor clay and silt.	An aquifer where saturated. Ground water is probably confined. Tapped by few wells.
		Deepest unconsolidated and undifferentiated deposits		Q(C)	Unknown	Unconsolidated deposits of largely unknown lithology.	Unit encountered in few wells; tapped by none. Ground water, if available, is probably confined.
Tertiary	Eocene	Bedrock		Br	Unknown	Andesite with minor amounts of basalt and diorite, and some sandstone, siltstone, and conglomerate.	Locally an aquifer, but often unreliable. Water contained in fractures and joints. Well yields relatively small.

Figure 10.--Lithologic and hydrologic chracteristics of geohydrologic units in east King County.

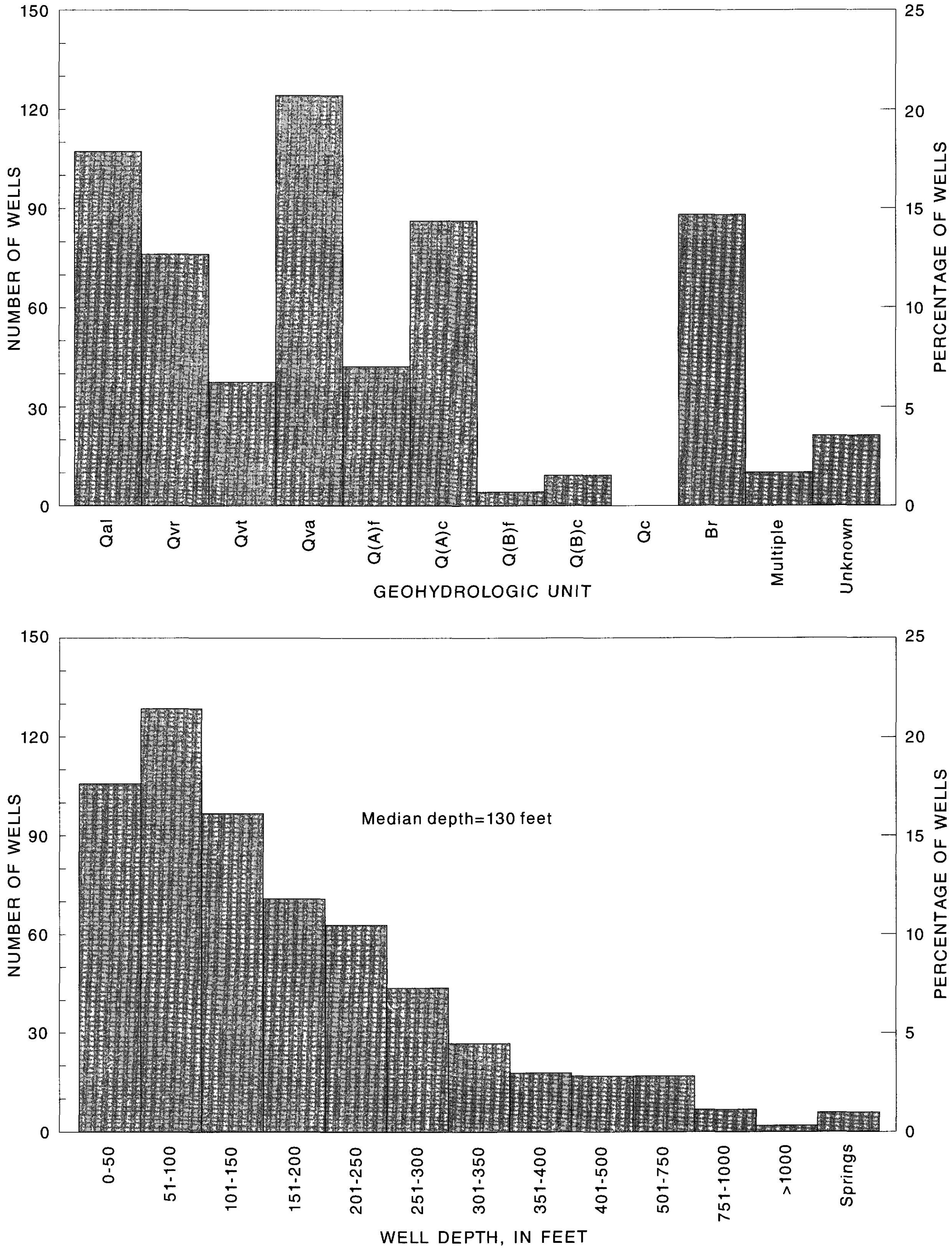


Figure 11.--Frequency distributions of geohydrologic units tapped and of well depths.

are saturated. In some areas east of the Snoqualmie River and along the edges of the Sammamish Plateau, however, little water is available from the unit because it is thin or lies above the water table. Most of the 76 inventoried wells that tap Qvr are either east of Fall City, northeast of Snoqualmie, or on the Sammamish Plateau where ground water within Qvr is under water-table (unconfined) conditions, and the wells produce moderate yields for domestic purposes (plate 2).

The Vashon till, Qvt, is broadly distributed throughout a large part of the study area, but it is thin or absent in some areas where thick deposits of Qvr are present (plate 2). This implies that the till was probably eroded within the fluvial environment during the deposition of the Qvr. Like Qvr, it is also absent beneath the Snoqualmie Valley floor. Although the unit can be as much as 200 feet thick, a more typical thickness is 70 ft. The altitude of the top of the unit ranges from 100 to 1,400 feet above sea level. Qvt generally produces low yields of water and is considered a confining bed. However, 37 inventoried wells tap thin layers of relatively clean sand and (or) gravel within the unit. In many places the upper part of the Vashon till is more permeable than the lower part. Therefore, the upper part can contain perched water bodies that will yield usable short-term quantities of water to shallow wells (Liesch and others, 1963). Because Qvt is typically dense and unsorted, well yields from it are variable.

The Vashon advance outwash, Qva, is present throughout much of the study area, mostly in the subsurface (plate 2). Like Qvr and Qvt, it too is absent beneath the Snoqualmie River Valley floor and its extent east of the valley cannot be readily defined at this time due to a lack of data. A typical thickness of the unit is 200 ft. The top of the unit varies from slightly below sea level (plate 2) to 900 ft. Qva is tapped by 124 of the inventoried wells and is one of the major aquifers of east King County. Ground water in this aquifer is usually confined by the overlying Qvt and the underlying Q(A)f.

The upper fine-grained unit, Q(A)f, consists primarily of all of the transitional beds (Qtb) and local occurrences of pre-Fraser till from Qpf. It is present at depth throughout nearly all of the study area (plate 2). It is the youngest continuous unit beneath the Qal of the Snoqualmie River Valley. The top of the unit ranges from 100 feet below to 800 feet above sea level. Q(A)f has a typical thickness of 250 feet but can be as thick as 550 ft; it is the thickest unconsolidated unit in the study area. Q(A)f is not made up completely of fine-grained materials; 42 inventoried wells tap local, thin lenses of sand or gravel that yield relatively small quantities of water suitable for domestic use. Q(A)f generally acts as a confining bed between the coarse-grained deposits above and below it. Because of this, Q(A)f retards the percolation of ground water into Q(A)c and causes vertical head gradients between Qva and Q(A)c in places.

The upper coarse-grained unit, Q(A)c, consists of interglacial sand and gravel from Qpf and is extensive throughout the study area (plate 2). The average thickness of the unit is approximately 140 feet (plate 1). The top of the unit varies from 300 feet below to 700 feet above sea level in the north-central part of the study area (plate 2). This unit may be present at even higher altitudes in the easternmost part of the study area where small exposures of pre-Fraser deposits have been mapped. Because of the lack of wells in that area, however, the hydrologic characteristics of the deposits are unknown and including them with Q(A)c is not warranted. Q(A)c is a major aquifer in the study area. Eighty-six inventoried wells tap this mostly confined unit.

The three deepest unconsolidated units in the study area are the lower fine-grained unit Q(B)f, the lower coarse-grained unit Q(B)c, and the deepest unconsolidated and undifferentiated deposits Q(C), all from geologic unit Qpf. Estimated thicknesses and depths of these units, where they are known to exist, are shown on the geohydrologic sections (plate 1). On the basis of the few available drilling records, Q(B)f is a mostly fine-grained confining bed. There is little information about the productivity and extent of Q(B)c and Q(C). Four inventoried wells are completed in Q(B)f and nine are completed in Q(B)c. No inventoried wells are completed in Q(C).

The consolidated Tertiary and pre-Tertiary rocks that constitute the bedrock, Br, contain small quantities of water in fractures and joints that are probably more numerous near the top of the unit. In general, however, the bedrock is an unreliable source of ground water, and many wells drilled into that unit yield insufficient or poor-quality water. Most of the 88 inventoried wells that tap bedrock are located in the southwestern and northeastern parts of the study area, and the wells supply water for domestic use. In these areas, bedrock is either exposed at land surface or is covered by a thin, unproductive layer of unconsolidated deposits. Because bedrock is the only source of water in these areas, water supplies in these areas are often tenuous at best. In some areas northeast of Duvall, for example, wells in bedrock typically go dry in summer. Where the bedrock is exposed at land surface, the ground water is likely under water-table conditions; where the bedrock is covered by a significant thickness of unconsolidated deposits, especially clays and silts, the ground water is likely to be confined.

Hydraulic Conductivity

Estimates of the horizontal hydraulic conductivity of the geohydrologic units were used to help understand the availability and movement of ground water. Hydraulic conductivity is a measure of a geohydrologic unit's ability to transmit water. It is defined as the volume of water that will move in unit time through a unit cross-sectional area under a unit hydraulic gradient. For unconsolidated materials, hydraulic conductivity depends on the size, shape, and arrangement of the particles. Because these physical characteristics vary greatly within the glacial deposits of the study area, hydraulic conductivity values are also highly variable. Hydraulic conductivity data were statistically summarized so that differences between aquifers could be determined. A summary by geohydrologic unit is presented in table 1. Individual values of hydraulic conductivity can be found in Appendix A.

The median hydraulic conductivities are reasonable for all units except Qvt. The median hydraulic conductivities for the coarser grained units, Qal, Qvr, Qva, Q(A)c, and Q(B)c range from 34 to 130 ft/day and are the larger values observed (table 1). The median hydraulic conductivity of 130 ft/day for Qal is the largest of any unit. The median hydraulic conductivity of 51 ft/day for Qvt is somewhat anomalous because Qvt is relatively fine grained, and its hydraulic conductivity is larger than those determined for the coarse-grained Qva and Q(A)c. The median hydraulic conductivities for Q(A)f and Q(B)f are 9 ft/day and 15 ft/day, respectively, and are consistent with the fine-grained deposits present in those units. However, the median hydraulic conductivity for Q(B)f is based on only two samples. The lowest median hydraulic conductivity (0.88 ft/day) was for the Br unit. Because ground water in bedrock is present primarily in the fractures, a low median hydraulic conductivity suggests that the Br unit generally is not fractured enough to produce large quantities of water. This low hydraulic conductivity is the primary reason the bedrock is generally a poor source of water.

Table 1.--Summary of hydraulic conductivity values, by geohydrologic unit
[--, not determined]

		Hydraulic conductivity (feet per day)				
Geohydrologic unit	Number of wells	Minimum	25th percentile	Median	75th percentile	Maximum
Qal	59	0.64	37	130	310	1,800
Qvr	39	.43	18	61	200	670
Qvt	24	.04	19	51	120	1,900
Qva	94	.13	14	35	150	6,100
Q(A)f	24	.03	2.3	9.0	22	37
Q(A)c	51	.38	18	37	78	1,700
Q(B)f	2	6.0	--	15	--	24
Q(B)c	6	1.4	8.6	34	97	1,100
Total	299	.03	14	39	150	6,100
Br[1]	53	.00	.12	.88	8.1	430

[1] Hydraulic conductivities for Br were not included in the totals because the Br unit is lithologically quite different from the other units. The Br unit consists of consolidated material and all of the other units consist of unconsolidated material.

The relatively large median hydraulic conductivity of Qvt is likely a reflection of the presence of more permeable zones, as described in the Principal Geohydrologic Units section. It is likely that most wells in this unit have been completed in sand and gravel lenses or in the upper part of the unit. Wells completed in the less-permeable zones either have been abandoned or may not have produced enough water for a pump test to be practical. As a result, the data are biased toward the more productive zones in the unit and are not representative of Qvt as a whole. This bias is unavoidable when relying upon production well data; the bias probably exists for all of the units to various degrees, depending upon the heterogeneity of the unit. As a result, all of the median hydraulic conductivity values may be biased high. Because Qvt is probably the most heterogeneous of the units, the bias for it is probably the largest. The minimum hydraulic conductivities for the geohydrologic units illustrate that there are 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 amount of heterogeneity.

No data were available to estimate the vertical hydraulic conductivity of aquifers or of confining layers between aquifers. Estimates made as part of other studies indicate that in glacial materials vertical hydraulic conductivity is commonly several orders of magnitude less than horizontal hydraulic conductivity.

Conceptual Model of the Ground-Water System

A generalized conceptual model of the ground-water system beneath east King County is shown in figure 12. Four coarse-grained major aquifers (Qal, Qvr, Qva, and Q(A)c) and two fine-grained confining layers (Qvt and Q(A)f) were identified. Beneath this assemblage and above the relatively impermeable bedrock are the older unconsolidated deposits (Q(B)f, Q(B)c, and Q(c)) that could contain significant quantities of water, but for which little data exist. The bedrock (Br) is not considered a principal source of water because it has relatively poor yields, as discussed previously. The resulting ground-water flow system described for east King County is local to intermediate in scale and is controlled mostly by the relief between the upland foothills of the Cascade Range and the Snoqualmie River Valley.

Part of the precipitation that falls on and around the study area recharges the ground-water system. Ground water in upland areas (such as the Sammamish Plateau and Cascade Range foothills) moves vertically downward and laterally to discharge points (such as Lake Sammamish and the Snoqualmie River). The general directions of ground-water movement in the system are indicated with arrows on figure 12. The amount of time required for an individual molecule of water to travel through the system is roughly proportional to the length of the arrow. Water molecules along a relatively short travel path from recharge point to discharge point may be in the ground-water system for only a few months; molecules along relatively long flow paths may be in the system for years or centuries. Also, water may be withdrawn from any point in the system, creating an artificial discharge point.

Flow into and out of the study area can be qualitatively assessed by evaluating the ground-water conditions along the study boundaries. Ground water flows out of the study area along the northern boundary. Along the eastern boundary, including the Snoqualmie River upstream of North Bend, ground water flows into the study area. Except for the western boundary along Lake Sammamish, all of the southwestern and western boundaries are along surface-water drainage divides; shallow ground water likely flows neither into nor out of the study area along the divides. However, along the Lake Sammamish boundary, ground water flows out of the study area to the west and in some areas deeper ground-water flow may be to the west also.

More-detailed descriptions of the recharge, movement, and discharge of water in the ground-water system of east King County are presented in the following sections of the report.

Recharge

The bulk of the recharge to the ground-water system of the study area comes from precipitation. Recharge is present everywhere, with the possible exceptions of (1) areas of ground-water discharge, such as along the Snoqualmie River, and (2) those areas covered by impermeable, man-made materials such as asphalt and concrete. Impermeable materials at land surface may only delay and redistribute the recharge water; precipitation that runs off of impermeable surfaces may seep into the ground as soon as it encounters natural permeable materials. Where runoff from impermeable surfaces is channeled into sewer systems, recharge is lessened. However, the total area covered with impermeable material is negligible in east King County. The quantity of recharge in the study area is probably largest from October to March, when precipitation is greatest.

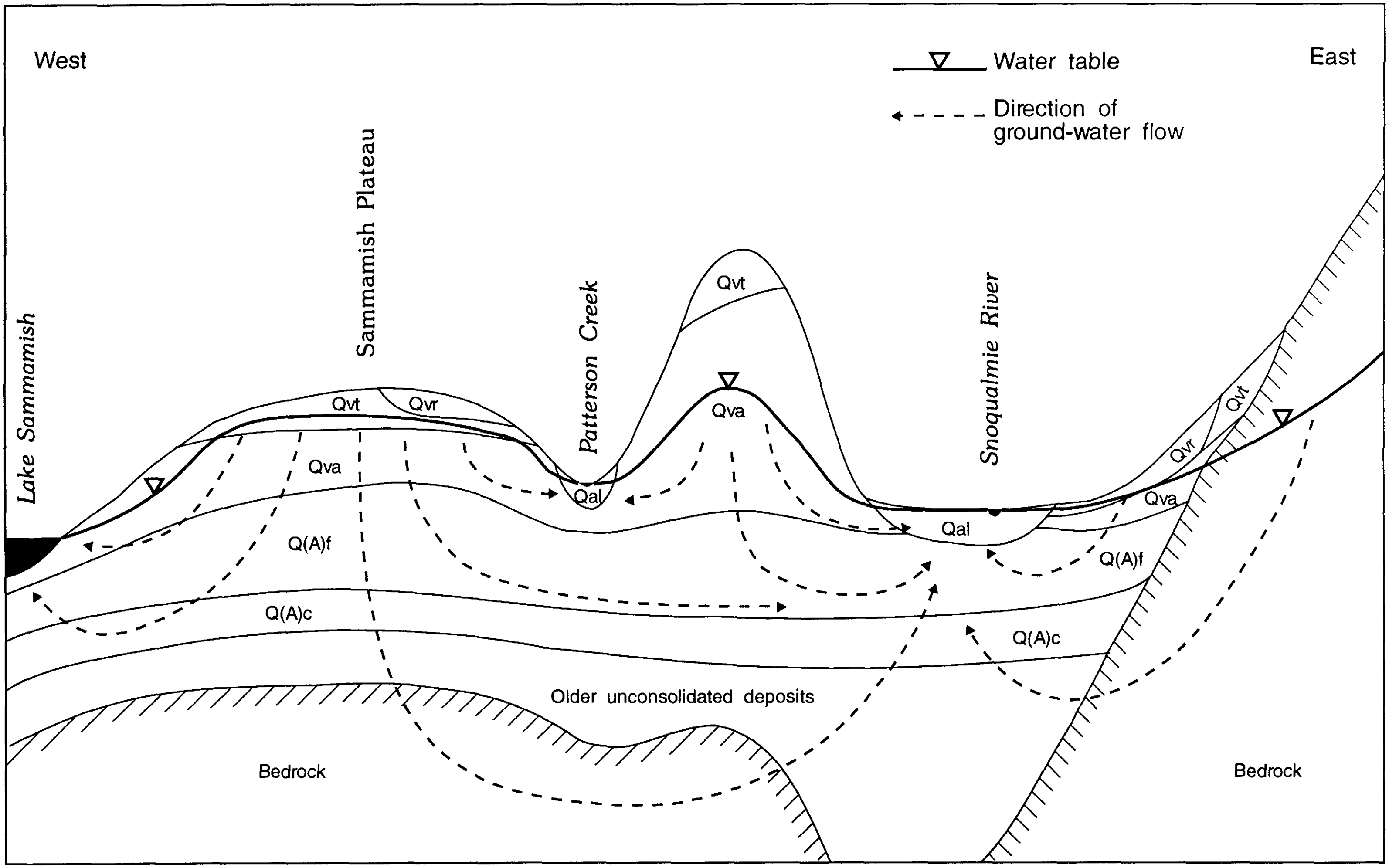


Figure 12.--Conceptual model of the ground-water system in east King County. (See Figure 10 for a description of the geohydrologic units.)

The quantity of recharge to the ground-water system of east King County was estimated using precipitation/recharge relations derived from a study of southwest King County (Woodward and others, in press). These relations are based on the application of a deep-percolation recharge model developed by Bauer and Vaccaro (1987). Regression equations determined from the southwest King County data showed that precipitation and surficial geology were the most significant independent variables in determining recharge. For the two predominant types of surficial geology in east King County, outwash (Qvr and Qva) and till (Qvt), curves were drawn relating precipitation to recharge based on the data from southwest King County (fig. 13). These curves were applied to east King County because the geohydrologic units, climate, and vegetation in both areas are similar.

Given the derivation of the curves in figure 13, some observations and assumptions needed to be made regarding their use. First, the percentage of precipitation becoming recharge increases with increasing precipitation. This is likely due to evapotranspiration, which decreases proportionally with increasing precipitation because of increased cloud cover. Second, data from southwest King County included only annual precipitation up to approximately 60 in., whereas some areas of east King County

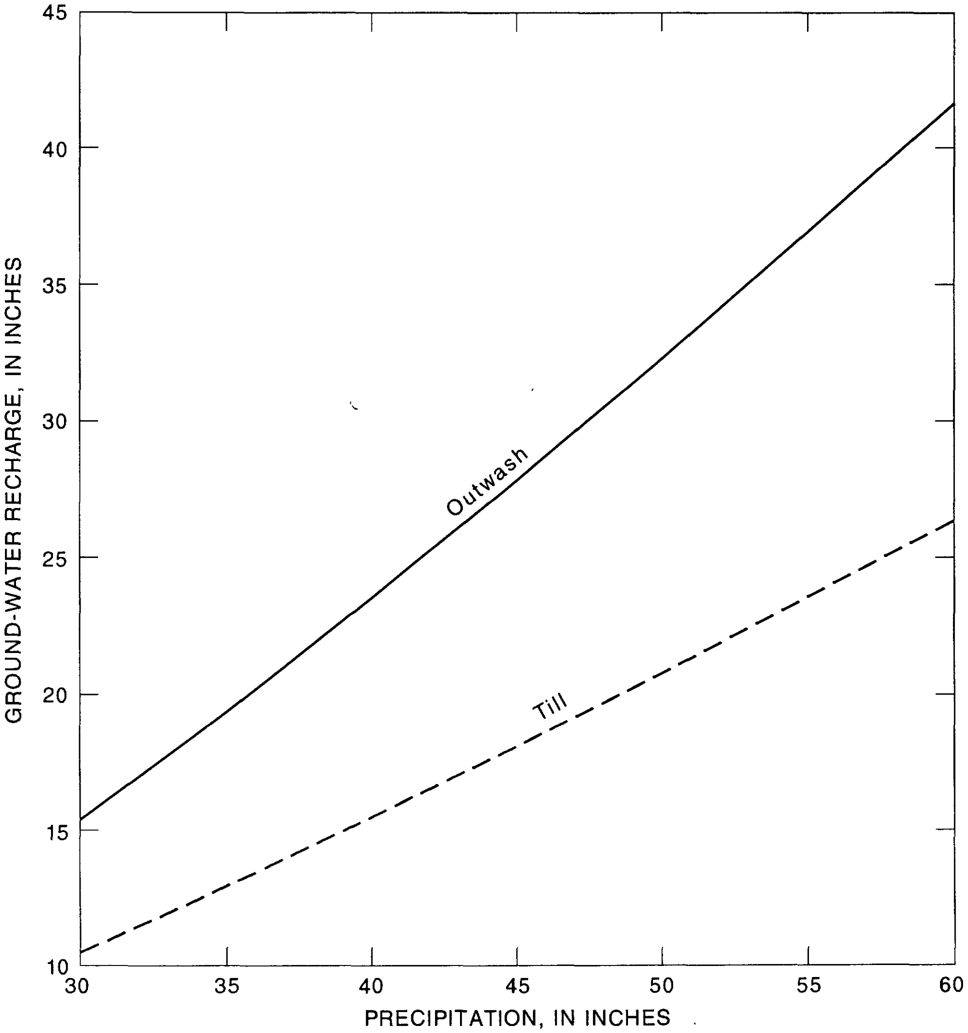


Figure 13.--Precipitation-recharge relations used in the estimation of recharge in east King County.

receive almost 100 in. To estimate recharge for areas receiving between 60 and 100 in. of annual precipitation, the percentage of precipitation that goes to recharge at 60 in. was assumed to be constant above 60 in. Therefore, for precipitation values greater than 60 in., recharge was calculated as 69 percent of precipitation for outwash, and 44 percent of precipitation for till. Because, as noted above, the effects of evapotranspiration decrease with increased precipitation, this was considered a somewhat conservative approach. Also, at 100 in. of precipitation, evapotranspiration is estimated to be 20 to 25 in. based on published values for the area (U.S. Department of Agriculture, 1973), leaving 75 to 80 in. for recharge and runoff. Because the calculated recharge for outwash is 69 in. for 100 in. of precipitation, one must assume in this method that there is negligible runoff on outwash in the higher precipitation areas. Outwash is generally quite permeable, and these high-precipitation areas tend to be densely vegetated, both of which are factors that contribute to the land's ability to absorb precipitation as recharge, so runoff is indeed likely to be minimal. Finally, because data existed only for outwash and till, estimates needed to be made for other surficially exposed geohydrologic units. The alluvium (Qal) was assumed to have lithologic and hydrologic characteristics similar to the outwash, so the outwash curve was used for Qal as well. Similarly, recharge into bedrock (Br) was estimated with the till curve, because exposed bedrock in the study area usually is weathered and is assumed to be less permeable than outwash and approximately equivalent to till. Units other than alluvium, till, outwash, and bedrock are not surficially exposed over a large enough area in east King County to affect the recharge estimates. These other units are the bog deposits (Qb), which were aggregated into whichever unit surrounded a given Qb exposure, and the transition beds (Qtb) and pre-Fraser deposits (Qpf), for which the till curve was used.

To determine the distribution of recharge, a detailed contour map of long-term precipitation rates was overlaid on the map of the surficial geologic units (plate 1). Geographic information system techniques were used to combine like units and calculate recharge based on the relations shown in figure 13. The resulting map (plate 3) shows higher recharge rates in the eastern and southeastern parts of the study area, where precipitation is highest. There are large areas where recharge is 20 to 30 in/yr because of the aggregation of high-precipitation areas on till with lower-precipitation areas on outwash or alluvium. As a whole, the ground-water system of the study area (GWMA only) receives 413,000 acre-ft, or about 31 in., of recharge in a typical year, based on an area-weighted average of the recharge polygons on plate 3. This figure must be considered in light of the assumptions made, and may contain some degree of unquantifiable error.

No attempt was made to determine the fate of the recharge water in quantitative terms once it becomes part of the ground-water system. Some of the recharge may immediately discharge to nearby streams, while some may enter the deeper regional flow system and not be discharged for many years. Such determinations would require a three-dimensional ground-water flow model.

Movement

After the geohydrologic units were delineated and wells were assigned to one or more of the units, water-level maps were made for the major aquifers. These maps were used to describe and interpret the horizontal and vertical components of the ground-water flow system.

Water-level maps were drawn for Qal, Qvr, Qva, and Q(A)c, the four major aquifers of east King County for which adequate data are available. For the purposes of showing ground-water flow, Qal and Qvr were combined on one map because these two units are primarily surficial units and they have common boundaries. Lateral flow directions of ground water within all of the aquifers are shown with arrows on plate 3. Flow is from areas of higher to lower hydraulic head, and is generally perpendicular to the contours of equal head. Because the units are heterogeneous and complex, the mapped heads are considered regional in nature; local conditions may vary. Flow directions are also subject to the same conditions.

Ground water in the combined Qal-Qvr unit generally moves toward the Snoqualmie River, then northward along the Snoqualmie River Valley (plate 3). The gradient is nearly flat in the lower valley; in some places it is 5 ft/mi or less. In the upper valley, the gradient is somewhat steeper: at least 10 ft/mi. In contrast, in the vicinity of Snoqualmie Falls, local gradients may exceed an estimated 1,000 ft/mi over short distances. Flow from the uplands to the valley is significant in areas north and east of Carnation and north of Snoqualmie. Driven by local topography, the gradient in these areas is relatively steep. Flow within this unit on the Sammamish Plateau is not well defined because of a lack of data points and because much of the unit is completely unsaturated there. Similarly, a lack of data points in the Cascade Range foothills and in the Cherry Creek Valley precludes any contouring in these areas.

Ground-water flow in Qva is discontinuous because the unit is divided by Qal of the Snoqualmie River Valley (plate 3). Flow follows the general surface topography into the Snoqualmie River Valley. Ground water also flows toward Patterson Creek from the eastern Sammamish Plateau and Ames Lake areas. Flow from the western Sammamish Plateau is toward Lake Sammamish. The flatter gradients are less than 100 ft/mi in areas such as the Sammamish Plateau and southeast of Duvall. Steeper gradients in excess of 500 ft/mi are present along the slopes to the Snoqualmie River Valley and near Patterson Creek.

In Q(A)c, ground-water flow is also generally to the Snoqualmie River Valley, then northward down the valley (plate 3). There is a ground-water divide in the Sammamish Plateau, with ground water in the western part flowing to Lake Sammamish and ground water in the eastern part flowing ultimately toward the Snoqualmie River. Gradients are generally more gradual in this unit; some of the steeper gradients (200 to 300 ft/mi) are found between Snoqualmie Falls and Fall City. Gradients in the river valley and east of the Sammamish Plateau are less than 50 ft/mi in some places.

Vertical flow directions are difficult to ascertain because (1) the Qal-Qvr and Qva are discontinuous, and (2) in some areas the heads are similar from one unit to the next. In general, vertical flow is downward in upland areas. This is apparently the case in the Sammamish Plateau, where heads in Qva are generally larger than those in the underlying Q(A)c. Water-level altitudes in a set of five piezometers on the plateau decreased with piezometer depth, also indicating downward flow. The data are for wells 24N/06E-09A11 through 09A15, and are listed in table 2. The best evidence for upward vertical flow is in about 30 flowing wells located in lowlands and along valley floors near the base of uplands. Several such flowing wells are listed in Appendix A. The water-level altitude maps also show that heads in the lower Snoqualmie River Valley are less than 100 feet above sea level in Q(A)c, and heads in the overlying Qal-Qvr are less than 60 feet in some places. Although this difference does not confirm upward flow in the entire valley, it suggests that the upward flow is likely; the difference is also consistent with the existence of the flowing wells along the valley floors.

The presence of downward vertical flows indicates that some water may be moving into the deeper regional geohydrologic system, possibly even the bedrock. Although this water would probably tend to flow north and west also, it would flow within the deeper geohydrologic units not mapped, such as Q(B)c, Qc, and possibly Br. The ground water in these units could easily flow beneath surface waters such as Lake Sammamish and the Snoqualmie River, and ultimately flow to surface-water bodies well outside the study area.

Discharge

Ground water in east King County discharges as seepage to lakes and streams, spring flow, transpiration by plants, seepage to valley walls, ground-water flow out of the study area, and withdrawals from wells. Only a small

Table 2.--Water-level altitudes in five wells on the Sammamish Plateau, east King County

Local well number	Geohydrologic unit	Depth of well (in feet below land surface)	Water level (in feet below land surface)	Water-level altitude (in feet above sea level)
24N/06E-09A12	Qva	125	72.81	328.89
24N/06E-09A15	Qva	170	85.34	316.17
24N/06E-09A14	Qva	203	86.16	315.53
24N/06E-09A13	Q(A)f	231	87.96	313.91
24N/06E-09A11	Q(B)f	424	158.77	242.91

[1] Water levels were measured on July 6, 1990, except for 24N/06E-09A15, which was measured July 9, 1990. Any difference due to temporal changes apparently does not affect the relative water altitudes because in almost 10 years of monthly record, the relative water altitudes were always in the order shown.

part of discharge was quantified during this study: specifically, the quantity of water discharged to streams and springs and the quantity withdrawn from wells.

Ground water discharges to certain reaches of some of the rivers and streams and augments streamflow to produce what is usually referred to as a gaining reach. Ground-water discharge also sustains the late summer flow of numerous streams in the study area, especially those not fed by glacial meltwater. Conversely, some river reaches may discharge water to the ground-water system to produce a losing reach. The results of a seepage study conducted in September 1991 showed that the Snoqualmie River system generally gains ground water within the study area (table 3, fig. 14). The Snoqualmie River itself appeared to gain water along its entire length except for the reach from Carnation to Monroe. The two largest tributaries, the Raging River and Tolt River, lose water to the ground-water system. The total net discharge of ground water to the river system was 133 ft^3/sec. An estimated 3.3 ft^3/sec discharges from the Sammamish Plateau to Lake Sammamish. The total ground-water discharge to surface water bodies within the study area is therefore an estimated 136 ft^3/sec or 98,500 acre-ft/yr. This should be considered a minimum value, however, because these discharges were determined during the dry summer period of low river flow. During wetter periods, larger quantities of ground water likely flow to the river because regional water levels are usually higher, increasing water-level gradients. Also, interflow, which is water that enters the shallow water table and seeps directly and quickly to adjacent streams, can be large during wetter periods. Finally, many small streams were not measured, but they may collectively receive a significant quantity of ground-water discharge.

The principal known springs in east King County are listed in table 4; there are, in addition, probably hundreds of smaller springs scattered throughout the study area. The City of North Bend spring (24N/08E-35N01S) has by far the largest discharge of any spring in the study area, averaging 9.0 ft^3/s. The total spring discharge accounted for in this study is about 13.2 ft^3/sec, or 9,540 acre-ft/yr, but this quantity is probably low because of unaccounted springs. As noted in table 4, three of the major springs were not inventoried, and as such are not listed in Appendix A. The three springs are not shown on USGS maps and their size was not apparent until the water-use figures were compiled, after the inventory was completed.

Ground-water withdrawals from wells in the study area (GWMA only) in 1990 were an estimated 4,270 acre-ft of water. This quantity represents gross withdrawals and does not reflect the quantity of water returned to the ground-water system through septic tanks or excessive irrigation. The withdrawals from wells are categorized by water-use category in detail in the next section of this report.

The quantity of ground water that discharges through plant transpiration, as seepage to valley walls, or as ground-water flow out of the study area, is unknown at this time, but probably constitutes the bulk of the discharge from the ground-water system. The combined quantity was estimated, however, in a preliminary water-budget analysis that is addressed in greater detail in a later section of this report.

Table 3.--Summary of seepage run data collected in September 1991
[--, not determined]

Surface-water body	Discharge (cubic feet per second) at site	 total upstream	 gain (loss)
Boxley Creek near mouth	34.3	--	--
South Fork Snoqualmie River at Edgewick Road	66.3	--	--
South Fork Snoqualmie River at North Bend	132	101	31
Middle Fork Snoqualmie River near mouth	210	--	--
North Fork Snoqualmie River near mouth	104	--	--
Snoqualmie River below Snoqualmie Falls	534	446	88
Tokul Creek at mouth	27.6	--	--
Raging River (upstream)	14.9	--	--
Raging River at mouth	11.8	14.9	(3.1)
Snoqualmie River at Fall City	581	573	8
Patterson Creek near mouth	9.8	--	--
Tolt River (upstream - below South Fork/North Fork confluence)	136	--	--
Tolt River near mouth	114	136	(22)
Snoqualmie River at Carnation	798	705	93
Snoqualmie River near Monroe	736	798	(62)
Total gain on the Snoqualmie River system from North Bend to Monroe			133
Issaquah Creek near mouth	27.2	--	--
Pine Lake drainage near mouth	.15	--	--
Sammamish River at Lake Sammamish outlet	35.6	27.4	8.2
Gain to Lake Sammamish corrected for percentage of shoreline that drains the study area (approximately 40 percent)			3.3

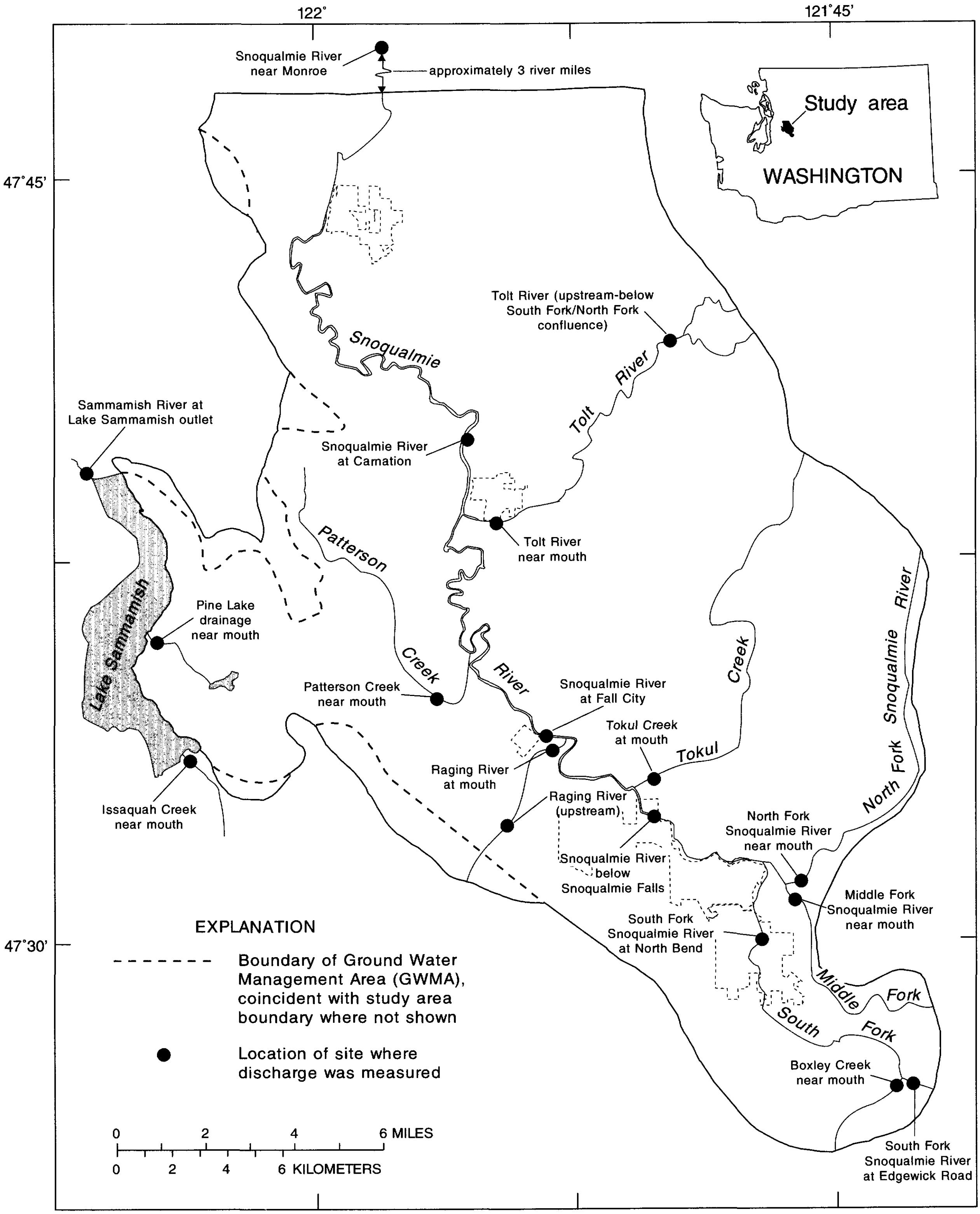


Figure 14.--Locations of stream sites where discharge was measured to determine ground-water seepage.

Table 4.--Principal springs in east King County
[P, public supply; Q, aquaculture (fish farms); I, irrigation; U, unused; --, not determined]

Local number	Owner	Land surface elevation (feet)	Use	Discharge (cubic feet per second)
24N/07E-11L01S	Fall City	330	U	--
24N/08E-18G__S[1]	Tokul Creek Community	--	P	0.25
24N/08E-19D__S[1]	Tokul Fish Hatchery	--	Q	.89
24N/08E-24Q01S	City of Snoqualmie	680	P	1.9
24N/08E-35N01S	City of North Bend	425	P,Q	9.0
25N/07E-21L__S[1]	Private owner	--	I	.36
25N/07E-23E01S	Unknown	290	U	--
25N/07E-23Q01S	City of Carnation	450	P	.78
25N/07E-26F01S	Private owner	380	I	--

[1] These springs were not inventoried and are not listed in Appendix A; locations are approximate.

Ground-Water Withdrawals

A summary of ground-water withdrawals from the study area (GWMA only) in 1990, compiled by water-use category, source (well or spring), and physiographic sub-area, is presented in table 5. As shown, approximately 4,270 acre-ft of water was withdrawn from wells. Another 5,290 acre-ft of the water that discharges naturally through springs was put to beneficial use, for a total use of 9,560 acre-ft. The use of spring water is not a true withdrawal of the ground-water resource because the spring would discharge anyway, regardless of the use. Nevertheless, water drawn from springs is discussed because it does represent a significant use of ground water. About 4,460 acre-ft (47 percent) of the total quantity was used for public supply, and another 3,010 acre-ft (31 percent) was used for aquaculture.

Of the estimated 56,500 people that resided in the study area in 1990, 48,100 (85 percent) obtained household water from Class I or Class II public supply systems. A total of 2,490 acre-ft of water was withdrawn from wells, and 1,970 acre-ft was drawn from springs to furnish these Class I and II public supply systems. The relatively large percentage (44 percent) drawn from springs reflects the fact that the Cities of North Bend, Snoqualmie, and Carnation use springs emanating from the Cascade Range foothills as their primary water supplies. More than 98 percent, or 1,110 acre-ft, of the total ground-water withdrawals in the Sammamish Plateau went to public supply systems, reflecting the suburban nature of that sub-area. Another 2,280 acre-ft, not shown in table 5, was imported for public supply systems from water systems outside the study area. For example, the City of Duvall imports its entire water supply from the City of Seattle system. Although most of the water withdrawn for public supply is used for individual households, undetermined quantities are used for commercial, institutional, industrial, or municipal purposes and for some dairies. Also, a significant quantity of water can be lost through leakage from distribution systems. There is a marked seasonal variation in the demand for, and therefore withdrawal of, water for public supply purposes. The greatest demand is in summer, when temperatures are high, precipitation is at a minimum, and ground-water levels are relatively low.

The remaining 15 percent of the population (8,400 people) relied on either privately owned wells or Class IV systems that supply nine or fewer households. An estimated 1,040 acre-ft of ground water was withdrawn from wells for domestic purposes. Most domestic withdrawals (958 acre-ft) were from the lower Snoqualmie Valley sub-area.

Irrigation water use totalled an estimated 679 acre-ft in 1990. Because not all irrigators could be contacted, this is probably a minimum value. About 529 acre-ft was used for irrigation of crops on truck farms, tree farms, nurseries, and pastures, all in the lower Snoqualmie Valley. About half of the crop irrigation water was drawn from springs.

Table 5.--Summary of ground-water withdrawals in 1990 by water-use category, source, and sub-area. Data are for the Ground-Water Management Area (250 mi^2), not the entire study area (259 mi^2)
[nr, no withdrawals reported]

Water use category	Withdrawals (acre-feet per year) Sub-area: Sammamish Plateau	Upper Snoqualmie Valley	Lower Snoqualmie Valley	Total
Public supply				
Wells	1,110	745	635	2,490
Springs	nr	1,540	433	1,970
Domestic				
Wells	16	63	958	1,040
Springs	nr	nr	nr	nr
Crop irrigation				
Wells	nr	nr	267	267
Springs	nr	nr	262	262
Non-crop irrigation				
Wells	4.5	86	48	138
Springs	nr	nr	12	12
Dairy livestock				
Wells	nr	nr	243	243
Springs	nr	nr	31	31
Other livestock				
Wells	nr	.3	8.1	8
Springs	nr	nr	4.0	4
Aquaculture				
Wells	nr	nr	nr	nr
Springs	nr	2,350	659	3,010
Industrial				
Wells	nr	82	1.3	83
Springs	nr	nr	nr	nr
Subtotal				
Wells	1,130	976	2,160	4,270
Springs	nr	3,890	1,400	5,290
Total	1,130	4,870	3,560	9,560

The remaining irrigation withdrawals, 150 acre-ft, were used for non-crop purposes, such as watering golf courses and school grounds. The quantity of water used to water residential lawns was accounted for in the domestic water category.

Most of the water withdrawn for livestock usage went to dairies, all located in the lower Snoqualmie Valley. About 274 acre-ft of water was withdrawn for these dairies, almost all from wells. A few dairies are in the upper Snoqualmie Valley, but their water comes from public supplies. The quantity of water withdrawn for other livestock is negligible.

Of the 3,010 acre-ft of water used for aquaculture, or fish hatcheries, 2,350 acre-ft was used by a single hatchery in the upper Snoqualmie Valley. The source of the water is the City of North Bend spring (24N/08E-35N01S) and the water is taken from the excess not used by the city. The remaining 659 acre-ft was used in the lower Snoqualmie Valley, and of this, 645 acre-ft was used by a State fish hatchery near Tokul Creek. All of the aquaculture water is from springs and, as mentioned previously, does not constitute a real withdrawal from the ground-water system. In addition, the use of spring water for fish propagation is nonconsumptive, although the quality of the water is probably altered slightly as a result.

One industrial operation, a sand and gravel quarry located about a mile east of Snoqualmie Falls, accounted for the 82 acre-ft of ground water used for industrial purposes in the upper Snoqualmie Valley. This use also represents almost all of the industrial withdrawals in the study area. However, as mentioned previously, ground water is provided to some minor industrial concerns by public supply systems.

The documentation of long-term trends in ground-water withdrawal is difficult because of a lack of readily available data. One can assume, however, that withdrawals have increased over time, at least with respect to public and domestic water supplies, because of the relatively steady growth in population in the study area (see fig. 4).

Water Budget of the Study Area

On a long-term basis, a hydrologic system is usually in a state of dynamic equilibrium; that is, inflow to the system is equal to outflow from the system and there is little or no change in the quantity of water stored within the system. An approximate water budget, or distribution of precipitation, for an average year in the study area (GWMA only) is presented in table 6. The total recharge to the system (31 in.) is from the recharge calculations described earlier. The value for evapotranspiration (23 in.) was calculated by averaging values reported for selected sites in and around the study area (U.S. Department of Agriculture, 1973). The value for runoff (3 in.) is a residual; that is, it represents the quantity that remains after recharge (31 in.) and evapotranspiration (23 in.) are subtracted from precipitation (57 in.). Similarly, the value of 22.6 in. for ground-water flow out of the study area also is a residual; it represents the remainder when the quantities known to be withdrawn by wells (0.3 in.), discharged to springs (0.7 in.), and discharged to rivers and lakes (7.4 in.), are subtracted from recharge (31 in.).

The water budget in table 6 indicates that more than half of the precipitation (54 percent) falling on the study area becomes ground-water recharge. Of this recharge, only 1 percent is withdrawn from wells for use. The spring discharge represents another 2 percent of recharge, but only about half of this (5,290 acre-ft of 9,540 acre-ft, or 55 percent; see table 5) is put to beneficial use. The ground water used from the study area is, therefore, a small quantity of the total water present in the system.

It would seem, then, that additional ground water may be withdrawn with little effect on the system. Certainly the water budget shows that 300,700 acre-ft, or 73 percent of the total recharge, simply flows as ground water north and west out of the study area and part could be available for additional withdrawal. This may not be the case, however.

First, less than 300,700 acre-ft/yr is present as ground-water flow, because this quantity includes unaccounted discharge to springs, rivers, and lakes, which may be significant. Second, any additional withdrawals from the ground-water system may reduce flows to other discharge points. As pointed out by Bredehoeft and others (1982), any additional withdrawal or discharge superimposed on a previously stable system must be balanced by an increase in recharge, a decrease in the discharge, a loss of storage within the aquifer (reflected by lower water levels), or by a combination of these factors. Considering the ground-water system of east King County in particular, the possibility of increased natural recharge on a long-term basis appears remote. In fact, the trend of increased residential development and construction of central storm sewers will most likely result in decreased recharge. Additional withdrawals, therefore, would result in a loss of storage (with an attendant decline in water levels) or a decrease in discharge to springs, rivers, or lakes, or a

Table 6.--*Water budget of the east King County study area*

Water budget component	Quantity		Percent
	Inches[1] per year	Acre-feet[1] per year	
Precipitation	57	760,000	100
Fate of precipitation			
Runoff	3	40,000	6
Evapotranspiration	23	307,000	40
Recharge	31	413,000	54
Total	57	760,000	100
Recharge	31	413,000	100
Fate of recharge			
Withdrawal from wells	.3	4,270	1
Discharge to springs[2]	.7	9,540	2
Discharge to rivers and lakes[2]	7.4	98,500	24
Ground-water flow out of study area[3]	22.6	300,700	73
Total	31	413,000	100

[1] Values are for the Ground Water Management Area (250 mi^2), not the entire study area (259 mi^2).

[2] These are likely minimum figures, due to unaccounted discharge to springs, rivers, and lakes.

[3] Also includes deep flow to the regional ground-water system and any unaccounted discharge to springs, rivers, or lakes.

decrease in ground-water flow out of the study area. Discharged water used either directly or indirectly for streamflow maintenance, fish propagation, waste dilution, or supply would decrease also. The magnitude of potential ground-water development, therefore, depends on the decrease in discharge that can be tolerated. Because it can take many years for a new equilibrium to become established, the effects of additional ground-water development may not be immediately apparent.

Bredehoeft and others (1982) also point out that the effects of additional development are independent of the magnitude of the original recharge and discharge and depend solely on how much of the original discharge can be diverted, or captured, without unwanted effects. Therefore, a water budget alone is of limited use in determining the magnitude of ground water available for development. Of much greater significance are the geometric boundaries and hydraulic properties of the aquifer system and the present uses of the discharged water that would be affected by pumping.

Water-Level Fluctuations and Trends

The configuration of the water table or potentiometric surface of an aquifer is determined by (1) the overall geometry of the ground-water system; (2) the hydraulic properties of the aquifer; and (3) the areal and temporal distribution of recharge and discharge. Where recharge exceeds discharge, the quantity of water stored will increase and water levels will rise; where discharge exceeds recharge, the quantity of water stored will decrease and water levels will fall.

As stated previously, most of the recharge in east King County is from the infiltration of precipitation during the months of October through March (fig. 3). Previous studies in western Washington have shown that, in years of typical precipitation, ground-water levels in shallow wells generally rise from October through March and fall from April through September. Water levels in deep wells generally respond more slowly, and usually with less change, than water levels in shallow wells. This happens because deeper wells are usually farther from the source of recharge, and any variability in recharge is dampened. Along rivers or lakes, water-level fluctuations also are influenced by river or lake level changes; these fluctuations due to these surface-water bodies are superimposed on the seasonal and long-term changes that are related to changing recharge-discharge relations.

Water-level fluctuations varied considerably throughout the study area but generally followed the patterns described above. Hydrographs of water levels in six selected observation wells are shown in figure 15 for the period May 1991 through December 1992. The water levels in well 23N/08E-03L03 probably exhibited the most month-to-month variability, but this well is in Qal less than a half mile from the Snoqualmie River, and the water levels closely reflect the discharge of the river (fig. 16). Likewise, the water levels in 24N/06E-04K01 reflect a

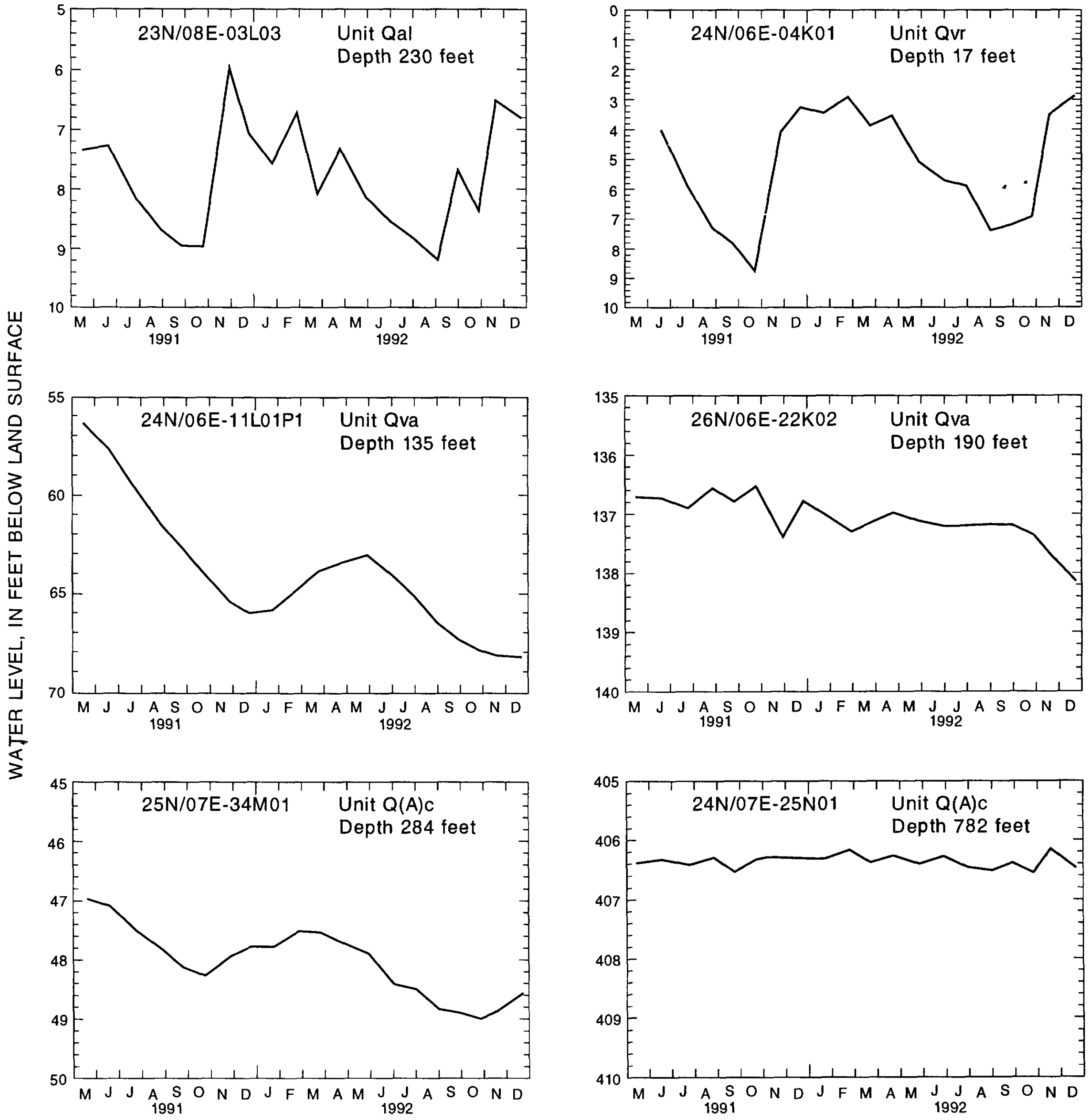
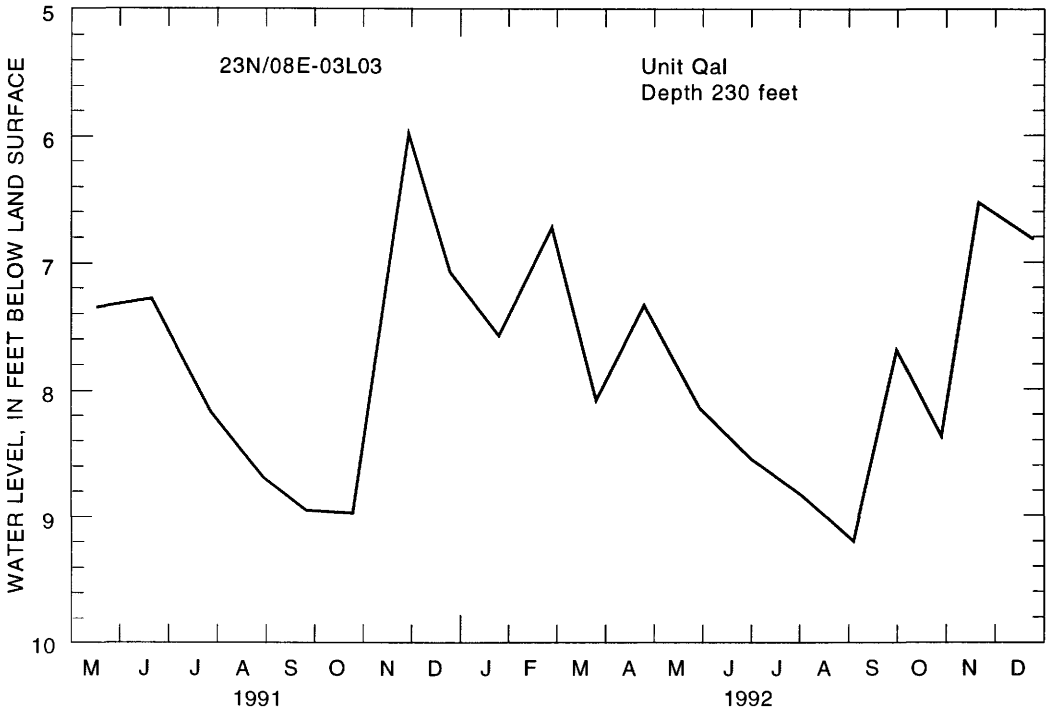


Figure 15.--Water levels in selected wells in east King County.



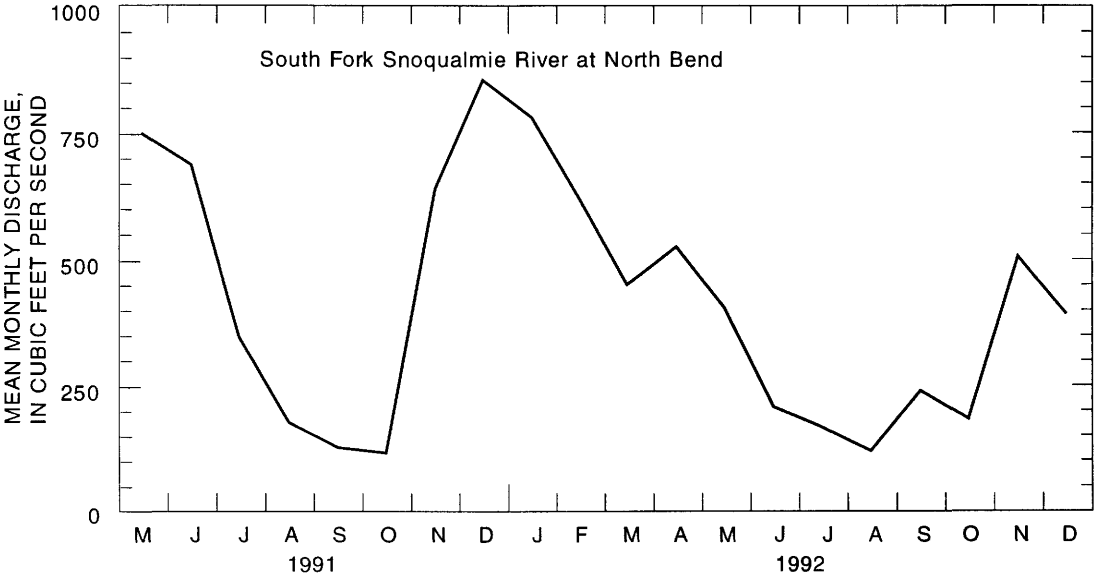


Figure 16.--Water levels in well 23N/08E-03L03 and mean monthly discharge of the South Fork Snoqualmie River at North Bend.

rapid response of the shallow ground water in the Qvr to variations in precipitation. When compared with figure 3, these water levels closely follow monthly precipitation. Hydrographs of water levels in wells 24N/06E-11L01P1 and 25N/07E-34M01 (fig. 15) are much smoother and the maximums and minimums take place several months after those for precipitation. This is typical of the response in deeper, confined systems. The total fluctuation in 24N/06E-11L01P1, which is in Qva, is more than 10 ft, and the total fluctuation in 25N/07E-34M01, which is in the lower Q(A)c, is only about 2 ft. Also, both hydrographs have a general downward trend, which is probably because annual precipitation in 1990 was 81 in., much larger than normal, and water levels were declining from the resulting higher-than-normal levels. This trend was common to several wells monitored throughout the study area. In contrast, the hydrographs of 26N/06E-22K02, in Qva, and 24N/07E-25N01, in Q(A)c (fig. 15), each exhibit about a foot of fluctuation, with no trend. The ground-water fluctuations observed in the course of this study are seasonal and are probably not typical of the long-term average conditions; rather, the fluctuations are a reflection of recharge-discharge relations over a relatively short period.

The detection of long-term trends in ground-water levels requires the plotting and analysis of water-level data for several years of record. These data are generally lacking for east King County. However, several wells on the Sammamish Plateau were monitored for water levels from 1979 to 1987 as part of a study of Pine Lake (Dion and others, 1983), and the wells were available for observation during this study. The water levels in one of the deep wells, 24N/06E-09A15, declined from 1982 to 1986 (fig. 17). Rainfall in 1982-84, 1986, 1988, and 1990 was above the long-term average, so the decline was not likely related to precipitation. Pumping may be a factor, as this well is located on the Sammamish Plateau where the population is rapidly increasing. In contrast, the shallow ground water in another well on the Sammamish Plateau, 24N/06E-04K01, showed little year-to-year variation (fig. 17).

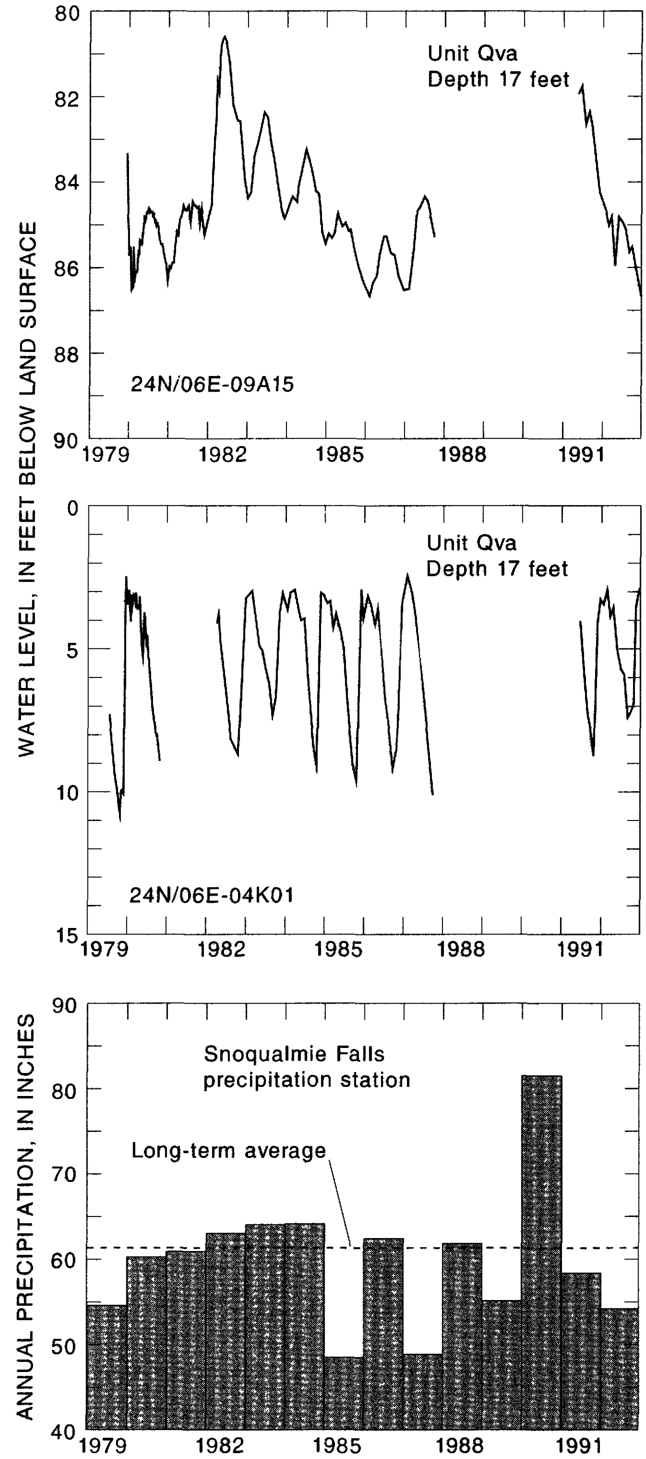


Figure 17.--Water levels in wells 24N/06E-09A15 and 24N/06E-04K01 and annual precipitation at Snoqualmie Falls.

GROUND-WATER QUALITY

In this section, the ground-water quality of the study area is described, based on the results of chemical analyses of water samples. Chemical concentrations and characteristics are discussed and related to geographic area and geohydrologic unit. Concentrations are compared with applicable U.S. Environmental Protection Agency (USEPA) drinking water regulations, and causes of widespread or common water-quality problems are identified.

Ground-Water Chemistry

Most of the data that describe the general chemistry of the ground water are presented statistically in summary tables. Table 7 presents the minimum, median, and maximum values of the common constituents determined; table 8 shows median values for each of the common constituents by geohydrologic unit. Similar summary tables are presented for other constituents and chemicals as needed for the discussion. The areal distributions of selected constituents are shown on plate 4. All supporting data are presented in Appendix B.

For many constituents, some concentrations are 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 pesticides are reported as <0.05 µg/L, where the reporting limit is 0.05 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 0.01 µg/L, or it may not be present at all, but that is impossible to tell with certainty because of the reporting limit of the analytical method used.

Table 7.--*Summary of field measurements and concentrations of common constituents*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations. Values are for samples from 124 wells and springs unless noted; µS/cm, microsiemens per centimeter at 25 °Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

Constituent	Minimum	25th percentile	Median	75th percentile	Maximum
pH (standard units)	5.6	6.8	7.8	8.3	9.5
Dissolved oxygen[1]	.0	.1	.6	5.5	10.6
Specific conductance (µS/cm, field)	50	130	163	233	830
Hardness (as $CaCO_3$)	2	45	61	78	250
Calcium	.79	11	15	20	55
Magnesium	.03	3.4	5.0	7.7	27
Sodium	1.9	5.1	6.6	17	200
Percent sodium	4	15	18	30	99
Potassium	.1	.7	1.3	2.0	7.0
Alkalinity (as $CaCO_3$)	20	54	76	105	266
Sulfate	<.1	2.2	4.8	7.1	170
Chloride	.3	1.6	3.0	4.2	140
Fluoride	<.1	<.1	.1	.1	2.5
Silica	8.5	17	23	28	43
Dissolved solids	37	95	115	164	551
Nitrate (as nitrogen)	<.05	<.05	.07	.81	6.3
Iron (µg/L)	<3	8	24	106	14,000
Manganese (µg/L)	<1	2	17	60	920

[1] Based on 123 samples.

Table 8.--*Median values of field measurements and concentrations of common constituents by geohydrologic unit*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations; µS/cm, microsiemens per centimeter at 25 °Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

	Geohydrologic unit (Number of samples)							
	Qal (20)	Qvr (15)	Qvt (8)	Qva (27)	Q(A)f (4)	Q(A)c (26)	Q(B)c (2)	Br (22)
pH (standard units)	6.9	7.0	6.7	7.6	8.4	8.2	7.8	8.4
Dissolved oxygen	3.0	3.9	6.7	2.1	.2	.1	.1	.9
Specific conductance (µS/cm)	124	156	158	148	200	193	176	226
Hardness (as $CaCO_3$)	49	59	62	64	62	73	74	34
Calcium	14	15	12	14	18	18	18	12
Magnesium	3.4	5.4	6.1	6.5	4.0	6.5	6.8	1.8
Sodium	3.9	5.9	7.2	5.7	26	11	8.0	26
Percent sodium	17	17	18	16	45	24	19	66
Potassium	.9	1.1	1.0	1.3	3.1	2.1	2.2	.5
Alkalinity (as $CaCO_3$)	52	58	68	66	109	94	85	97
Sulfate	4.3	5.8	4.1	5.0	2.5	4.0	4.4	5.4
Chloride	1.8	3.7	3.5	3.0	2.8	3.2	3.7	2.8
Fluoride	<.1	<.1	.1	.1	<.1	.1	.1	.1
Silica	16	24	28	23	24	26	26	21
Dissolved solids	89	106	116	103	145	141	121	152
Nitrate (as nitrogen)	.36	.71	1.2	.40	<.05	<.05	<.05	.06
Iron (µg/L)	30	13	14	33	52	39	372	15
Manganese (µg/L)	4	3	4	25	38	42	134	6
Arsenic (µg/L)	2	2	1	2	12	6	2	<1

pH, Dissolved Oxygen, and Specific Conductance

The acidity or basicity of water is measured by pH on a scale from 0 to 14. A pH of 7.0 is considered neutral; smaller values are acidic and larger values are basic. The scale is logarithmic; therefore, a pH of 6.0 indicates that a water is 10 times as acidic as water with a pH of 7.0.

The pH values of the samples collected as part of this study ranged from 5.6 to 9.5 (table 7), and the median was 7.8. The median pH by geohydrologic unit generally increased from 6.9 in Qal to 8.4 in Br (table 8). The variation in pH values is mostly natural, due to alterations of the water composition by chemical reactions with minerals in the geohydrologic unit. Some of these reactions and the effects they have on water chemistry will be discussed later, along with water types.

Dissolved-oxygen concentrations are used to help determine the types of chemical reactions that can take place in water. Small dissolved-oxygen concentrations indicate that a chemically reducing reaction can take place, and large concentrations indicate that a chemically oxidizing reaction can take place. In some instances, though, large dissolved-oxygen concentrations may have been caused by the introduction of air into plumbing systems by pumps, leaking tanks, or pipes. All attempts were made to avoid aeration of the samples, but sometimes it was unavoidable or undetectable.

Dissolved-oxygen concentrations ranged from 0.0 to 10.6 mg/L, and the overall median concentration was 0.6 mg/L. As shown in table 7, median concentrations varied considerably by unit with the largest in Qvt (6.7 mg/L) and the smallest in Q(A)f, Q(A)c, and Q(B)c (0.2, 0.1, and 0.1 mg/L, respectively). However, there was much variation within individual units in that the maximum value for each unit with eight or more samples was at least 8.0 mg/L, and the minimum value in each unit was either 0.0 or 0.1 mg/L. Much of this variation is natural and is due to reactions between the water and minerals or organic matter.

Specific conductance is a measure of the electrical conductance of the water (corrected for water temperature). Because specific conductance increases with the amount of dissolved minerals, it is a good indicator of the total concentration of those minerals, usually called dissolved solids. Dissolved-solids concentrations are discussed in detail in the next section; therefore, specific conductance data are presented in the tables for information only. The median specific conductance of the 124 samples was 163 µS/cm (microsiemens per centimeter at 25°C), and the values ranged from 50 to 830 µS/cm.

Dissolved Solids

The concentration of dissolved solids is the total concentration of all the minerals dissolved in the water. The major components of dissolved solids depend on many factors, but usually include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica. Other constituents such as carbonate and fluoride, or metals such as iron and manganese, are also components but are rarely found in large enough concentrations to significantly affect dissolved solids concentrations.

Dissolved-solids concentrations ranged from 37 to 551 mg/L, with a median concentration of 115 mg/L (table 7). The concentrations tended to be larger in the deeper, older units (table 8). The median concentration in Qal was 89 mg/L, and there was a general increase down to the Br unit, where the median concentration was 152 mg/L. Some of this variation is because of different rock types in the units, as reported by Liesch and others (1963), but some variation is likely due to increased residence time of water in the lower units. 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.

A map of dissolved-solids concentrations (plate 4) shows some areal variation. Throughout most of the study area, concentrations were between 100 and 200 mg/L. Concentrations east of North Bend and east of Carnation tended to be less than 100 mg/L. Around North Bend, the relatively large quantity of precipitation, which has a small dissolved-solids concentration, would have a diluting effect on the ground-water system. Concentrations exceeding 200 mg/L were found in samples from wells along the Snoqualmie River and in the foothills east of the river. These large concentrations appear to be due to natural conditions, and most of the wells are finished in older units such as Q(A)c, Q(A)f, or Br.

Major Ions

Most of the major components of dissolved solids are ions, meaning they have an electrical charge. Cations are ions with a positive charge and include calcium, magnesium, sodium, potassium, and most metals. Anions are ions with a negative charge and include bicarbonate, sulfate, chloride, nitrate, carbonate, and fluoride. Silica has no charge and is the only major component that is not a cation or anion.

The median concentration of calcium (table 7) was 15 mg/L, the largest of any of the cations. Magnesium and sodium had median concentrations of 5.0 and 6.6 mg/L, respectively, and account for most of the remaining cations. Maximum concentrations of all these cations are at least five times larger than the median concentrations, and variability is such that in a given sample, any of these three cations may be the dominant cation. Concentrations of potassium, iron, and manganese were generally small compared with calcium, magnesium, or sodium.

Hardness is calculated from the concentrations of calcium and magnesium. The most familiar effect of increased hardness is a decreased production of lather from a given amount of soap introduced into the water. Hard water may also cause a scale deposit on the inside of plumbing pipes. Ninety-five percent of the samples were classified as soft or moderately hard, as defined by the following scheme (Hem, 1985).

Description	Hardness range (milligrams per liter of $CaCO_3$)	Number of samples	Percentage of samples
Soft	0-60	57	46
Moderately hard	61-120	61	49
Hard	121-180	4	3
Very hard	Greater than 180	2	2
		124	100

The dominant anion was bicarbonate, as indicated by the median alkalinity concentration of 76 mg/L (table 7). Alkalinity consists mainly of bicarbonate, carbonate, and hydroxide, but the concentrations of each are dependent on pH. At all pH values observed, bicarbonate is the major component of the alkalinity. The largest alkalinity concentration observed in the study area was 266 mg/L, in a sample from well 23N/08E-08K01, which is completed in Br. The median concentrations of sulfate, chloride, nitrate, and fluoride were small compared with alkalinity, and as such they are generally negligible as major components of the water. The maximum concentration of chloride, however, was 140 mg/L, and chloride was the dominant anion in some samples. The maximum concentration of sulfate was 170 mg/L. Nitrate is discussed in more detail in a separate section of the report because it is generally considered an indication of ground-water contamination.

Silica was also a major component of the dissolved solids, with a median concentration of 23 mg/L. The maximum silica concentration observed was 43 mg/L.

Comparisons of median concentrations of the major ions by geohydrologic unit indicate that sodium and alkalinity vary the most between units, and concentrations are largest in Br and Q(A)f (table 8). This suggests that these major ions are the main source of the variation in dissolved-solids concentrations observed between units. Variations in median concentrations of calcium, magnesium, potassium, sulfate, chloride, fluoride, and nitrate are not large enough to account for the variations in median dissolved-solids concentrations between units. In fact, median calcium, magnesium, and potassium concentrations were actually smallest in Br. Median chloride and fluoride concentrations were the same for all units. The variations in concentration for all of the major ions except nitrate are within natural limits and are probably due to natural causes.

Water Types

Another way to describe major ion data is by water type (dominant ion). First, concentrations of the major ions are converted from milligrams, which are based on mass, to milliequivalents, which are based on the number of molecules and electrical charge. A milliequivalent is the amount of a compound that either furnishes or reacts with a given amount of H^+ or OH^-. When expressed as milliequivalents, all cations or anions are equivalent for the purpose of balancing chemical equations. A milliequivalent of sulfate will balance a milliequivalent of calcium, as would a milliequivalent of chloride. The milliequivalents of all the cations and anions are added into cation and anion sums. Because water is electrically neutral, the cation and anion sums should be close in value. The contribution of each ion to its respective sum is then calculated as a percentage. The cation(s) and anion(s) that are the largest contributors to their respective sums define the water type. For example, the water type of seawater is sodium/chloride.

To make the determination of water type easier, the percentages of cations and anions for a given sample, as milliequivalents, are plotted on a trilinear (Piper) diagram, as shown on plate 5. The water type is then determined from the area of the diagram in which the sample is plotted. One plot defines the dominant cation, another the dominant anion. Combined water types, where more than one cation or anion dominate, are possible and are actually common. An inspection of the explanation diagram on plate 5 shows that to be defined as a sole dominant ion, (1) an ion must account for 60 percent or more of the cation or anion sum, and (2) the analysis will be plotted near one of the corners. On the other hand, an ion that accounts for less than 20 percent of the sum will not be part of the water type. An exception to the latter case is when two ions, such as chloride and nitrate, are summed and plotted together on a single axis of the plot. If both together contribute 20 percent, then the plot will show chloride as a dominant anion, although individually chloride and nitrate contributions may be less than 20 percent. For the study, the actual percentages were used to determine the water type, and if both were less than 20 percent neither was considered dominant. For a combined water type, the ions are listed in order of dominance. For example, a calcium-magnesium/bicarbonate type has more calcium than magnesium, and a magnesium-calcium/bicarbonate type has more magnesium than calcium, but both plot in the same section of the diagram. The diagram is based only on percentages and does not show actual concentrations or milliequivalents.

For the study, all of the samples from each geohydrologic unit were plotted on a single trilinear diagram for each unit (plate 5) so that trends and anomalies could be more easily discerned. Samples that plotted away from the majority of samples for the unit were considered anomalies. They are listed, along with comments, on plate 5.

Samples with calcium and magnesium as the dominant cations and bicarbonate as the dominant anion were the most common throughout the study area. For the most part, these water types were from wells finished in the unconsolidated units. Such water types are characteristic of the glacial deposits of western Washington (Van Denburgh and Santos, 1965; Turney, 1986a; Dion and others, 1994). Freeze and Cherry (1979) attribute these water types to the interaction of dilute, slightly acidic recharge water with alumino-silicate minerals. These minerals dissolve slowly, resulting in low concentrations of dissolved solids and pH values that commonly do not exceed 7.0. Ultimately, carbonate minerals such as calcite and dolomite are dissolved, resulting in the characteristic water type. Chloride and sulfate-containing minerals are rare, so these anions are usually present in small concentrations.

Sodium/bicarbonate and sodium-calcium/bicarbonate water types were most common in Br. The elevated sodium proportions result from a series of geochemical reactions of the ground water with andesite and basalt, which make up much of this unit. Initially, slightly acidic calcium/bicarbonate water from precipitation or the upper, younger units enters Br as a result of downward vertical flow. The water begins to dissolve the minerals in Br, which contains calcium, magnesium, and sodium. Hydrolysis is part of the dissolution mechanism and produces excessive hydroxyl ions (OH^-) that raise the ground-water pH. Solubilities for calcium carbonate and magnesium carbonate, which are pH-controlled, are exceeded, and these minerals precipitate. However, the solubilities of the sodium minerals are not exceeded as quickly, resulting in water enriched in sodium. The pH is also higher, as can be seen by the higher median pH in Br (table 8), leading to the conversion of some of the bicarbonate to carbonate. This process also causes Br rocks to weather geochemically into clays such as kaolinite or montmorillonite. These reactions have been described in more detail by Freeze and Cherry (1979) for general cases, and by Hearn and others (1985) and Steinkampf and others (1985) for basalts in eastern Washington.

Many of the anomalous water types listed on plate 5 were related to uncharacteristically large percentages of sodium in some samples from the unconsolidated units. The inherent heterogeneity of these deposits and the possible presence of sodium-rich clays are factors, as is the incongruous dissolution of the minerals present. In the deeper unconsolidated units, such as Q(A)f and Q(A)c, water is likely to be older and has had more time to be in contact with the formation minerals and to undergo sodium-enrichment reactions, which can take place in glacial deposits as well as bedrock. Another consideration is that sodium-rich water may be flowing upward from Br into these overlying unconsolidated units. However, none of these mechanisms can be proven without further study.

Two other anomalous water types are those with large proportions of either sulfate or chloride. The three samples with high sulfate all came from wells finished in Br (plate 5). Sulfur-bearing minerals, in the form of metallic sulfides, are commonly associated with igneous and sedimentary rocks such as those found in Br. When sulfide minerals undergo geochemical weathering in contact with aerated water, the sulfur is oxidized into sulfate ions that dissolve in the water (Hem, 1985). As with the unconsolidated deposits, Br can be chemically heterogeneous, so these high-sulfate water types may be present only in local instances. The high-chloride samples (two from Q(A)c and one from Br) are more difficult to explain because no chloride-containing minerals are known to be present in the study area. Marine deposits, another source of chloride, are also not common in the study area. However, one possible source of chloride is connate seawater, which is seawater trapped in a geohydrologic unit during the time of formation. Connate seawater may be locally present in Q(A)c or Br, or may be flowing out of nearby formations into these units. The Q(A)c wells are flowing, which indicates upward ground-water flow, so ground-water contamination from local sources is unlikely.

Nitrate

Although not a major component of most water samples, nitrate is of interest in east King County because of a few locally large concentrations and the associated implications of ground-water contamination. Nitrate concentrations ranged from <0.05 mg/L to 6.3 mg/L (table 7). The analysis used for nitrate actually results in a combined nitrate and nitrite concentration; however, nitrite concentrations in ground water are usually negligibly small (National Research Council, 1978). The concentrations determined in this study are therefore considered to be entirely nitrate. With a median value of 0.07 mg/L, the nitrate concentrations observed in east King County are generally smaller than those reported for other areas of western Washington. Median nitrate concentrations have been reported as 0.16 mg/L in Clark County (Turney, 1990), 0.33 mg/L in Thurston County (Dion and others, 1994), and 0.10 mg/L or greater for much of the Puget Sound area (Turney, 1986a).

Concentrations of nitrate were small throughout most of the study area (plate 4). About 80 percent of the samples analyzed had concentrations of 1.0 mg/L or less, a level above which some sort of contamination may be suspected. Two areas appeared to have nitrate concentrations generally exceeding 1.0 mg/L: west of Fall City and east of Duvall. However, no large areal sources of nitrate are present in these areas because they have fairly low population densities and no extensive agricultural activities. It is likely that these areas coincidentally had several wells with local sources of nitrate that are not related on a larger scale. Nitrate concentrations in samples from wells on the Sammamish Plateau were also relatively large. Although much of the area currently has sewers, septic tanks were widely used in the past and are a likely source.

Most of the samples having nitrate concentrations exceeding 1.0 mg/L came from wells less than 100 feet deep (table 9). The nitrate most probably originated from local sources such as septic tanks, pastures, or lawn

Table 9.--*Wells and springs with sample concentrations of nitrate exceeding 1.0 milligram per liter*
[mg/L, milligrams per liter]

Local well number	Date	Geohydrologic unit	Land surface elevation (feet)	Depth of well (feet)	Nitrate (mg/L as nitrogen)
23N/08E-04L01	08-08-91	Qal	430	47	1.1
24N/06E-02E01	08-02-91	Qvt	530	40	1.2
24N/06E-09E03	08-01-91	Qva	385	251	1.9
24N/06E-10H02	08-08-91	Qva	455	155.2	1.4
24N/07E-08A02	08-15-91	Qvt	310	39	4.4
24N/07E-15D01	07-29-91	Qal	105	49.5	1.9
24N/07E-16F01	08-06-91	Qvr	150	122	2.4
24N/07E-17B01	08-05-91	Qvr	210	74	3.8
24N/07E-18F03	08-05-91	Qva	520	80	3.8
25N/06E-24K01	08-01-91	Qvt	420	120	3.3
25N/06E-25E01	07-31-91	Q(A)c	190	49	1.7
25N/06E-32F03	08-02-91	Q(A)c	50	116	4.9
25N/07E-07P01	08-03-91	Qvr	130	39	1.4
25N/07E-23Q01S	08-16-91	Qvt	340	spring	1.1
25N/07E-26F01S	08-07-91	Qvr	380	spring	6.3
25N/07E-28Q01	08-05-91	Qal	85	25	1.2
25N/07E-33Q01	08-05-91	Q(A)c	80	100	3.1
26N/06E-13J01	08-16-91	Qva	405	90	1.1
26N/07E-06K01	08-14-91	Br	50	40	2.7
26N/07E-08A01	08-05-91	Br	600	120	1.6
26N/07E-09F02	08-07-91	Br	295	30	2.8
26N/07E-18B01	08-07-91	Qva	60	46	1.3
26N/07E-28E02	08-08-91	Qva	500	113	2.5
26N/07E-30P01	08-06-91	Qvt	410	60	1.9
26N/07E-33Q02	08-09-91	Qvr	290	134	2.7

fertilizers. Some of the wells sampled were indeed located in or adjacent to pastures with livestock, a common nitrate source. Deeper wells may also contain nitrate from local sources, but the reason for this may be poor well construction that allows seepage of surface water into the ground next to the well casing.

Nitrate concentrations were generally larger in the upper aquifers, as indicated by the median nitrate concentration for each geohydrologic unit (table 8). This is because nitrate sources are typically on or near the land surface. However, because depths to the geohydrologic units vary considerably throughout the study area, nitrate concentrations exceeding 1.0 mg/L can be found in almost all of the units (table 9). Also, because of this variability in unit depth and the large number of wells with small concentrations, there was no strong correlation of nitrate concentration with either geohydrologic unit or well depth.

Iron and Manganese

Iron concentrations ranged from <3 µg/L to 14,000 µg/L, with a median concentration of 24 µg/L (table 7). Median concentrations ranged from 13 to 52 µg/L for all geohydrologic units except Q(B)c, which had a median concentration of 372 µg/L (table 8). However, four of the six concentrations exceeding 1,000 µg/L were observed in samples from Qal. Areal distributions of iron concentrations varied, but some patterns were noted (plate 4). Large numbers of samples with iron concentrations of 30 µg/L or less were from wells located west of Fall City, east of Carnation, and on the Sammamish Plateau. Conversely, large iron concentrations exceeding 300 µg/L were found in samples from a few wells north of North Bend, and in two wells close to Fall City. In general, however, these delineations are subtle; the concentration of iron is geographically highly variable.

Manganese concentrations ranged from <1 µg/L to 920 µg/L, and the median concentration was 17 µg/L. Like iron, the median concentration for individual units was largest (134 µg/L) for samples from Q(B)c; median concentrations in all other units ranged from 3 µg/L to 42 µg/L. Areally, manganese concentrations followed the same general pattern as iron concentrations, although some large concentrations were also noted east of Duvall.

The variation and range of iron and manganese concentrations in east King County are typical of western Washington ground waters (Van Denburgh and Santos, 1965; Turney, 1986a, 1990; Dion and others, 1994), and usually are due to natural processes. These processes are closely dependent upon ambient geochemical conditions, in particular the concentration of dissolved oxygen. Water that is depleted of oxygen will dissolve iron from the surrounding minerals as the chemically reduced ferrous (Fe^{2+}) form of iron. Iron is highly soluble under these conditions and large concentrations can result. If the water is reoxygenated, then the iron is oxidized to the ferric (Fe^{3+}) form, which is much less soluble than the ferrous form and will precipitate as an oxide or a carbonate, resulting in a lower dissolved-iron concentration. Manganese undergoes a similar set of reactions. Because these reactions are oxygen-sensitive and the oxygen content of the ground water may vary considerably in a given area, dissolved iron and manganese concentrations may also vary greatly. Regardless, neither iron nor manganese concentrations correlated well with dissolved-oxygen concentrations in this study. This may be because the occurrence of iron and manganese in the aquifer material varies greatly. Additionally, the dissolution of iron from the aquifer material depends, to a degree, on the particle size of the material, which also is highly variable.

The large iron and manganese concentrations in Q(B)c are due in part to the small dissolved-oxygen concentrations in that unit. Water samples from Q(B)c had a median dissolved-oxygen concentration of only 0.1 mg/L, the smallest of any unit (table 8). Although dissolved oxygen is an obvious factor, this unit may also have more iron- and manganese-rich minerals than do the other unconsolidated units.

Trace Elements

Concentrations of most trace elements were small. For all except zinc and radon, the median concentrations were 5 µg/L or less (table 10). Nevertheless, some of the trace elements, most notably arsenic and radon, are present at levels that may indicate regional ground-water problems.

Arsenic concentrations ranged from <1 to 77 µg/L, with a median concentration of 2 µg/L. Arsenic was present in samples from 79 wells (64 percent) and of these, 18 (15 percent) had concentrations of 20 µg/L or larger. Areally, most of the samples with larger concentrations were from wells along or east of the Snoqualmie River, between Carnation and Duvall (plate 4). Median concentrations were 2 µg/L or less for all geohydrologic units except Q(A)f and Q(A)c, which had median concentrations of 12 and 6 µg/L, respectively. The current USEPA maximum contaminant level (MCL) for arsenic is 50 µg/L, however that value is being reviewed and may be lowered to 3 µg/L or less. Therefore some concern over the arsenic present is warranted.

Table 10.--*Summary of concentrations of selected trace elements*

[Concentrations in micrograms per liter unless otherwise noted. All are dissolved concentrations. Values are for samples from 124 wells and springs; <, not detected at the given concentration; pCi/L, picocuries per liter]

	Concentrations					Wells with trace element present	
Element	Minimum	25th percentile	Median	75th percentile	Maximum	Number	Percent
Arsenic	<1	<1	2	8	77	79	64
Barium	<2	2	5	9	75	98	79
Cadmium	<1	<1	<1	<1	<1	0	0
Chromium	<1	<1	<1	<1	5	21	17
Copper	<1	<1	1	4	180	69	56
Lead	<1	<1	<1	<1	5	4	3
Mercury	<.1	<.1	<.1	<.1	.8	8	6
Selenium	<1	<1	<1	<1	<1	0	0
Silver	<1	<1	<1	<1	<1	0	0
Zinc	<3	5	15	62	550	106	85
Radon (pCi/L)[1]	<80	165	250	340	530	[1]15	88

[1] Based on 17 samples.

The source of the arsenic in the ground water is probably natural. Arsenic is present in many igneous rocks, such as andesite, diorite, and basalt, which are common in the Br unit. Igneous rocks are also a source of much of the material in the unconsolidated, glacial units. Furthermore, arsenic tends to concentrate in alumino-silicate minerals and igneous rocks that contain iron oxide (Welch and others, 1988), both of which are present in the study area. Elevated concentrations of arsenic have been documented in nearby areas of western Washington and are thought to be due to natural conditions. In particular, in Snohomish County to the immediate north of the study area, concentrations as large as 15,000 µg/L have been observed (Ficklen and others, 1989). Frost and others (1991) also found considerable seasonal variations in arsenic concentrations in Snohomish County and recommended additional sampling of wells with samples having concentrations larger than 10 µg/L.

Radon concentrations ranged from <80 pCi/L (picocuries per liter) to 530 pCi/L, with a median concentration of 250 pCi/L. (The picocurie is a measure of radioactivity, not mass.) Radon is a naturally occurring element and is part of the radioactive decay chain of uranium. Radon concentrations showed no areal or geohydrologic patterns. The USEPA has proposed an MCL of 300 pCi/L, so there may be cause for concern in the study area. However, the radon concentrations observed in east King County are less than those found in ground water in Clark and Thurston Counties, where radon concentrations ranged from <80 to 820 pCi/L and <80 to 660 pCi/L, respectively, with median concentrations of 315 and 410 pCi/L (Turney, 1990; Dion and others, 1994). The concentrations in east King County are not large compared with some other areas of the nation, such as Maine, where concentrations in excess of 10,000 pCi/L have been observed in water from granitic formations.

Barium was present in 98 samples (79 percent), ranging in concentration from <2 to 75 µg/L (table 10); the median concentration was 5 µg/L. The presence of some barium is natural, and concentrations were well below the MCL of 2,000 µg/L, so the presence of barium poses no concern.

Copper and zinc were present in most samples, and the concentrations were highly variable (table 10). This is because a major source of the copper and zinc is pipe used in wells and in home plumbing systems. These metals may be leached from the pipes, especially if the water is slightly acidic and low in dissolved-solids concentration, as is much of the ground water in east King County. Concentrations of copper and zinc were well within applicable drinking water regulations in all cases.

The remaining trace elements, rarely present, were not found at significant concentrations when compared with USEPA standards. Chromium was present in 21 samples (17 percent) but the maximum concentration was 5 µg/L. Such a level is likely due to the natural occurrence of chromium in the mineral matrix. Lead was present in only four samples (3 percent) with a maximum concentration of 5 µg/L. Like copper and zinc, lead may come from plumbing systems, specifically the lead-based solder used in some older homes. Mercury was present in eight samples (6 percent) at concentrations as large as 0.8 µg/L. However, there are no obvious ground-water sources for the mercury, natural or otherwise. The mercury could be due to isolated instances of sample contamination from the mercuric chloride preservative used for the nutrient samples, but mercury was not found in any of the quality-assurance samples collected. Finally, cadmium, selenium, and silver were not detected in any samples.

Volatile Organic Compounds

Of the individual volatile organic compounds listed in table 11, none were detected in any of the samples collected from 11 wells (plate 4). Any volatile organic

Table 11.--*Summary of concentrations of volatile organic compounds*

[Volatile organic compounds listed are those analyzed for in samples from 11 wells. None was present at the detection limit of 0.2 micrograms per liter]

Constituents
Chloromethane
Dichloromethane
Trichloromethane
Tetrachloromethane
Bromomethane
Dibromomethane
Tribromomethane
Bromodichloromethane
Dibromochloromethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chloroethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
1,2-Dibromoethane
Chloroethene
1,1-Dichloroethene
1,2-Dichloroethene
Trichloroethene
Tetrachloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,2,3-Trichloropropane
1,1-Dichloropropene
cis 1,3-Dichloropropene
trans 1,3-Dichloropropene
Benzene
Chlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Bromobenzene
Toluene
2-Chlorotoluene
4-Chlorotoluene
Dimethylbenzene
Ethylbenzene
Ethenylbenzene

compound detected generally has an anthropogenic source. As discussed earlier, the wells sampled were selected because they were in more populated areas, increasing the likelihood of detecting these compounds. Because none was detected, it may therefore be concluded that no widespread sources of these compounds exist. However, because the 11 wells sampled provide a limited geographic coverage of the study area, smaller localized sources of these compounds may remain undetected.

Pesticides

Samples from 12 wells were analyzed for concentrations of chlorophenoxy and triazine herbicides (table 12, plate 4). These groups of pesticides include many of those commonly used within the study area. Of these pesticides, only dicamba and 2,4-D were detected in any samples. Dicamba and 2,4-D are used for weed control in many different applications in the study area. None of the triazine herbicides was detected.

Dicamba was present at a small concentration of 0.01 µg/L in samples from three wells (table 13). Well 25N/07E-21C01 is located near a Christmas tree farm, and well 25N/07E-28Q01 is next to a pasture with 50 to 100 head of cattle. The wells are 35 and 25 feet deep, respectively, so the presence of dicamba may be related to the nearby agricultural activities. Moderate levels of nitrate also are present in both samples, so some type of contamination appears probable. Well 26N/06E-13D03 is in a city park and near a major State highway, and pesticides used

Table 12.--*Summary of concentrations of selected pesticides*

[Concentrations in micrograms per liter. The chlorophenoxy herbicides are total concentrations and the triazine herbicides are dissolved concentrations. Values are from samples from 12 wells; <, not detected at given concentration]

	Concentrations			
Pesticide	Minimum	Median	Maximum	Number of wells where pesticide was detected
Chlorophenoxy herbicides				
2,4-D	<0.01	<0.01	0.02	1
2,4-DP	<.01	<.01	<.01	0
2,4,5-T	<.01	<.01	<.01	0
Silvex	<.01	<.01	<.01	0
Dicamba	<.01	<.01	.01	3
Picloram	<.01	<.01	<.01	0
Triazine herbicides				
Alachlor	<.05	<.05	<.05	0
Ametryn	<.05	<.05	<.05	0
Atrazine	<.05	<.05	<.05	0
Cyanazine	<.2	<.2	<.2	0
De-ethylatrazine	<.05	<.05	<.05	0
De-isopropyl atrazine	<.05	<.05	<.05	0
Metolachlor	<.05	<.05	<.05	0
Metribuzin	<.05	<.05	<.05	0
Prometon	<.05	<.05	<.05	0
Prometryn	<.05	<.05	<.05	0
Propazine	<.05	<.05	<.05	0
Simazine	<.05	<.05	<.0.5	0

Table 13.--*Concentrations of pesticides in samples where they were detected*

[Concentrations in micrograms per liter except where indicated. All are total concentrations; <, not detected at given concentration]

Local well number	Well depth (feet)	2,4-D	Dicamba	Nitrate (mg/L as nitrogen)
24N/07E-08A02	39	0.02	<0.01	4.4
25N/07E-21C01	35	<.01	.01	.32
25N/07E-28Q01	25	<.01	.01	1.2
26N/06E-13D03	215	<.01	.01	<.05

in the maintenance of these areas might be a possible source of dicamba. However, the well is 215 feet deep and flowing, so it is unlikely that surface contaminants from the immediate vicinity of the well can migrate deeply enough in the ground-water system to enter the well. A more distant source of contaminants is likely for this well.

The 2,4-D was detected in only one sample, from well 24N/07E-08A02, at a concentration of 0.02 µg/L (table 13). This well is 39 feet deep, and some agricultural activities, including a berry farm and a dairy farm are in the vicinity. The nitrate concentration is large, 4.4 mg/L, so some contamination is present. However, given the widespread use of 2,4-D in various applications, including use on private lawns and gardens, it is not possible to determine the source at this time.

Septage-Related Compounds

Concentrations of methylene blue active substances (MBAS), boron, and dissolved organic carbon (DOC) were determined for samples from 19 wells (plate 4) located mostly in areas with septic systems. Nitrate is also a septic-related compound, and has been discussed earlier. MBAS and boron are present in household waste-water as detergent residues and have been identified in septage-contaminated ground water (LeBlanc, 1984). Large concentrations of DOC may indicate the presence of several types of organic compounds, including septage compounds, oil and grease, or solvents. The concentrations of MBAS, boron, and DOC, in conjunction with nitrate, can provide an indication of the degree of ground-water contamination from septic tanks.

MBAS were not detected in any of the samples (table 14). The median value of <0.02 mg/L is less than 0.02 mg/L, the concentration above which ground-water quality can be considered degraded (Hughes, 1975). The lack of MBAS in the ground water does not by itself lead to the conclusion that septic tanks are not contributing to ground-water contamination. However, in conjunction with the overall small nitrate concentrations observed in the study area, contamination by septic tanks on a large areal scale does not appear likely. A meaningful statistical correlation between MBAS and nitrate could not be made because MBAS was not detected in any of the samples. A good correlation might be seen if the two had a similar source, such as septic tanks. Such a correlation was observed in Thurston County (Dion and others, 1994).

The median concentration of boron, 10 µg/L, was also quite low (table 14). Samples from only three wells had concentrations exceeding 20 µg/L, and the maximum concentration of 120 µg/L was observed in a sample from well 25N/07E-15C01. Although these elevated boron concentrations could be associated with septic systems, the boron concentrations correlated poorly with nitrate; a better correlation might have been observed if septic systems were the true source. It is likely that the elevated boron concentrations are merely due to natural causes. Natural boron concentrations in excess of 100 µg/L are actually common (Hem, 1985).

Most DOC concentrations were 1.0 mg/L or less (table 14). The median concentration was 0.5 mg/L, smaller than the value of 0.7 mg/L given by Thurman (1985) as the median concentration of DOC in ground waters throughout the United States. Samples from only three wells had concentrations exceeding 1.0 mg/L, and the maximum concentration was 1.6 mg/L. Overall, the correlations of DOC concentrations with nitrate and boron concentrations were low. Given the diversity of sources and the lack of correlation with other septage-related

Table 14.--*Summary of concentrations of septage-related compounds*

[Concentrations are in milligrams per liter unless otherwise noted. All except methylene blue active substances are dissolved concentrations. Based on samples from 19 wells; <, not detected at given concentration; μg/L, micrograms per liter]

Constituent	Minimum	25th percentile	Median	75th percentile	Maximum
Methylene blue active substances (MBAS, or detergents)	<0.02	<0.02	<0.02	<0.02	<0.02
Boron (μg/L)	<10	<10	10	20	120
Dissolved organic carbon (DOC)	.2	.4	.5	.8	1.6

compounds, it is difficult to attribute the few larger concentrations of DOC to septic systems. In addition to the anthropogenic sources of DOC mentioned, there are several natural sources, including surface organic matter and kerogen, the fossilized organic matter present in most aquifer materials (Thurman, 1985).

Bacteria

Bacteria were present in samples from 16 of 121 wells and springs (3 wells were not sampled for bacteria). Fecal streptococci were present in all 16 samples and 2 samples also contained fecal coliform (table 15). Median concentrations of both fecal-coliform and fecal-streptococci bacteria were less than 1 colony per 100 milliliters. Both types of bacteria are indicators; they are not normally pathogenic themselves, but they can be indicative of pathogenic bacteria. A quantitative relation between fecal coliform and salmonellae (a pathogen) has been observed (Geldreich and Van Donsel, 1970).

The sites from which samples contained bacteria are listed in table 16. Some of the wells, including 26N/07E-06K01 and 26N/07E-33Q02, were located near pastures, which suggests that farm animals may be a source of the bacteria. Other wells were near septic tanks, another potential source of bacteria. Nitrate concentrations in most bacteria-contaminated wells were less than 1.0 mg/L, and most of the wells were over 100 feet deep, suggesting a source other than local septic systems or animal wastes. Areally, half of the samples having bacteria were collected from wells in township 26N/07E, east of Duvall. Nevertheless, most samples from that township contained no bacteria, and the presence of bacteria in ground water in the study area appears to have been limited to isolated areas.

Drinking Water Regulations

The USEPA has established drinking water regulations with several sets of laws. Two sets of regulations were applicable when these samples were collected. Primary drinking water regulations generally concern chemicals that affect human health. The maximum concentration allowed for each constituent is referred to by the USEPA as the maximum contaminant level (MCL) (U.S. Environmental Protection Agency, 1988a, 1988b, 1989, 1991), and is legally enforceable by the USEPA or State regulatory agencies. Secondary drinking water regulations (U.S. Environmental Protection Agency, 1988c, 1991) pertain to the esthetic quality of water and are guidelines only. A secondary maximum contaminant level (SMCL) is not enforceable by a Federal agency. Both sets of regulations legally apply only to public supplies, but can also be used to help assess the quality of private systems.

The drinking water regulations for all constituents analyzed in this study are shown in table 17. Because the regulations are subject to revision, this report uses the MCL or SMCL in effect at the time the samples were collected. Along with each MCL or SMCL, the number of wells from which samples did not meet the regulation is also shown in table 17.

Table 15.--*Summary of concentrations of bacteria*

[All concentrations are in colonies per 100 milliliters; <, not detected at given concentration; >, concentration is greater than the given value]

Bacteria type	Concentrations Minimum	 Median	 Maximum	Number of wells sampled	Number of wells with bacteria present	Number of springs with bacteria present
Fecal coliform	<1	<1	>60	121	2	0
Fecal streptococci	<1	<1	17	121	15	1

Table 16.--*Concentrations of bacteria in samples where they were detected*

[mg/L, milligrams per liter; cols. per 100 mL, colonies per 100 milliliters; <, not detected at given concentration; >, concentration is greater than the given value]

Local well number	Geo hydro-logic unit	Depth of well (feet)	Nitrate (mg/L as nitrogen)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
23N/08E-13N01	Qal	194	0.40	<1	1
23N/08E-22A01	Qal	18.2	.30	<1	7
24N/06E-10H02	Qva	155.2	[1]1.4	<1	[1]7
24N/07E-10K01	Qal	36	<.05	>60	2
24N/08E-24Q01S	Br	Spring	.55	<1	1
24N/08E-26K01	Qal	59	.49	<1	1
25N/06E-34D01	Qva	214	.53	<1	1
25N/07E-34E02	Qvr	220	.64	<1	8
26N/07E-03M01	Br	160	<.05	<1	1
26N/07E-06K01	Br	40	2.7	5	7
26N/07E-08A01	Br	120	1.6	<1	1
26N/07E-14G02	Br	182	.10	<1	2
26N/07E-19J02	Q(A)f	416	<.05	<1	17
26N/07E-20E01	Qva	260	.40	<1	2
26N/07E-33Q02	Qvr	134	2.7	<1	1
26N/07E-35D01	Qva	138	<.05	<1	2

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[1] Average value for two samples.

Table 17.--*Drinking water regulations and the number of samples not meeting them*

[mg/L, milligrams per liter; μg/L, micrograms per liter; cols. per 100 mL, colonies per 100 milliliters]

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
	Primary drinking water regulations (MCLs)			
Inorganic				
Fluoride	4 mg/L	0	0	124
Nitrate (as nitrogen)	10 mg/L	0	0	124
Arsenic	50 μg/L	1	1	124
Barium	2,000 μg/L	0	0	124
Cadmium	5 μg/L	0	0	124
Chromium	100 μg/L	0	0	124
Lead	50 μg/L	0	0	124
Mercury	2 μg/L	0	0	124
Selenium	50 μg/L	0	0	124
Silver	50 μg/L	0	0	124
Organic				
Trihalomethanes[1]	100 μg/L	0	0	11
Tetrachloromethane	5 μg/L	0	0	11
1,2-Dichloroethane	5 μg/L	0	0	11
1,1,1-Trichloroethane	200 μg/L	0	0	11
1,2-Dibromoethane	.05 μg/L	0	0	11
Chloroethene	2 μg/L	0	0	11
1,1-Dichloroethene	7 μg/L	0	0	11
cis 1,2-Dichloroethene[2]	70 μg/L	0	0	11
trans 1,2-Dichloroethene[2]	100 μg/L	0	0	11
Trichloroethene	5 μg/L	0	0	11
Tetrachloroethene	5 μg/L	0	0	11
1,2-Dichloropropane	5 μg/L	0	0	11
Benzene	5 μg/L	0	0	11
Chlorobenzene	100 μg/L	0	0	11
1,2-Dichlorobenzene	600 μg/L	0	0	11
1,3-Dichlorobenzene	600 μg/L	0	0	11
1,4-Dichlorobenzene	75 μg/L	0	0	11
Toluene	1,000 μg/L	0	0	11
Xylene	10,000 μg/L	0	0	11
Ethylbenzene	700 μg/L	0	0	11
Ethenylbenzene	100 μg/L	0	0	11

Table 17.--*Drinking water regulations and the number of samples not meeting them--Continued*

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
	Primary drinking water regulations (MCLs)--Continued			
Organic				
2,4-D	70 μg/L	0	0	12
Alachlor	2 μg/L	0	0	12
Atrazine	3 μg/L	0	0	12
Silvex	50 μg/L	0	0	12
Microbiological				
Total coliform[3]	0 cols. per 100 mL	2	2	121
	Secondary drinking water regulations (SMCLs)			
Inorganic				
pH	6.5-8.5 units	27	22	124
Sulfate	250 mg/L	0	0	124
Chloride	250 mg/L	0	0	124
Fluoride	2 mg/L	1	1	124
Dissolved solids	500 mg/L	1	1	124
Iron	300 μg/L	14	11	124
Manganese	50 μg/L	36	29	124
Copper	1,000 μg/L	0	0	124
Silver	100 μg/L	0	0	124
Zinc	5,000 μg/L	0	0	124
Organic				
MBAS (methylene blue active substances)	.5 mg/L	0	0	19

[1] Includes trichloromethane, tribromomethane, bromodichloromethane, and dibromochloromethane.

[2] The concentration for these two compounds is reported in the data tables as a combined concentration under 1,2-dichloroethene.

[3] The presence of fecal-coliform bacteria indicates that this standard has been exceeded.

The only primary MCL that was not met was the one for arsenic; one sample, from well 26N/06E-14D01, had an arsenic concentration of 77 μg/L. The arsenic MCL of 50 μg/L is based on the concentration at which arsenic can cause chronic poisoning if continually ingested. The current MCL does not take into account the carcinogenic effects of arsenic, but the USEPA is considering lowering the MCL, possibly to 3 μg/L or less, on the basis of these carcinogenic effects. Samples from 42 wells (34 percent) would not meet a lower MCL of 3 μg/L.

Total coliform bacteria were not analyzed for, but the presence of fecal-coliform bacteria in samples from two sites implies that this MCL was exceeded. The presence of fecal-coliform bacteria suggests some type of contamination, and as such, is considered a drinking water problem.

More samples did not meet the SMCL for manganese than for any other constituent. Of 124 wells sampled, samples from 36 (29 percent) did not meet the SMCL of 50 µg/L. However, as described previously, these large manganese concentrations are natural and common. The SMCL for manganese is based on the level at which laundry and plumbing fixtures may be stained (the stain is usually black or purple). The taste of the water may also be affected at concentrations greater than 50 µg/L. Extremely large concentrations of manganese may cause human health problems, but no such concentrations have ever been reported in the United States (U.S. Environmental Protection Agency, 1986).

Concentrations of iron in samples from 14 wells (11 percent) did not meet the SMCL of 300 µg/L for iron. As with manganese, these large concentrations are likely due to natural causes. Iron concentrations exceeding the SMCL may cause objectionable tastes and may stain plumbing fixtures a characteristic red or brown color. Some industrial applications, such as paper production, food processing, and chemical production, may require concentrations less than 300 µg/L.

Samples from 27 wells (22 percent) had pH values outside the acceptable range of 6.5 to 8.5. Of these, 10 (8 percent) had values less than 6.5 and 17 (14 percent) had values greater than 8.5. The SMCL for pH is based on several criteria (U.S. Environmental Protection Agency, 1986). The range used is based on the acceptable pH limits for marine aquatic life, which are not directly applicable to ground-water systems. A pH range from 5 to 9 is usually considered acceptable for domestic uses (U.S. Environmental Protection Agency, 1986), and samples from only four wells were above this range. None had a pH value below this range. Water with small pH values may be corrosive to pipes and plumbing and can increase copper, lead, zinc, and cadmium concentrations. Water with large pH values may adversely affect the chlorination process and may cause carbonate deposits to form in pipes.

The SMCLs of 500 mg/L for dissolved solids and 2 mg/L for fluoride each were exceeded once, in the same sample. The sample collected from well 23N/08E-08K01 had a dissolved-solids concentration of 551 mg/L and a fluoride concentration of 2.5 mg/L. The source of these elevated concentrations is most likely natural. The SMCL for dissolved solids is based mostly on taste, although other undesirable properties such as corrosiveness or hardness may be associated with large dissolved-solids concentrations. The SMCL for fluoride is based on the concentration at which teeth may become mottled.

The USEPA is in the process of establishing an MCL for radon. A value of 300 pCi/L was under consideration at the time of this study. Samples from five wells (29 percent) would not meet this proposed MCL.

All other applicable USEPA drinking water regulations were met. For certain constituents, even if the MCL for a particular regulation was met, the presence of the constituent indicates contamination. This is especially true for the organic compounds 2,4-D and dicamba. As discussed previously in this report, because these compounds don't occur naturally their mere presence indicates some degree of contamination.

Because the study was designed to determine large-scale areal variation, the areal density of wells may have been too sparse to detect relatively small areas where drinking water regulations were not met. The identification of small areas of contamination was outside the scope of this study.

For more information on drinking water regulations, refer to documents of the U.S. Environmental Protection Agency (1976, 1986, 1988a, 1988b, 1988c, 1989, 1991).

Factors Affecting Water Quality

Although elevated constituent concentrations in ground water were not observed over large areas of east King County, isolated occurrences of elevated concentrations have been identified and attributed to one or more potential contamination sources. Sometimes the elevated concentrations are a health concern; at other times they affect only the esthetic qualities of the water. In either instance, a water-quality problem exists, and it is helpful to better understand the source and its impact on water quality and water chemistry. A complete description of all the sources of water-quality problems in east King County is beyond the scope of this report. However, brief discussions of the more important sources of ground-water-quality problems are presented below. In addition to the source, the extent and severity of water-quality problems depend on many geohydrologic conditions, such as aquifer mineralogy, ground-water flow direction and rate, depth to water, recharge rate, and water chemistry.

Agricultural Activities

Agricultural activities in the study area include crop production, dairy farming, livestock production, and forestry. These activities can result in several types of water-quality problems, most commonly the presence of various nitrogen species, pesticides and associated compounds, and bacteria. Sulfate, chloride, and phosphorous also may be present. Most problems are related to fertilizer or pesticide application, or barnyard wastes.

Virtually all fertilizers include some type of nitrogen. In some, the nitrogen is part of a solid organic compound and is released over several days or weeks to the soil; in others, an aqueous solution of nitrogen, usually as ammonia, is injected directly into the soil and is released immediately. Any nitrogen is usually converted by bacteria to nitrite and then to nitrate during the process of nitrification. Some nitrate is then taken up by crops. Any remaining nitrate may be transported down through the soil and the unsaturated zone to the water table. Nitrate generally does not sorb, or attach, to the aquifer material, therefore it is transported at a rate similar to that of the ground water. In some instances, unconverted nitrogen may be transported to the ground water, either as ammonia or as part of an organic compound. Ammonia tends to sorb to soil particles, so it may not be transported as quickly as nitrate. Usually, any ammonia or ammonia compound reaching the ground water ultimately will be converted to nitrate. Fertilizers also contain other chemicals that may be introduced into the ground water, such as potassium, sulfate, and phosphorous, but the resulting effects on natural concentrations are usually minimal.

Barnyard wastes, including those from dairies and feedlots, contain urea, chloride, and bacteria, along with other constituents in smaller quantities. Urea is eventually converted to nitrate, which is transported to the aquifer in a manner similar to nitrate from fertilizers. Chloride is generally unreactive and will also be transported to the water table. Many different types of bacteria are present in barnyard wastes, including the indicator bacteria (fecal coliform and fecal streptococci) analyzed for in this study. Their transport to and within the ground water depends on such factors as depth to water and water temperature, which greatly affects bacterial survival. Other constituents that may also be transported to the ground water from barnyard wastes are sodium, potassium, sulfate, and phosphorous, but natural sources generally mask these contributions.

The transport of pesticides and their associated compounds to the ground water is complex. Most pesticides undergo chemical and biological transformations as part of one or more of the following processes: biodegradation, photolysis, hydrolysis, or oxidation. The products of these reactions may be as great a contamination problem as the original pesticide. Also, solvents and carriers, such as toluene, are applied with pesticides to assure an even application of the pesticide and can themselves become contaminants. The transport of all these pesticide-related compounds is affected by physical processes such as dissolution in the water, sorption to aquifer material, and volatilization to the atmosphere as soil gas. Because all of these variables, the occurrence of pesticides in ground water can vary widely over both space and time.

One group of agricultural activities that is not included in the above assessment is that which is sometimes referred to as hobby farming. Hobby farming consists of agricultural activities similar to those discussed, but on a smaller scale for private rather than commercial use. Examples include backyard gardens, pet pens or corrals, and lawns. Most hobby farms are in suburban or urban areas, and as such are not considered commercial agricultural activities. However, pesticide and fertilizer use is extensive, and these chemicals are commonly overapplied because of a lack of knowledge, experience, or motive for cost effectiveness. Little documentation has been done on hobby farming, but researchers have reported that urban lawn fertilizers may contribute as much nitrate to ground water as do septic systems (Porter, 1980).

The most important agriculture-related water-quality problem identified in east King County is the presence of small amounts of pesticides in samples from 4 of 12 sampled wells. Three samples contained dicamba and the fourth contained 2,4-D. The occurrences were isolated and likely were due to local sources of pesticides; however, the exact sources have not been positively identified. Production agriculture is a likely source in some instances, but hobby farming activities or nonagricultural activities, such as roadside spraying for weed control, are also possible sources.

Barnyard wastes likely contributed to elevated nitrate concentrations in a few isolated instances, but this does not appear to be a widespread problem. The overall small nitrate concentrations indicate there are likely no large inputs from barnyards, or, for that matter, any agricultural sources. The data may be somewhat misleading because few shallow wells were available to sample in the northern part of the Snoqualmie River Valley, where several dairy farms are located. However, ground water likely discharges directly to the river in this area, so contamination could be present in the shallow ground water and transported directly to the river without entering the deeper ground-water system. Such contamination could go undetected because the shallow ground water is not used extensively and the contaminants are greatly diluted in the river.

Septic Systems

A septic system, consisting of a septic tank and drainfield, can be a source of several constituents in ground water. The most familiar of these is nitrate, but others are sodium, potassium, sulfate, chloride, phosphorous, ammonia, boron, MBAS, and bacteria. Because septic systems are used virtually everywhere that central sewer systems are not available, they can be a widespread source of these constituents and may remain so even after they are abandoned.

In the operation of a septic system, household sewage is piped into a tank that has an average capacity of approximately 1,000 to 1,500 gal for a single household unit. In the tank, solids settle to the bottom and liquids discharge to a drainfield, which is a subsurface trench filled with permeable material such as sand or gravel. This allows the liquid to infiltrate the natural soil or geologic formation over a large area. Ultimately, the effluent flows through the unsaturated zone to the ground water. Where septic tanks are used in densely populated areas, the combined discharge from them may be a large component of the total ground-water recharge.

Once in the unsaturated zone, the individual constituents in the effluent are susceptible to the same chemical and biological transformations as constituents that originate at land surface. Urea is transformed to ammonia and eventually to nitrate. The nitrate, along with chloride, then flows through the aquifer at a rate similar to the ground water. Sodium, potassium, sulfate, MBAS, and other constituents, however, may undergo sorption, ion exchange, or degradation reactions that can hinder their transport to and within the ground water.

As with agricultural activities, the small overall nitrate concentrations observed in this study indicate that septic tanks are not contributing to water-quality problems on a large areal basis. The low MBAS, boron, and DOC concentrations, and lack of correlation among them and nitrate concentrations, support this conclusion. However, some isolated large nitrate concentrations are likely due to instances of local contamination by septic tanks.

Commercial and Industrial Activities

Commercial and industrial activities in east King County are minimal, but in some of them, chemicals are used that are potential ground-water contaminants. Service stations are sources of benzene and benzene-related compounds from fuels and oils. Dry cleaners and paint shops are potential sources of solvents such as 1,1,1-trichloroethane and trichloroethene. Solvents, along with metals such as chromium, copper, zinc, and lead, can come from electronic, machine, and automotive-repair shops. Parking lots and roads may also be sources of many of these chemicals. In general, most of the chemicals are volatile organic compounds or trace elements. Industrial activities such as shipping, manufacturing, and food processing can also be sources of these chemicals, but there are few of these activities in east King County. Roadside spraying to inhibit the growth of vegetation along road shoulders is a possible source of pesticides in the ground water, but this practice is diminishing in the study area.

Chemicals are sometimes spilled or dumped onto the ground where they are dissolved or otherwise incorporated into the recharge water. Also, runoff water from impervious areas, such as roads and parking lots, can carry chemicals to permeable areas and into the ground. In the case of large spills of liquids such as fuels or oils, the chemicals may travel into the unsaturated zone unaltered. In other instances the chemicals may reach the ground water only after being subjected to physical or chemical transformation processes, such as volatilization, sorption, biodegradation, hydrolysis, or oxidation. As a result, the contaminants in ground water may include any of the compounds initially spilled or their transformation products.

Contamination of east King County ground water by commercial and industrial activities appears to be minimal. No volatile organic compounds were detected, but the presence of pesticides in samples from four wells could be related to roadside spraying, in addition to agricultural sources. No large concentrations of trace elements were associated with these activities.

Natural Conditions

Most of the water-quality problems in the study area were due to natural conditions. Large concentrations of arsenic, iron, and manganese are the most widespread problems, and the chemistry of those three elements was discussed previously. Elevated radon concentrations and pH values outside of the accepted range are also due to natural causes.

NEED FOR MONITORING AND ADDITIONAL STUDIES

Many gaps or deficiencies in the available data were noted during the course of this study. In some instances, a reported calculation or number was not as accurate as would be preferred; in others, entire geographic areas could not be considered because there were no data available. Sometimes questions were raised that would require more data in order to be answered. Listed below are the major information gaps that were identified, with no implied priority.

There are few long-term (5 years or more) water-level data sets for the area as a whole. As part of this study, water levels were measured monthly in more than 40 wells beginning in May 1991. This effort could be continued, with a reduced number of wells. A representative mix of geohydrologic units, however, needs to be maintained. The resulting data would provide a good baseline for ground-water levels and allow the delineation of future trends.

Throughout much of the study area, and especially in the Snoqualmie River Valley, the depth to bedrock, and therefore the thickness of the potential water-bearing sediments, is unknown. Geophysical work in the Snoqualmie River Valley would help determine the geometry of the underlying bedrock. This also would help answer questions about the dimensions of the valley fill and its potential as a significant source of ground water. The information gathered would help to guide any future drilling efforts.

In three major areas--the Snoqualmie River Valley, the Sammamish Plateau, and the Cascade Range foothills --the geologic framework could not be readily determined because of a lack of deep wells. There are presently (1992) few wells of any depth in the Cascade Range foothills, east of the Snoqualmie River, because this area has not been developed. Nevertheless, if the ground-water resource is to be further investigated or developed in any coordinated manner, more deep wells (500 to 1,000 ft deep) will be needed in these three areas to further define the geologic framework.

The effects of ground-water development on the ground-water system and the Snoqualmie River cannot be reasonably estimated or quantified at present. A ground-water model of the Snoqualmie River Valley would help predict these effects and would be valuable if the ground-water resource in the valley is developed further. Some additional data would be required, however, to construct and calibrate the model.

There are virtually no long-term water-chemistry data available for the study area. Water samples could be collected from selected wells quarterly and analyzed for concentrations of nitrate, bacteria, and arsenic. At the time of sampling, pH, specific conductance, dissolved oxygen, and temperature also could be measured. Twice a year, at times of the highest and lowest water levels, samples also could be collected and analyzed for concentrations of common ions and trace elements. These data could be compared with data collected in this study; this comparison would help identify any cyclic or long-term changes in water chemistry.

Pesticides were found in 4 of 12 wells sampled in the study area, but no other pesticide data for the study area exist. The wells where pesticides were present could be sampled twice more, during times of high and low water levels. Besides the pesticide groups analyzed for (chlorophenoxy and triazine herbicides), others should be considered, including the organochlorine and organophosphate pesticides. If any pesticides are present in the subsequent samples, a study to determine the sources could be undertaken. If no pesticides are present, samples could be collected from a dozen or so wells every 2 years and analyzed for concentrations of chlorophenoxy and triazine herbicides.

Although no volatile organic compounds were detected in samples collected in the study, few other data exist. Samples could be collected every 2 years from a network of a dozen or so wells and analyzed for concentrations of volatile organic compounds. The wells should be located in suburban and commercial areas.

Given the health implications of the widespread presence of arsenic in the ground water, it is important to understand its source, fate, and transport. A thorough geochemical study, investigating the mineralogy of the various units, water chemistry, and flow paths in relation to arsenic concentrations, would provide some insight into the specific conditions under which arsenic is present in ground water.

Excessive iron and manganese concentrations probably are the most widespread water-quality problems in the study area, and indeed, in the Puget Sound area. Although iron and manganese are generally not considered health threats (though some concerns are beginning to be voiced about that), they undoubtedly cause significant expenses because of the need for water-treatment systems and the replacement of stained plumbing fixtures, appliances, and clothing. A geochemical study, similar to that proposed for arsenic, would help identify the conditions under which large iron and manganese concentrations are present, and might help reduce the number of wells with related problems.

Any of these efforts, once implemented, would be reviewed annually and modified as necessary to make sure that goals and objectives continue to be met. This is especially true of the monitoring efforts. Also, monitoring and study efforts need to be integrated with other ongoing work. For example, the bacteria, nitrate, and volatile organic compound samplings could be coordinated with sampling required by the Washington State Department of Health, if possible.

SUMMARY AND CONCLUSIONS

East King County encompasses 250 mi^2 of King County east of Seattle and Lake Sammamish, and includes much of the Snoqualmie River Valley and Sammamish Plateau. The population in the study area tripled to about 56,500 from 1970 to 1990, and is projected to double from 1990 to 2020. This rapid population growth has brought an attendant increase in the demand for water, which, if growth continues as projected, will increase into the future. Ground-water resources have been developed to meet much of this present demand and probably will be developed further to meet the future needs.

The importance of ground water in east King County has led to, among other things, this study of the ground-water system with the following objectives:

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

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

(3) evaluate the potential for ground-water development on the basis of aquifer characteristics, ground-water interaction with surface water, and ground-water recharge; and

(4) determine what additional data are needed to further quantify ground-water availability.

East King County is underlain by as much as 1,200 feet of Quaternary unconsolidated deposits, which are of both glacial and nonglacial origin. Beneath these unconsolidated deposits is bedrock, composed of Tertiary and pre-Tertiary consolidated rocks. A net of 12 geohydrologic sections was constructed and used to delineate 10 geohydrologic units. They are, in order of increasing geologic age:

(1) Quaternary alluvium (Qal);
(2) Vashon recessional outwash (Qvr);
(3) Vashon till (Qvt);
(4) Vashon advance outwash (Qva);
(5) Upper fine-grained unit (Q(A)f);
(6) Upper coarse-grained unit (Q(A)c);
(7) Lower fine-grained unit (Q(B)f);
(8) Lower coarse-grained unit (Q(B)c);
(9) Deepest unconsolidated and undifferentiated deposits (Q(C)); and
(10) Bedrock (Br).

In general, the unconsolidated deposits are lithologically variable and have a limited areal extent, especially to the southwest and east where these units begin to pinch out over the rising bedrock. The extent of Qal is limited to the floor of the Snoqualmie River Valley and its major tributaries, but the river has eroded away some of the older unconsolidated units so that Q(A)f is the youngest unit that is continuous from one side of the Snoqualmie River Valley to the other.

Units Qal, Qvr, Qva, and Q(A)c form the major aquifers of the study area, but usable quantities of ground water can sometimes be obtained from Br. Units Qvt and Q(A)f generally act as confining beds, although numerous wells produce water from local lenses of sand and gravel within these deposits. The deeper unconsolidated units, Q(B)f, Q(B)c, and Q(C) are tapped by a few wells, but it is likely that Q(B)f is a confining bed and Q(B)c may produce significant quantities of water. The productivity of Q(c) is unknown.

Precipitation is estimated to be 57 in/yr over the entire study area. Of this, 31 in. (413,000 acre-ft) is estimated to enter the ground-water system as recharge. Recharge, like precipitation, varies considerably throughout the study area, but tends to be largest in the east where precipitation is highest.

Within the major aquifers, some ground water in the study area flows toward the Snoqualmie River Valley, then northward up the valley and out of the study area. Ground water in much of the Sammamish Plateau flows westward, toward Lake Sammamish. Flow to the deeper regional ground-water system is unknown, but may be significant. Gradients range from less than 5 ft/mi in the Snoqualmie River Valley floor to more than 1,000 ft/mi over short distances near Snoqualmie Falls. Vertical flow tends to be downward in upland areas such as the Sammamish Plateau. In the lower Snoqualmie River Valley, vertical flows tend to be upward, resulting in several flowing wells in the valley floor near the base of the uplands. Median hydraulic conductivities ranged from 34 to 130 ft/day for the aquifers (Qal, Qvr, Qva, Q(A)c, and Q(B)c). The median hydraulic conductivities for confining units Q(A)f and Q(B)f were much lower, 9.0 and 15 ft/day, respectively. The median hydraulic conductivity for Qvt was 51 ft/day, relatively higher than most of the other units, including some of the aquifers. This was attributed to the heterogeneity of the unit and the fact that wells in Qvt tend to be preferentially completed in coarser zones. The median hydraulic conductivity of Br was only 0.88 ft/day, indicating it is not a reliable source of large quantities of water.

Ground water in the study area discharges as seepage to lakes and streams, spring flow, transpiration by plants, seepage to valley walls, ground-water flow out of the study area, and withdrawals from wells. Discharges to the Snoqualmie River and Lake Sammamish were estimated to total 98,500 acre-ft/yr, on the basis of low-flow measurements made in September 1991. Discharges to known major springs were estimated to be 9,540 acre-ft/yr, and ground-water withdrawals from wells were estimated to be 4,270 acre-ft/yr. The remaining 300,700 acre-ft of recharge is thought to discharge mostly as ground water flowing north and west out of the study area, but this estimate is high because the estimates of river and spring discharge and ground-water withdrawals are incomplete.

In addition to the 4,270 acre-ft of ground water withdrawn from wells in 1990, another 5,290 acre-ft of spring discharge was put to beneficial use. Of the 9,560 total acre-ft used, 4,460 acre-ft (47 percent) was used by Class I and Class II public supply systems, which supply water to 48,100 people, or 85 percent of the total population. An additional 2,280 acre-ft of water was imported from outside the study area to augment these public supplies. Some 3,010 acre-ft (31 percent), all from springs, was used for aquaculture. The remaining ground water used is primarily for domestic supplies, irrigation, and dairy cattle.

The chemical quality of ground water in the study area was typical for western Washington. Dissolved-solids concentrations ranged from 37 to 551 mg/L, with a median concentration of 115 mg/L, and tended to increase in the lower units. Some 95 percent of the water samples were classified as soft or moderately hard. The major cations were calcium and magnesium, but sodium was predominant in a few samples. The major anion was bicarbonate. Calcium/bicarbonate and calcium-magnesium/bicarbonate were the most common water types in samples from wells finished in the unconsolidated deposits. These water types also are typical of glacial deposits of western Washington. Sodium/bicarbonate and sodium-calcium/bicarbonate water types were common in Br.

Nitrate concentrations were small, ranging from <0.05 mg/L to 6.3 mg/L, with a median concentration of only 0.07 mg/L. These small concentrations suggest that there is no widespread contamination from septic tanks or agricultural activities. However, 20 percent of the nitrate concentrations exceeded 1.0 mg/L, and most of these came from samples from wells less than 100 feet deep. Local contamination from septic tanks, pastures, or lawn fertilizers is the probable source.

Water-quality problems in east King County, when present, were commonly due to natural causes. Iron concentrations were as large as 14,000 µg/L, and manganese concentrations were as large as 920 µg/L. At these levels, taste may be adversely affected and plumbing fixtures may be stained red, brown, or black. These problems were evident throughout much of the study area, and are common throughout western Washington. These large concentrations are due to the dissolution of iron and manganese present in the aquifer minerals.

Another natural water-quality problem, and perhaps the one of largest concern, is the presence of arsenic in ground water throughout much of the study area. Arsenic concentrations ranged from <1 to 77 µg/L, with a median concentration of 2 µg/L. Arsenic was present in samples from 79 wells (64 percent) and 18 samples (15 percent) had concentrations of 20 µg/L or larger. Most of the larger concentrations were from wells along or east of the Snoqualmie River, between Carnation and Duvall. The arsenic is likely natural, as it is commonly associated with igneous rocks that constitute much of the Br. Igneous rocks are also a source of much of the unconsolidated glacial material.

Radon concentrations ranged from <80 to 530 pCi/L, with a median concentration of 250 pCi/L. Radon concentrations observed in the study area are smaller than those observed in other areas of western Washington. The presence of other trace elements and the septage-related compounds was minimal. Concentrations exceeding natural levels were rare, and no water-quality problems were indicated.

No volatile organic compounds were detected in the samples collected from 11 wells. Although the absence of these compounds suggests industrial contamination is not widespread, it does not eliminate the possibility of their presence locally in the ground water.

The pesticide dicamba was present at a concentration of 0.01 µg/L in samples from 3 of the 12 wells sampled. In another sample, 2,4-D was present at a concentration of 0.02 µg/L. The presence of these pesticides suggests some type of contamination, possibly related to agricultural activities or road maintenance. Although these concentrations are small and no widespread contamination is evident, further investigation as to the potential sources may be warranted.

Concentrations of selected constituents were compared with maximum contaminant levels, or MCLs, for applicable USEPA drinking water regulations. The only primary MCL that was not met in all cases was the one for arsenic, which is 50 µg/L. One sample had an arsenic concentration of 77 µg/L. However, the USEPA is reviewing the arsenic MCL, and may lower it to 3 µg/L or less to consider the carcinogenic effects of arsenic. Samples from 42 wells (34 percent) would not meet this lower MCL. The presence of fecal-coliform bacteria in samples from two sites suggests the MCL for total coliform was not met. More samples did not meet the secondary maximum contaminant level (SMCL) for manganese than for any other standard. Some 29 percent of all wells had samples that did not meet the manganese SMCL of 50 µg/L. Likewise, 11 percent did not meet the SMCL of 300 µg/L for iron. The SMCL for pH was not met in 22 percent of the samples; 8 percent of the samples had values below the lower limit of 6.5, and 14 percent of the samples had values larger than the upper limit of 8.5. The SMCL of 500 mg/L for dissolved solids and 2 mg/L for fluoride were each not met once, in the same sample. This sample was collected from a well completed in bedrock and the dissolved-solids concentration of 551 mg/L and fluoride concentration of 2.5 mg/L are most likely due to natural conditions. All other applicable drinking water regulations were met, including those for trace elements and organic compounds. However, samples from five wells, or 29 percent, would not meet the proposed radon MCL of 300 pCi/L.

SELECTED REFERENCES

Bauer, H.H., and Vaccaro, J.J., 1987, Documentation of a deep percolation model for estimating ground-water recharge: U.S. Geological Survey Open-File Report 86-536, 180 p.

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

Blunt, D.J., Easterbrook, D.J., and Rutter, N.W., 1987, Chronology of Pleistocene sediments in the Puget Lowland, Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 321-353.

Booth, D.B., 1990, Surficial geologic map of the Skykomish and Snoqualmie Rivers Area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1745, scale 1:50,000, 22 p., 2 pls.

Booth, D.B., and Minard, J.P., 1992, Geologic map of the Issaquah quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-2206, scale 1:24,000, 1 sheet.

Bortleson, G.C., Dion, N.P., McConnell, J.B., and Nelson, L.M., 1976, Reconnaissance data on lakes in Washington, volume 2, King and Snohomish Counties: Washington State Department of Ecology Water-Supply Bulletin 43, v. 2, 424 p.

Bredehoeft, J.D., Papadopulos, S.S., and Cooper, H.H., Jr., 1982, Groundwater: The water-budget myth, *in* Studies in Geophysics, Scientific Basis of Water-Resource Management: National Academy Press, p. 51-57.

Bretz, J.H., 1913, Glaciation of the Puget Sound region: Washington Geological Survey Bulletin 8, 244 p.

Britton, L.J., and Greeson, P.E., 1988, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A4, Open-File Report 88-190, 685 p.

Carey, Barbara, 1986, Quality assurance interim guidelines for water quality sampling analysis: Ground Water Management Areas: Washington State Department of Ecology, 108 p.

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

Crandell, D.R., 1965, The glacial history of western Washington and Oregon, *in* Wright, H.E., Jr., and Frey, D.G., eds., The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, p. 341-353.

Crandell, D.R., Mullineaux, D.R., and Waldron, H.H., 1958, Pleistocene sequence in the southeastern part of the Puget Sound Lowland, Washington: American Journal of Science, v. 256, p. 384-397.

_____1965, Age and origin of the Puget Sound trough in western Washington: U.S. Geological Survey Professional Paper 525-B, p. B132-B136.

Dion, N.P., Sumioka, S.S., and Winter, T.C., 1983, General hydrology and external sources of nutrients affecting Pine Lake, King County, Washington: U.S. Geological Survey Water-Resources Investigations Report 83-4057, 29 p.

Dion, N.P., Turney, G.L., and Jones, M.A., 1994, Geohydrology and quality of ground water in Thurston County: U.S. Geological Survey Water-Resources Investigations Report 92-4109, 188 p., 6 pls.

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

Ficklen, W.H., Frank, D.G., Briggs, P.K., and Tucker, R.E., 1989, Analytical results for water, soil, and rocks collected near Granite Falls, Washington, as part of an arsenic-in-ground water study: U.S. Geological Survey Open-File Report 89-148, 9 p.

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 545 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.

Friedman, L.C., and Erdmann, D.E., 1982, Quality assurance practices for the chemical and biological analyses of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A6, 181 p.

Frizzell, V.A., Jr., Tabor, R.W., Booth, D.B., Ort, K.M., and Waitt, R.B., Jr., 1984, Preliminary geologic map of the Snoqualmie Pass quadrangle, Washington: U.S. Geological Survey Open-File Report 84-693, scale 1:100,000, 43 p., 1 pl.

Frost, Floyd, and ten others, 1991, Seasonal study of arsenic in ground water, Snohomish County, Washington: Washington State Department of Health, 18 p.

Geldreich, E.E.. and Van Donsel, D.J., 1970, Salmonellae in fresh water pollution, *in* Proceedings of the National Specialty Conference on Disinfection: Amherst, Mass., July 8-10, 1970, American Society of Civil Engineers, p. 495-514.

Gower, H.D., Yount, J.C., and Crosson, R.C., 1985, Seismotectonic map of the Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Field Investigations Map I-1613, 15 p., 1 pl.

Hall, J.B., and Othberg, K.L., 1974, Thickness of unconsolidated sediments, Puget Lowland, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-12, scale approximately 1:316,800, 3 p., 1 pl.

Hearn, P.P., Steinkampf, W.C., Bortleson, G.C., and Drost, B.W., 1985, Geochemical controls on dissolved sodium in basalt aquifers of the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4304, 38 p., 1 pl.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water, 3rd ed.: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hubbert, M.K., 1940, The theory of ground-water motion: Journal of Geology, v. 48, no. 8, pt. 1, p. 785-944.

Hughes, J.L., 1975, Evaluation of ground-water degradation resulting from waste disposal to alluvium near Barstow, California: U.S. Geological Survey Professional Paper 878, 33 p.

King County Parks, Planning, and Resources Department, 1991, The 1991 annual growth report, 132 p.

LeBlanc, D.R., 1984, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts: U.S. Geological Survey Water-Supply Paper 2218, 28 p.

Liesch, B.A., Price, C.E., and Walters, K.L., 1963, Geology and ground-water resources of northwestern King County, Washington: Washington Division of Water Resources, Water-Supply Bulletin no. 20, 241 p., 3 pls.

Livingston, V.E., Jr., 1971, Geology and mineral resources of King County, Washington: U.S. Geological Survey Bulletin 63, 200 p., 6 pls.

Mackin, J.H., 1941, Glacial geology of the Snoqualmie-Cedar area, Washington: The Journal of Geology, v. 49, no. 5, p. 449-481.

Minard, J.P., 1985, Geologic map of the Maltby quadrangle, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1746, scale 1:24,000, 1 sheet.

Minard, J.P., and Booth, D.B., 1988, Geologic map of the Redmond quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-2016, scale 1:24,000, 1 sheet.

National Oceanic and Atmospheric Administration, 1982, Monthly normals of temperature, precipitation, and heating and cooling degree days, 1951-80: Climatography of the United States no. 81 (Washington), 17 p.

National Research Council, 1978, Nitrates: An environmental assessment: Washington, D.C., National Academy of Sciences, 723 p.

Phillips, E.L., 1960, Climate of Washington: U.S. Department of Commerce, Weather Bureau, Climatography of the United States, no. 60-45, 27 p.

Porter, K.S., 1980, An evaluation of sources of nitrogen as causes of ground water contamination in Nassau County, Long Island: Ground Water, v. 18, no 6, p. 617-625.

Pritt, Jeffrey, and Jones, B.E., 1989, National Water Quality Laboratory Services catalog: U.S. Geological Survey Open-File Report 89-386, unpaginated.

Richardson, Donald, Bingham, J.W., and Madison, R.J., 1968, Water resources of King County, Washington: U.S. Geological Survey Water-Supply Paper 1852, 74 p.

Steinkampf, W.C., Bortleson, G.C., and Packard, F.A., 1985, Controls on ground-water chemistry in the Horse Heaven Hills, south-central Washington: U.S. Geological Survey Water-Resources Investigations Report 85-4048, 26 p.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., Whetten, J.T., Waitt, R.B., Jr., and Zartman, R.E., 1982, Preliminary geologic map of the Skykomish River 1:100,000 quadrangle, Washington: U.S. Geological Survey Open-File Map 82-747, 31 p., 1 pl.

Thorson, R.M., 1980, Ice-sheet glaciation of the Puget Lowland, Washington, during the Vashon Stade (late Pleistocene): Quaternary Research, v. 13, p. 303-321.

Thurman, E.M., 1985, Organic geochemistry of natural waters: Martinus Nijhoff/Dr. W. Junk, Publishers, Dordecht, The Netherlands, 497 p.

Todd, D.K., 1980, Groundwater hydrology: New York, John Wiley and Sons, 535 p.

Tóth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, v. 68, p. 4,795-4,812.

Turney, G.L., 1986a, Quality of ground water in the Puget Sound region, Washington, 1981: U.S. Geological Survey Water-Resources Investigations Report 84-4258, 170 p., 2 pls.

_____1986b, Quality of ground water in southeastern and south-central Washington, 1982: U.S. Geological Survey Water-Resources Investigations Report 84-4262, 158 p., 5 pls.

_____1986c, Quality of ground water in the Columbia Basin, Washington, 1983: U.S. Geological Survey Water-Resources Investigations Report 85-4320, 172 p., 5 pls.

_____1990, Quality of ground water in Clark County, Washington, 1988: U.S. Geological Survey Water-Resources Investigations Report 90-4149, 97 p.

U.S. Department of Agriculture, 1973, Soil survey of King County area, Washington: U.S. Department of Agriculture Soil Conservation Service, 100 p.

U.S. Environmental Protection Agency, 1976, National interim primary drinking water regulations: U.S. Government Printing Office, 159 p.

_____1986, Quality criteria for water, 1986: U.S. Environmental Protection Agency Publications EPA 440/5-86-001, unpaginated.

_____1988a, Maximum contaminant levels (subpart B of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised as of July 1, 1988, p. 530-533.

_____1988b, National revised primary drinking water regulations: Maximum contaminant levels (subpart G of part 141, National interim primary drinking water regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised as of July 1, 1988, p. 586-587.

_____1988c, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking water regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised as of July 1, 1988, p. 608.

_____1989, Final rule, National primary drinking water regulations; Giardialamblia, viruses, Legionella, and total coliforms (subparts F and G of part 141): U.S. Federal Register, v. 54, no. 124, June 29, 1989, p. 27,486-27,568.

_____1991, Drinking water regulations and health advisories, April 1991: U.S. Environmental Protection Agency Office of Water, unpaginated.

Van Denburgh, A.S., and Santos, J.F., 1965, Ground water in Washington, its chemical and physical quality: Washington State Pollution Control Commission Water-Supply Bulletin 24, 93 p.

Washington State Department of Ecology, 1988, Guidelines for development of ground-water management areas and programs, Chapter 173-100 WAC, 16 p.

Washington State Department of Social and Health Services, 1983, Rules and regulations of the State Board of Health regarding public water systems: Division of Health, Water-Supply and Waste Section, Olympia, Washington, 40 p.

Welch, A.H., Lico, M.S., and Hughs, J.L., 1988, Arsenic in ground water of the western United States: Ground Water, v. 26, no. 3, p. 333-347.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, chap. A3, 80 p.

White, A.F., Peterson, M.L., and Solbau, R.D., 1990, Measurement and interpretation of low levels of dissolved oxygen in ground water: Ground Water, v. 28, no. 4, p. 584-590.

Willis, Bailey, 1898, Drift phenomena of Puget Sound: Geological Society of America Bulletin, v. 9, p. 111-162.

Wood, W.W., 1981, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations Book 1, chap. D2, 24 p.

Woodward, D.G., Packard, F.A., Dion, N.P., and Sumioka, S.S., in press, Occurrence and quality of ground water in southwestern King County, Washington: U.S. Geological Survey Water-Resources Investigations Report 92-4098.

APPENDIX A.--PHYSICAL AND HYDROLOGIC DATA FOR THE INVENTORIED WELLS AND SPRINGS

[--, not determined]

Explanation

Geohydrologic Unit:	Qal, alluvium; Qvr, Vashon recessional outwash; Qvt, Vashon till; Qva, Vashon advance outwash; Q(A)f, Upper fine-grained unit; Q(A)c, Upper coarse-grained unit; Q(B)f, Lower fine-grained unit; Q(B)c, Lower coarse-grained unit; Br, Bedrock; for more explanation, see figure 10 in the text.
Use of Water:	C, commercial; H, domestic; I, irrigation; N, industrial; P, public supply; R, recreational; S, stock; T, institutional; and U, unused.
Water Level:	Code indicates status of well at time of visit: F, flowing; P, pumping; R, recently pumping; S, nearby well pumping; and T, nearby well recently pumping.
Remarks:	L, driller's (lithologic) log available; W, project observation well for water level; M, sampled for major ions, bacteria, trace metals, and field parameters; V, sampled for volatile organic compounds; P, sampled for pesticides; and S, sampled for detergents, boron, and dissolved organic carbon.

Table A1.--*Physical and hydrologic data for the inventoried wells and springs*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
23N/07E-01C01	473042	1215124	Q(A)c	870	92	6	H	46.57 R	05-31-90	120	L
23N/07E-01C02	473045	1215121	Q(A)c	860	96	6	U	--	--	--	L
23N/07E-01D01	473047	1215143	Br	1,030	163	8	H	67.48	10-22-90	.10	L
23N/07E-02A01	473041	1215205	Br	980	140	6	P	41.80	09-19-90	17	L
23N/07E-02A02	473042	1215205	Br	983	180	6	P	44.36	09-19-90	--	L
23N/07E-02D01	473045	1215252	Br	985	379	8	U	40.61	07-10-90	--	--
23N/07E-02F01	473039	1215245	Br	970	170	8	P	--	--	3.6	L
23N/07E-02G01	473026	1215213	Br	920	78	8	H	3.11	05-31-90	69	L
23N/08E-03E02	473028	1214626	Qal	432	60	6	P	10.57	05-02-90	300	L
23N/08E-03F01	473028	1214620	Qal	428	49	6	H	5.53	05-02-90	11	L
23N/08E-03L03	473019	1214612	Qal	435	230	6	H	6.79 R	05-02-90	98	LWM
23N/08E-03P01	473009	1214619	Qal	437	35	6	H	4.45	05-02-90	32	L
23N/08E-04A01	473038	1214656	Qal	422	28	6	H	6.56 R	07-02-90	42	L
23N/08E-04G01	473037	1214706	Qal	418	36	6	H	7.06	05-03-90	51	L
23N/08E-04H01	473034	1214702	Qal	419	29.5	6	H	8.14	05-02-90	28	L
23N/08E-04L01	473012	1214730	Qal	430	47	6	I	8.75	06-05-90	--	LMVP
23N/08E-04P01	473012	1214733	Qal	430	22	33	U	6.85	05-03-90	--	--
23N/08E-05K01	473023	1214831	Qal	430	8.3	33	H	4.06	05-03-90	--	--
23N/08E-05K02	473015	1214822	Qal	430	39	6	H	4.96	05-03-90	220	LMVS
23N/08E-06F01	473038	1215014	Qva	970	80	6	C	5.68	09-06-90	250	L
23N/08E-08K01	472921	1214834	Br	680	240	6	H	35.10	05-09-90	--	LM
23N/08E-08K02	472927	1214827	Qvr	570	40	6	H	21.57	05-10-90	100	L
23N/08E-08K03	472927	1214823	Qvr	550	37	6	H	10.74	05-10-90	31	L
23N/08E-09J01	472926	1214701	Qal	443	16	36	R	8.76	05-03-90	--	W
23N/08E-10B01	472948	1214603	Qal	448	30	6	P	13.75	07-05-90	--	L
23N/08E-10F02	472934	1214618	Qal	450	14	36	U	4.98	05-03-90	--	--
23N/08E-10F03	472934	1214618	Qal	450	18.5	6	H	5.21	05-03-90	--	LMVS
23N/08E-10H01	472934	1214531	Qal	470	40	6	H	17.07	05-04-90	310	L
23N/08E-10J01	472919	1214543	Qal	473	78	8	H	9.06	05-10-90	--	--
23N/08E-10L01	472931	1214608	Qal	450	40	6	H	10.45	05-10-90	860	L
23N/08E-10P02	472910	1214622	Qal	463	50	8	H	12.74 R	05-04-90	1,000	L
23N/08E-12J01	472918	1214303	Qal	700	49	6	H	26.46	05-07-90	660	L
23N/08E-12J02	472920	1214255	Qvr	720	99	6	H	56.61	05-18-90	610	L
23N/08E-13G01	472837	1214329	Qal	650	183	8	H	136.32	11-29-90	74	L
23N/08E-13H01	472843	1214255	Qal	620	60	8	H	38.40	05-08-90	140	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
23N/08E-13N01	472812	1214354	Qal	595	194	8	H	75.01	05-07-90	78	LWM
23N/08E-13R01	472817	1214257	Qal	715	237	6	H	187.63	05-07-90	--	L
23N/08E-14B01	472902	1214438	Qal	555	81	6	H	43.01	05-08-90	310	L
23N/08E-14C01	472900	1214459	Qal	485	140	8	H	12.83	05-10-90	--	L
23N/08E-14G02	472838	1214438	Qal	510	57	6	H	21.95	05-08-90	--	L
23N/08E-14G03	472843	1214443	Qal	515	96	8	H	28.43	05-10-90	110	L
23N/08E-15A05	472859	1214543	Qal	484	43	6	H	16.97	05-09-90	180	L
23N/08E-15B05	472902	1214548	Qal	482	38	6	H	17.15	05-21-90	120	L
23N/08E-15D01	472904	1214627	Qal	462	53	8	H	11.04	05-11-90	920	L
23N/08E-15J06	472836	1214542	Qal	482	40	6	H	12.90	05-11-90	380	LWM
23N/08E-15K07	472827	1214556	Qal	475	57	6	H	8.77 R	05-11-90	--	L
23N/08E-15P01	472824	1214615	Qal	472	11	30	H	7.48	05-16-90	--	--
23N/08E-15P02	472827	1214615	Qal	470	12	30	I	4.93	05-16-90	--	--
23N/08E-16B01	472854	1214707	Qal	448	43	6	P	--	--	540	L
23N/08E-16C01	472858	1214740	--	525	41	6	U	37.08	05-22-90	--	--
23N/08E-16F01	472842	1214734	Br	650	400	6	H	89.19 R	05-15-90	15	L
23N/08E-16L01	472830	1214739	Br	750	415	6	H	115.48	06-01-90	.03	L
23N/08E-16M01	472834	1214739	Br	720	750	8	P	249.10 R	07-11-90	.12	LM
23N/08E-16Q01	472819	1214709	Br	510	53	6	H	8.17	05-16-90	6.6	L
23N/08E-22A01	472803	1214528	Qal	493.62	18.2	36	H	14.95	05-16-90	--	MVS
23N/08E-23A01	472808	1214430	Qal	525	60	8	P	--	--	--	L
23N/08E-23A02	472809	1214430	Qal	525	47	8	U	26.30 T	05-22-90	610	L
23N/08E-23A03	472811	1214430	Qal	525	62	8	P	--	--	--	L
23N/08E-23F02	472755	1214503	Qal	510	112	8	U	6.34	09-13-90	19	L
23N/08E-24A01	472807	1214258	Qal	680	207	8	C	153.97 R	05-17-90	160	L
23N/08E-24C01	472803	1214336	Qal	580	97	6	H	17.57 R	05-18-90	49	L
23N/08E-24H01	472754	1214314	Qal	610	119	8	H	70.31 R	05-22-90	--	L
23N/08E-24J01	472735	1214313	Br	580	178	8	H	5.20	05-30-90	2.2	LM
23N/08E-24J02	472735	1214304	Qal	590	25	8	U	3.05 P	05-30-90	--	L
23N/08E-25F01	472658	1214336	Qal	630	48	6	H	1.82	05-18-90	13	LM
23N/08E-25L01	472646	1214341	Qvt	660	82	6	H	14.07	05-18-90	2.2	L
23N/08E-25R01	472638	1214310	Qvr	780	78	6	H	48.25 R	05-21-90	150	L
23N/08E-25R02	472638	1214308	Qvr	780	215	6	H	161.52	05-30-90	49	L
23N/08E-26C01	472721	1214506	Br	795	144	6	U	57.82	05-21-90	--	--
23N/08E-26Q01	472638	1214439	Qvt	770	45	8	H	26.82 R	06-04-90	200	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
23N/08E-27N01	472633	1214629	Br	1,130	240	6	H	28.89 R	05-31-90	0.17	L
23N/08E-27R01	472637	1214541	Qvr	975	196	6	U	66.31	06-14-90	--	L
23N/09E-07P01	472912	1214223	Qvr	875	111	6	H	102.73	06-29-90	--	L
23N/09E-07Q01	472905	1214215	Qal	860	99.5	6	H	59.00	06-28-90	--	L
23N/09E-18N01	472812	1214237	Qal	760	248	8	P	195.67	09-12-90	130	L
23N/09E-19N01	472718	1214249	Qal	590	54	6	H	1.52	06-29-90	28	L
24N/06E-01E01	473543	1215910	Qvr	450	17	20	U	--	--	--	--
24N/06E-02E01	473551	1220042	Qvt	530	40	6	P	11.84	07-09-90	220	LMS
24N/06E-02P01	473520	1220010	--	420	110	10	U	--	--	--	--
24N/06E-02P02	473518	1220011	--	420	100	6	U	--	--	--	--
24N/06E-03E01	473547	1220200	Qva	560.44	176	6	P	--	--	--	L
24N/06E-03P01	473529	1220136	Qva	380	68	6	U	26.68	07-10-90	28	L
24N/06E-03P02	473522	1220142	Qva	375	97	6	H	--	--	63	L
24N/06E-03R01	473519	1220054	Qvr	385	12	30	U	--	--	--	--
24N/06E-04J01	473533	1220220	Qvt	412.65	31.5	1.25	U	12.14	07-10-90	--	L
24N/06E-04K01	473533	1220235	Qvr	426.77	17	72	U	4.82	07-10-90	--	W
24N/06E-04N01	473527	1220302	Q(A)c	449	300	10	U	--	--	--	L
24N/06E-04N01P1	473527	1220302	Q(A)c	449	300	10	U	187.11	09-14-90	--	L
24N/06E-04N02	473527	1220303	Q(A)c	449	346	12	U	--	--	84	L
24N/06E-04N02P1	473527	1220303	Q(A)c	449	316	12	U	191.95	09-14-90	--	L
24N/06E-04N02P2	473527	1220303	Q(A)c	449	265	12	U	187.66	09-14-90	--	L
24N/06E-04P02	473519	1220257	Qvt	406.24	54.1	1.25	U	18.61	07-06-90	--	L
24N/06E-05D01	473606	1220416	Qal	130	6.5	36	U	3.61	07-13-90	--	--
24N/06E-05D02	473605	1220420	Qal	135	12	30	H	9.66	07-13-90	--	--
24N/06E-05H01	473551	1220324	Qva	350	153	6	H	--	--	--	L
24N/06E-06A05	473605	1220449	Q(A)c	25	87	6	H	-- F	07-10-90	1,100	LM
24N/06E-06J02	473542	1220448	Qva	125	143	6	H	51.38	07-13-90	46	L
24N/06E-08F01	473459	1220413	Q(A)c	355	342	6	H	--	--	--	L
24N/06E-08J01	473451	1220329	Qvt	384.32	25	84	Z	--	--	--	--
24N/06E-08K02	473450	1220343	Qvt	410	47	36	U	24.21	07-19-90	--	--
24N/06E-08P02	473433	1220409	Q(A)f	110	185	8	Z	--	--	--	L
24N/06E-09A07	473511	1220208	Qva	402.27	110	6	H	85.07	07-11-90	--	--
24N/06E-09A09	473517	1220205	Qvr	417.22	29.2	1.25	U	8.71	07-06-90	--	L
24N/06E-09A10	473517	1220214	Qvt	401.19	47.5	1.25	U	31.98	07-06-90	--	L
24N/06E-09A11	473518	1220214	Q(B)f	401.68	424	2	U	158.77	07-06-90	--	LW

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/06E-09A12	473518	1220214	Qva	401.70	123	2	U	72.81	07-06-90	--	W
24N/06E-09A13	473518	1220214	Q(A)f	401.87	231	2	U	87.96	07-06-90	--	W
24N/06E-09A14	473518	1220214	Qva	401.69	203	2	U	86.16	07-06-90	--	W
24N/06E-09A15	473518	1220214	Qva	401.51	170	2	U	85.34	07-09-90	--	W
24N/06E-09E03	473503	1220306	Qva	385	251	6	H	120.78	07-06-90	4.1	LM
24N/06E-09E04	473504	1220306	Q(A)f	386.27	420	2	U	75.23	07-06-90	--	L
24N/06E-09H02	473502	1220212	Qva	403.53	101	6	H	87.54	07-11-90	--	L
24N/06E-09J01	473449	1220205	Qva	430	130	12	C	115.72 S	07-12-90	3,400	L
24N/06E-09J02	473449	1220207	Qva	430	132.5	12	C	119.20 R	07-12-90	6,100	L
24N/06E-09N02	473429	1220302	Qva	310	199	6	H	99.40	07-11-90	10	LWM
24N/06E-09N03	473428	1220313	Q(A)f	350	202	6	H	99.08	07-11-90	32	L
24N/06E-10C01	473513	1220127	--	370	20	30	Z	--	--	--	--
24N/06E-10D01	473517	1220159	Qvr	387.12	31.7	1.25	U	6.17	07-13-90	--	L
24N/06E-10H01	473502	1220059	Qva	455	150	12	U	119.79	08-22-90	930	L
24N/06E-10H02	473501	1220059	Qva	455	155.2	16	P	120.96	08-22-90	1,400	LMVPS
24N/06E-10H03	473503	1220058	Qva	455	169	8	U	121.29	09-14-90	1,300	L
24N/06E-10L02	473441	1220128	Qvt	360	109	6	U	43.48	07-16-90	32	L
24N/06E-10P02	473430	1220124	Qva	355	72	6	H	--	--	46	LMS
24N/06E-11B01	473506	1215956	Qva	440	92	6	Z	--	--	--	--
24N/06E-11K01	473448	1215954	Qva	430	116	12	P	63.95	08-22-90	200	L
24N/06E-11L01P1	473439	1220016	Qva	420	135	8	U	65.18	09-14-90	--	LW
24N/06E-11L01P2	473439	1220016	Qva	420	95	8	U	66.45	09-14-90	--	LW
24N/06E-11L01P3	473439	1220016	Qvt	420	25	8	U	23.05	09-14-90	--	L
24N/06E-12B01	473510	1215845	Q(A)c	430	160	6	H	119.67	08-10-90	92	LM
24N/06E-12L01	473439	1215909	Q(A)f	440	362	6	H	--	--	12	LM
24N/06E-12N02	473425	1215915	Q(A)c	450	208	6	H	--	--	11	L
24N/06E-12R01	473429	1215819	Qva	450	108	8	P	80.10	07-16-90	1,100	L
24N/06E-13D01	473411	1215918	Qva	475	155	6	H	136.20	07-16-90	310	L
24N/06E-14H02	473410	1215943	Qva	480	124	6	H	91.13	07-16-90	540	L
24N/06E-14N01	473341	1220032	Multiple	460	198	6	U	111.93	07-17-90	--	L
24N/06E-14N02	473337	1220045	Qvr	470	146	6	Z	--	--	230	L
24N/06E-15C01	473420	1220137	Qva	355	79	6	H	19.69	07-17-90	9.6	L
24N/06E-15F01	473403	1220128	Qvt	370	156	6	H	-- F	07-17-90	.04	L
24N/06E-15N01	473334	1220148	Br	450	160	6	H	--	--	.72	L
24N/06E-16E01	473410	1220312	Q(A)c	125	196	6	H	54.06	09-26-90	--	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/06E-16E02	473406	1220310	--	60	10	48	Z	--	--	--	L
24N/06E-16L02	473354	1220301	--	55	84	6	H	-0.52 F	07-19-90	--	L
24N/06E-17H01	473413	1220330	Q(A)f	135	228	8	H	--	--	19	L
24N/06E-21A01	473328	1220216	Br	425	120	8	U	40.87	07-19-90	1.4	L
24N/06E-21B01	473332	1220231	Br	390	200	8	H	63.49	07-19-90	28	L
24N/06E-21J01	473306	1220221	Qva	55	150	6	P	-- F	10-30-90	150	L
24N/06E-22A02	473327	1220059	Qvt	450	85	6	I	49.53	08-10-90	61	L
24N/06E-22C01	473332	1220133	Br	420	240	6	H	51.90	08-09-90	.21	L
24N/06E-22F01	473319	1220136	Br	555	510	12	P	112.74	10-30-90	--	L
24N/06E-22H02	473311	1220105	Qvr	425	86	6	H	62.38	08-09-90	8.7	LM
24N/07E-03P01	473515	1215406	Q(A)c	90	320	6	H	-- F	09-28-90	6.8	LM
24N/07E-04E01	473540	1215534	Qal	75	65	6	H	12.53	10-05-90	9.7	LMP
24N/07E-04M01	473530	1215528	Qal	79	23	24	U	16.65	09-25-90	--	L
24N/07E-04M02	473527	1215528	Qal	76	60	6	I	16.38	09-25-90	240	L
24N/07E-05B01	473551	1215604	Qva	90	87	6	I	--	--	59	L
24N/07E-05F01	473548	1215628	Br	400	765	8	C	231.50	09-25-90	3.8	LM
24N/07E-06A01	473555	1215704	Q(A)c	270	211	6	H	148.47	09-25-90	150	L
24N/07E-06B01	473558	1215714	Q(A)c	230	106	6	H	90.88	10-11-90	--	LM
24N/07E-06B02	473601	1215723	Q(A)c	185	89	6	H	--	--	45	L
24N/07E-07Q01	473425	1215740	Q(A)f	480	247	6	H	--	--	--	L
24N/07E-08A01	473513	1215609	Qva	330	169	8	H	157.00	10-05-90	8.0	L
24N/07E-08A02	473510	1215607	Qvt	310	39	6	H	22.38	10-05-90	37	LMP
24N/07E-08B01	473512	1215612	Q(A)f	330	460	6	H	240.01	10-05-90	.03	L
24N/07E-08F02	473457	1215631	Q(B)c	90	880	10	U	-.78 F	09-13-90	1.4	LW
24N/07E-08G01	473453	1215623	Qal	85	8	30	H	6.21	10-05-90	--	LW
24N/07E-08J01	473440	1215552	Qvrl	95	104	6	Z	--	--	--	L
24N/07E-08P01	473425	1215631	Qvr	210	58	6	H	27.57	09-27-90	--	L
24N/07E-08R01	473433	1215601	Qvr	90	188	6	H	17.45	09-28-90	6.8	L
24N/07E-09D02	473507	1215546	Qva	120	72	6	S	--	--	3.0	L
24N/07E-09M01	473438	1215546	Q(A)f	105	353	6	H	22.12 R	09-26-90	9.1	L
24N/07E-09N01	473423	1215548	Qvr	120	114	6	H	69.93 R	09-26-90	.43	L
24N/07E-10C01	473505	1215356	Qal	85	52	8	Z	--	--	--	L
24N/07E-10K01	473436	1215334	Qal	85	36	6	S	9.25	09-26-90	410	LMVP
24N/07E-11L01S	473436	1215233	Qvr	330	--	--	U	--	--	--	--
24N/07E-12E01	473452	1215145	Qva	815	112	6	H	96.96	09-28-90	230	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-12E02	473451	1215148	Qvr	815	115	6	H	96.33	10-19-90	450	LM
24N/07E-12F02	473455	1215119	Qvt	760	40	6	U	24.80	10-19-90	--	L
24N/07E-12J01	473433	1215044	Br	965	700	6	U	354.15	06-06-90	--	LM
24N/07E-12K01	473440	1215105	Qvr	950	255	6	S	223.75	10-23-90	--	L
24N/07E-12K02	473433	1215103	Q(A)f	970	360	8	H	218.19	10-26-90	9.0	L
24N/07E-12Q01	473428	1215107	Q(A)f	960	840	6	H	--	--	.34	L
24N/07E-13E01	473358	1215147	Br	295	398	8	H	194.28 R	09-27-90	--	LWM
24N/07E-13M01	473353	1215143	--	250	206	8	P	173.89 R	10-19-90	--	L
24N/07E-13Q01	473338	1215056	Q(A)c	240	240	6	H	120.84	07-10-90	--	L
24N/07E-13R01	473332	1215049	Br	185	298	6	H	81.94 R	09-20-90	--	L
24N/07E-13R02	473330	1215052	Q(A)c	178	246	6	H	74.44 R	09-20-90	27	L
24N/07E-14A01	473418	1215154	Qvr	580	221	5	H	--	--	2.7	L
24N/07E-14D01	473417	1215252	Qal	85	150	6	I	.66	10-11-90	15	LW
24N/07E-14D02	473419	1215252	Qal	86	13	38	U	2.29	10-11-90	--	W
24N/07E-14F02	473408	1215242	Qal	93	14.8	4	Z	--	--	--	--
24N/07E-14G01	473404	1215217	Qal	120	65	6	H	30.51	07-20-90	--	LM
24N/07E-14G02	473400	1215210	Br	140	545	6	H	149.57 R	08-09-90	--	L
24N/07E-14J01	473347	1215152	Br	190	185	6	H	91.77	07-20-90	--	L
24N/07E-14J02	473344	1215154	Qal	175	100	6	H	78.83	07-20-90	310	L
24N/07E-15A01	473408	1215320	Qal	85	46	10	I	13.55	08-03-90	660	L
24N/07E-15D01	473409	1215420	Qal	105	49.5	6	H	32.38	07-19-90	110	LWMVS
24N/07E-15F01	473401	1215357	Qvr	110	206	16	P	39.79 T	07-19-90	--	L
24N/07E-15F02	473401	1215356	Qvr	110	177	16	P	--	--	--	L
24N/07E-15K01	473347	1215333	Qal	117	150	6	H	31.49	07-20-90	--	L
24N/07E-16F01	473356	1215508	Qvr	150	122	6	H	34.65	09-21-90	--	LM
24N/07E-16L01	473347	1215526	Q(A)f	305	185	6	H	121.83 R	09-13-90	--	L
24N/07E-16L02	473349	1215517	Qvr	180	24	30	H	--	--	--	L
24N/07E-16R01	473330	1215446	Q(A)c	380	272	6	U	191.40	09-13-90	2.4	L
24N/07E-17A02	473418	1215554	Qvr	140	197	6	H	31.12	09-18-90	--	L
24N/07E-17B01	473418	1215625	Qvr	210	74	6	H	18.57	09-18-90	--	LM
24N/07E-17H01	473359	1215558	Qvr	240	58	6	H	-- F	09-07-90	18	L
24N/07E-17H02	473404	1215605	Qvr	240	82	6	H	30.23 R	09-18-90	5.6	L
24N/07E-18C03	473410	1215801	Multiple	465	210	6	H	119.90 R	09-07-90	--	L
24N/07E-18F02	473408	1215800	Qvt	475	60	6	H	23.19	09-07-90	46	L
24N/07E-18F03	473405	1215747	Qva	520	80	6	H	44.72	09-06-90	48	LM

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-18G01	473405	1215733	Q(A)c	580	252	6	H	95.57 R	09-06-90	4.5	L
24N/07E-19L01	473253	1215751	Br	1,200	283	6	H	36.79	08-14-90	--	L
24N/07E-19P02	473246	1215756	Br	1,000	91	10	H	28.86	08-15-90	6.4	L
24N/07E-19R02	473250	1215719	Br	1,000	220	6	H	34.33 R	08-15-90	.05	LM
24N/07E-20F01	473308	1215638	Br	1,225	287	6	H	197.00 R	08-17-90	8.1	L
24N/07E-20H01	473309	1215549	Br	1,295	300	6	P	20.86	08-22-90	.21	L
24N/07E-20J01	473303	1215603	Br	1,280	149	6	H	47.99	08-17-90	.61	L
24N/07E-20J02	473301	1215555	Br	1,240	100	6	H	8.61	08-22-90	70	LM
24N/07E-20K01	473302	1215617	Br	1,260	125	6	H	27.02 R	08-23-90	.40	L
24N/07E-21H01	473308	1215440	Br	490	118	6	H	13.84	08-24-90	.29	LWM
24N/07E-21J01	473257	1215430	Br	550	140	6	H	36.41	08-23-90	.49	L
24N/07E-21M01	473300	1215545	Br	1,200	120	6	H	7.81	08-17-90	13	L
24N/07E-21P01	473238	1215527	Br	1,088	275	6	P	179.15	08-17-90	.48	L
24N/07E-22B01	473319	1215340	Q(B)c	240	567	16	P	182.69 R	09-12-90	1,100	L
24N/07E-22E01	473305	1215412	Q(B)f	450	378	6	H	--	--	24	L
24N/07E-22E02	473303	1215418	Qvt	495	92	6	H	57.29	08-23-90	120	L
24N/07E-22L01	473255	1215358	Qal	185	23	8	U	4.04	08-09-90	230	L
24N/07E-22P01	473246	1215404	Q(A)c	200	220	6	H	-- F	08-23-90	--	L
24N/07E-23A01	473325	1215152	Qal	115	52	8	U	19.09	07-18-90	--	L
24N/07E-23D01	473321	1215252	Qal	105	44	6	H	24.71	08-03-90	150	LM
24N/07E-23E01	473305	1215308	Multiple	340	473	8	U	55.22	08-09-90	--	L
24N/07E-23G01	473312	1215213	Q(B)f	115	362	8	H	37.72	08-03-90	6.0	L
24N/07E-23H01	473312	1215207	Qal	105	48	6	H	16.84 R	08-09-90	--	L
24N/07E-23H02	473310	1215154	Br	105	222	6	H	21.88 R	08-07-90	--	L
24N/07E-23H03	473311	1215158	Br	105	223	6	H	15.31	08-09-90	--	LM
24N/07E-24E01	473308	1215150	Br	120	230	6	H	38.30 R	07-13-90	.02	L
24N/07E-24G01	473303	1215107	Q(A)c	121	150.5	6	P	5.11	07-13-90	--	L
24N/07E-24Q01	473246	1215100	Qva	341	119	8	C	52.67 R	07-13-90	39	LM
24N/07E-25N01	473148	1215147	Q(A)c	760	782.3	8	U	407.10	06-27-90	6.1	LW
24N/07E-25P01	473145	1215129	Q(A)c	670	540	8	U	316.13	08-14-90	57	L
24N/07E-26G01	473221	1215214	Q(A)c	860	782	8	U	--	--	.38	L
24N/07E-26M01	473159	1215257	Q(A)c	878	282	6	P	259.82	08-02-90	--	L
24N/07E-26N01	473148	1215303	Q(A)c	900	295	8	P	264.72	08-07-90	1,700	L
24N/07E-27A01	473227	1215324	Q(B)f	818	1,050	8	U	--	--	--	L
24N/07E-27D01	473225	1215424	Q(A)c	250	91	6	H	-- F	08-03-90	--	LM

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-27J01	473159	1215324	Qva	876	267	6	P	244.31	07-02-90	63	L
24N/07E-28K01	473209	1215450	Q(A)c	340	163	8	P	-- F	08-03-90	8.3	L
24N/07E-28Q01	473154	1215505	Q(A)c	370	136	8	H	-.75 F	09-19-90	27	L
24N/07E-29A01	473236	1215554	Br	1,085	240	6	H	146.36	08-14-90	11	L
24N/07E-29D01	473234	1215703	Qvt	880	194	6	H	34.21	08-22-90	18	L
24N/07E-29P02	473155	1215631	Qvr	510	49	8	N	8.80	09-19-90	670	L
24N/07E-29Q01	473146	1215614	Qvr	515	50	6	N	33.94 P	09-19-90	--	--
24N/07E-30C01	473231	1215746	Br	1,000	127	6	H	90.09 R	11-02-90	.17	L
24N/07E-32A01	473133	1215559	Br	523	205	8	Z	--	--	1.5	L
24N/07E-32A02	473134	1215559	Qvr	523	48	8	N	30.12	09-20-90	150	L
24N/07E-33D01	473132	1215545	Qvr	530	80	6	H	42.44	08-02-90	16	LM
24N/07E-33G01	473131	1215456	Multiple	620	320	6	U	--	--	--	L
24N/07E-33G02	473130	1215501	Qvr	580	76	6	H	39.98	07-13-90	140	L
24N/07E-34N02	473101	1215410	Q(A)c	985	432	12	T	354.96	08-07-90	190	L
24N/07E-34N03	473102	1215406	Multiple	950	413	12	I	336.88 P	08-07-90	--	L
24N/07E-36D02	473140	1215145	Qva	740	196	6	H	173.65	07-11-90	24	L
24N/07E-36G01	473122	1215100	--	750	393	6	U	358.40 R	07-17-90	--	L
24N/07E-36L01	473113	1215124	Q(A)c	760	410	6	U	--	--	18	L
24N/07E-36L02	473113	1215125	Q(A)c	765	185	6	H	93.97	09-10-90	--	L
24N/07E-36M01	473112	1215146	Q(A)c	850	260	6	H	190.13 R	07-10-90	13	LM
24N/07E-36P01	473101	1215120	Qva	730	59	6	H	30.07	07-09-90	33	L
24N/07E-36P02	473054	1215112	Qva	800	141	6	H	83.86	08-24-90	24	L
24N/07E-36R01	473058	1215038	Br	790	338	6	H	185.00	07-09-90	.60	LM
24N/08E-18K01	473343	1214947	Qvr	572	185	6	H	165.98	06-26-90	34	L
24N/08E-18K02	473343	1214942	Qva	575	217	6	H	--	--	16	LM
24N/08E-18Q02	473332	1214950	Qvr	550	361	8	P	311.35	06-26-90	210	L
24N/08E-19J01	473248	1214927	Qva	440	586	20	U	--	--	8.6	L
24N/08E-19J02	473250	1214925	Qvr	460	200	6	U	--	--	--	L
24N/08E-19J03	473247	1214928	Qvr	440	160	6	U	--	--	--	L
24N/08E-19M01	473256	1215025	Br	160	100	6	H	35.91	07-05-90	6.1	LM
24N/08E-20A01	473316	1214808	Qva	755	222	10	H	170.07	06-21-90	3.5	L
24N/08E-20H01	473306	1214805	Qva	740	90	6	H	69.50	06-22-90	38	L
24N/08E-20J01	473252	1214802	Qva	720	186	6	H	157.02 R	06-21-90	12	L
24N/08E-20M01	473255	1214906	Qvr	560	281	6	H	255.10	06-26-90	--	LWM
24N/08E-20M02	473256	1214902	Qvr	565	276	8	P	247.99	06-27-90	130	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/08E-20P01	473248	1214842	Qvr	475	354	8	N	189.61 P	06-14-90	--	L
24N/08E-20R02	473249	1214809	Qvr	700	34	6	H	10.31	06-22-90	18	LMS
24N/08E-20R03	473240	1214813	Qva	745	356	6	H	243.17 R	06-20-90	9.8	L
24N/08E-21E01	473304	1214759	Qva	785	260	6	Z	--	--	--	L
24N/08E-21N01	473245	1214758	Br	715	420	6	H	256.33	06-20-90	--	L
24N/08E-21N02	473248	1214800	Qvr	718	210	6	H	--	--	--	L
24N/08E-24Q01S	473238	1214316	Br	680	--	--	P	--	--	--	M
24N/08E-26F01	473217	1214502	Qvr	490	68	6	U	50.98	06-18-90	--	L
24N/08E-26K01	473158	1214445	Qal	450	59	6	H	12.81	06-15-90	--	LM
24N/08E-26K02	473202	1214438	Qal	450	51	6	H	30.35	06-22-90	53	L
24N/08E-26P03	473150	1214450	Qal	470	50	6	U	--	--	160	L
24N/08E-26Q01	473146	1214434	Qvr	620	178	6	H	126.64	06-18-90	37	L
24N/08E-28E02	473218	1214742	Qvr	750	108	6	H	49.30	06-20-90	--	LWM
24N/08E-28G01	473217	1214718	Qva	840	138	6	H	83.55	06-07-90	77	L
24N/08E-28H01	473213	1214652	Qva	1,025	321	8	H	223.93	06-13-90	18	LM
24N/08E-28P01	473148	1214741	Qvr	565	81	6	H	46.63	06-13-90	320	L
24N/08E-29H01	473217	1214802	Qvr	725	212	6	H	180.42 R	06-07-90	26	L
24N/08E-30N01	473154	1215021	Qal	445	26	6	H	3.55	06-07-90	11	LMS
24N/08E-30N02	473155	1215026	Q(A)c	455	169	6	H	100.92 R	06-13-90	93	L
24N/08E-31Q01	473104	1214939	Q(A)f	430	130	4	Z	--	--	--	L
24N/08E-31Q02	473102	1214939	Q(A)f	435	130	4	Z	--	--	--	L
24N/08E-32F01	473130	1214851	Q(A)c	420	544	16	U	36.42	06-05-90	39	LM
24N/08E-35E01	473125	1214520	Qal	431	79	6	U	2.93	06-06-90	--	L
24N/08E-35E02	473122	1214516	Qal	431	43	6	P	2.26	06-06-90	380	L
24N/08E-35N01S	473102	1214523	Br	425	--	--	P	--	--	--	--
25N/06E-01F01	474050	1215904	Qal	75	57	38	P	10.72	05-11-90	--	--
25N/06E-01N01	474032	1215923	Qva	560	165	6	H	76.14	06-26-90	--	LM
25N/06E-02L01	474043	1220018	Q(A)c	600	270	6	P	--	--	18	L
25N/06E-02P01	474033	1220013	Br	590	460	6	H	413.17	05-11-90	24	L
25N/06E-10A02	474029	1220045	Qva	580	211	6	H	201.99	08-08-90	19	L
25N/06E-10J01	474001	1220050	Q(A)c	550	373	6	H	--	--	33	L
25N/06E-10J02	473955	1220050	Qva	550	194	6	H	149.60	07-06-90	33	LM
25N/06E-10R01	473943	1220050	Q(A)f	570	314	6	U	--	--	18	L
25N/06E-11L01	473958	1220013	Qva	550	90	6	H	46.27	06-27-90	4.8	L
25N/06E-11M01	473958	1220042	Qva	550	149	6	H	125.87	06-26-90	150	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/06E-12E01	474004	1215923	Q(A)c	645	954	12	P	--	--	28	L
25N/06E-12H02	474007	1215826	Q(A)f	100	143	6	H	-- F	06-21-90	--	L
25N/06E-12J01	473953	1215816	Qva	145	73	6	H	55.70	05-11-90	97	L
25N/06E-13F01	473906	1215906	Qva	645	145	10	P	--	--	--	L
25N/06E-13F02	473906	1215905	Qva	645	260	12	U	--	--	7.0	L
25N/06E-14M01	473905	1220044	Qvt	485	58	6	H	44.60	06-21-90	110	LM
25N/06E-15A01	473928	1220055	Qva	535	47	6	H	20.43	06-21-90	--	L
25N/06E-15B01	473933	1220111	Q(A)c	495	370	6	H	335.39	06-21-90	61	L
25N/06E-15G01	473909	1220117	Q(A)f	395	260	6	H	242.81	07-03-90	37	L
25N/06E-15Q01	473847	1220119	Qvt	200	128	6	H	28.51 R	06-27-90	4.9	L
25N/06E-17E01	473912	1220425	Qal	110	68	6	H	23.63	06-28-90	660	L
25N/06E-18F05	473924	1220521	Qvr	105	75	6	H	39.02 R	05-10-90	180	L
25N/06E-18K01	473903	1220515	Q(B)c	100	297	6	P	-- F	06-27-90	--	L
25N/06E-19H03	473831	1220450	Q(A)c	60	78	12	P	9.33 R	05-10-90	--	--
25N/06E-20E01	473819	1220427	Q(B)c	70	122	6	H	24.97	05-10-90	--	LWM
25N/06E-23E03	473822	1220035	Q(A)c	140	69	10	H	-- F	07-06-90	920	L
25N/06E-23E04	473831	1220028	Q(A)c	175	175	20	U	--	--	--	L
25N/06E-23M02	473816	1220042	Q(A)c	260	414	6	H	124.00	06-28-90	--	L
25N/06E-23Q01	473751	1215948	Qal	130	21.5	36	H	15.35	06-28-90	--	L
25N/06E-24B01	473828	1215848	Qva	480	333	12	P	244.27	11-02-90	31	L
25N/06E-24K01	473801	1215839	Qvt	420	120	6	H	97.71	08-16-90	20	LWM
25N/06E-24Q01	473749	1215835	Q(A)c	395	342	6	H	201.06	08-09-90	43	L
25N/06E-25E01	473727	1215920	Q(A)c	190	49	6	H	--	--	370	LM
25N/06E-25F01	473747	1215906	Q(A)f	380	167	6	H	149.75	08-09-90	--	L
25N/06E-25K01	473719	1215844	Q(A)c	280	335	6	H	136.64	09-25-90	18	LWM
25N/06E-26A02	473748	1215945	Qal	115	60	8	H	10.73	06-29-90	1.7	L
25N/06E-26P01	473712	1220020	Qvr	345	63	6	H	8.88	09-14-90	11	L
25N/06E-27J01	473718	1220056	Qvr	405	152	6	P	128.58 R	09-19-90	26	L
25N/06E-27K01	473719	1220108	Qvr	370	150	6	P	87.34	09-19-90	8.3	L
25N/06E-27N01	473712	1220145	Qvr	425	238	6	H	229.93	08-08-90	--	LW
25N/06E-28H01	473728	1220207	Qvr	425	47	6	H	11.26	07-03-90	24	LM
25N/06E-29C01	473742	1220407	Q(B)c	100	178	8	H	-- F	06-28-90	97	L
25N/06E-32F03	473645	1220403	Q(A)c	50	116	6	H	-- F	06-28-90	31	LM
25N/06E-32L02	473626	1220406	Q(A)c	100	101	12	H	-- F	06-28-90	--	L
25N/06E-33K01	473623	1220239	Q(A)c	480	337	6	H	273.72	12-12-90	--	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/06E-33N03	473616	1220310	Qva	410	200	6	H	163.27	08-07-90	--	L
25N/06E-34D01	473659	1220148	Qva	360	214	6	H	174.35 P	07-03-90	860	LMS
25N/06E-34E02	473634	1220144	Q(B)c	370	714	20	P	--	--	37	LM
25N/06E-34M01	473633	1220150	Q(B)c	360	717	12	P	237.15	08-22-90	--	L
25N/07E-01N01	474026	1215132	Qvt	260	98	6	H	64.65	09-18-90	--	LM
25N/07E-01N02	474024	1215128	Qal	240	72	6	H	14.59	09-18-90	--	L
25N/07E-04J01	474039	1215423	Qal	60	108	6	S	4.99	10-03-90	1.1	LM
25N/07E-06B01	474108	1215720	Q(A)c	40	490	6	H	-- F	10-28-90	21	LM
25N/07E-06L01	474040	1215730	--	75	728	14	S	--	--	--	L
25N/07E-06R01	474035	1215702	Q(A)c	55	630	16	U	-- F	09-26-90	--	L
25N/07E-07E01	474005	1215753	Q(A)c	55	647	10	H	-- F	12-08-90	72	LWM
25N/07E-07N01	473940	1215804	Qva	120	110	6	H	-- F	09-26-90	--	L
25N/07E-07P01	473942	1215748	Qvr	130	39	6	H	27.40	09-26-90	650	LM
25N/07E-08D01	474017	1215647	Qva	135	161	12	U	7.17	09-26-90	93	L
25N/07E-08D02	474016	1215644	Q(A)c	135	729	12	S	61.33	09-26-90	48	LM
25N/07E-08M01	473945	1215642	Qva	390	380	8	P	153.82	05-11-90	500	L
25N/07E-10C01	474017	1215347	Qva	175	44	6	H	-- F	09-18-90	88	L
25N/07E-10D01	474017	1215407	Qal	75	90	6	H	--	--	.64	L
25N/07E-10E01	474006	1215406	Qal	70	44	6	H	31.35	09-20-90	120	LWM
25N/07E-10J01	473950	1215310	Qva	460	150	6	H	109.20	09-18-90	15	LM
25N/07E-10J02	473952	1215317	Br	450	305	6	H	190.30 R	09-26-90	--	L
25N/07E-10L01	473954	1215400	Q(A)f	60	145	6	H	-- F	09-26-90	--	L
25N/07E-11A01	474011	1215157	Qal	230	60	8	P	1.39	09-25-90	20	L
25N/07E-11B01	474021	1215213	Q(A)f	580	260	8	U	--	--	--	L
25N/07E-11K01	473945	1215213	Q(A)c	200	225	6	P	-- F	10-12-90	--	--
25N/07E-11M01	473950	1215300	Qva	460	160	6	H	138.24	10-03-90	10	L
25N/07E-11Q01	473942	1215219	Q(A)c	190	177	6	H	14.16	09-27-90	31	LM
25N/07E-14C01	473925	1215229	--	180	177	6	U	--	--	--	L
25N/07E-14M01	473853	1215250	Q(A)f	135	350	6	C	1.29	09-25-90	18	L
25N/07E-14N01	473851	1215300	Q(A)f	135	64	6	H	2.36	09-25-90	34	L
25N/07E-15B01	473927	1215330	--	310	220	6	U	61.63	09-26-90	--	L
25N/07E-15C01	473923	1215358	Q(A)c	65	103	6	H	19.62	09-26-90	--	LMS
25N/07E-15E01	473907	1215408	Qal	75	41	6	H	21.77	10-11-90	330	L
25N/07E-15M01	473857	1215416	Qal	90	101	10	U	--	--	1,800	L
25N/07E-15P01	473849	1215338	Qal	115	35	6	H	25.52	09-20-90	310	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/07E-15R02	473847	1215308	Qvr	240	115	6	H	79.35	09-20-90	74	LWM
25N/07E-16B01	473925	1215452	Qal	60	30	6	H	8.56	09-25-90	230	L
25N/07E-16R01	473851	1215424	Qal	85	110	10	P	--	--	--	--
25N/07E-17A01	473929	1215548	Qva	425	247	6	H	214.22	09-26-90	170	LWMS
25N/07E-18C01	473922	1215749	Qva	190	101	6	H	22.80	10-03-90	82	L
25N/07E-18M01	473858	1215806	Q(A)c	360	268	8	P	--	--	69	L
25N/07E-18P01D1	473841	1215742	--	310	198	38	I	96.33	09-19-90	--	L
25N/07E-19A01	473828	1215709	Qvr	270	36	6	H	--	--	--	--
25N/07E-19A02	473832	1215711	--	255	13.5	36	U	12.70	09-26-90	--	--
25N/07E-19E01	473816	1215757	Qvr	390	205	8	P	--	--	460	L
25N/07E-19E02	473816	1215756	Qvr	390	201	10	P	170.28 R	05-11-91	390	L
25N/07E-20L01	473809	1215619	Q(A)f	400	265	6	H	126.35	09-19-90	26	L
25N/07E-20M01	473812	1215645	Q(A)c	540	392	10	P	--	--	4.8	L
25N/07E-20P01	473756	1215618	Q(A)c	160	269	6	H	73.95	09-19-90	37	LM
25N/07E-20P02	473757	1215625	Q(A)f	240	88	6	U	--	--	--	L
25N/07E-20Q01	473755	1215615	Qal	120	71	6	H	52.90	10-22-90	95	L
25N/07E-21C01	473836	1215458	Qal	70	35	6	H	10.27	09-20-90	--	LWMVPS
25N/07E-22C01	473835	1215345	Qal	110	30	6	P	11.68	10-03-90	610	L
25N/07E-22G01	473828	1215335	Qal	100	60	6	P	19.86	10-03-90	--	--
25N/07E-22G02	473826	1215334	Qal	110	60	8	P	17.50	10-03-90	--	--
25N/07E-23D01	473836	1215245	Q(A)f	180	138	6	H	-- F	10-22-90	11	L
25N/07E-23E01S	473815	1215246	Qvr	290	--	--	U	--	--	--	--
25N/07E-23M01	473816	1215259	Q(A)f	150	215	6	U	14.47	10-03-90	1.0	L
25N/07E-23M02	473813	1215247	Qvr	280	113	6	H	19.43	03-01-91	--	L
25N/07E-23Q01S	473755	1215215	Qvt	450	--	--	P	--	--	--	M
25N/07E-26F01	473726	1215237	Qvr	350	96	6	H	37.92	10-16-90	--	L
25N/07E-26F01S	473726	1215233	Qvr	380	--	--	I	--	--	--	M
25N/07E-26K01	473718	1215224	Qvt	460	54	6	H	35.22	10-16-90	--	L
25N/07E-26K02	473715	1215223	Qvt	440	60	6	H	22.57	10-16-90	120	L
25N/07E-26L01	473718	1215239	Q(A)c	340	244	6	H	28.52	10-16-90	61	L
25N/07E-27D01	473742	1215411	Qvr	100	95	6	H	--	--	61	LMV
25N/07E-27D02	473742	1215404	Q(A)f	100	195	6	H	2.29 R	10-11-90	8.2	L
25N/07E-27M01	473714	1215405	Qva	140	128	18	R	14.54	10-04-90	--	L
25N/07E-27M02	473712	1215413	Qal	120	16.5	36	H	7.08	10-04-90	--	L
25N/07E-27N01	473656	1215419	Qal	101	27	6	H	4.84	08-03-90	25	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/07E-28Q01	473658	1215444	Qal	85	25	36	H	11.47	10-11-90	--	MP
25N/07E-28R01	473658	1215424	--	100	180	6	H	--	--	--	L
25N/07E-29H02	473728	1215539	Q(A)c	70	214	6	H	2.83 R	10-16-90	--	LMPS
25N/07E-29N01	473705	1215647	Qva	400	97	6	U	--	--	28	L
25N/07E-29N01D1	473705	1215647	Q(A)c	400	190	6	U	--	--	--	L
25N/07E-30C01	473735	1215748	Q(A)c	365	360	6	H	164.96	10-03-90	41	L
25N/07E-30F01	473733	1215735	Q(A)c	425	241	6	H	208.30	09-25-90	--	LM
25N/07E-30H01	473723	1215657	Q(A)c	520	560	8	P	--	--	11	L
25N/07E-30H02	473734	1215658	Qvt	570	41	6	U	12.41	05-11-91	400	L
25N/07E-30H03	473734	1215659	Qvt	570	38	10	U	--	--	1,900	L
25N/07E-30M01	473721	1215754	Qva	120	98	6	I	10.13	10-16-90	23	L
25N/07E-31D01	473647	1215752	Qal	115	95	6	H	6.45	10-16-90	13	LMP
25N/07E-31E02	473631	1215752	Qva	160	87	6	H	--	--	--	L
25N/07E-31J01	473623	1215659	Q(A)c	315	241	6	H	166.36	10-12-90	22	LM
25N/07E-31M01	473618	1215750	Qva	160	50	6	H	--	--	430	L
25N/07E-31N01	473612	1215751	Qva	160	200	6	H	152.35	10-12-90	82	L
25N/07E-31R01	473607	1215706	Q(A)c	290	193	6	H	--	--	19	L
25N/07E-32F01	473635	1215627	Q(A)f	100	93	6	H	--	--	3.8	L
25N/07E-32G01	473643	1215600	--	70	18	48	Z	--	--	--	--
25N/07E-32G02	473643	1215600	Qal	70	79	6	H	9.75	10-16-90	--	--
25N/07E-32J01	473624	1215539	Qal	70	21	36	H	--	--	--	--
25N/07E-32R01	473608	1215540	Qal	70	25	1.5	H	--	--	--	--
25N/07E-33A01	473653	1215428	Qal	97	141	6	H	--	--	63	L
25N/07E-33G01	473642	1215441	Qal	80	21	30	H	2.40	10-11-90	--	--
25N/07E-33J01	473619	1215436	Qal	80	84	6	H	--	--	--	L
25N/07E-33N01	473608	1215534	Qal	60	43	6	I	16.92	10-12-90	--	--
25N/07E-33N02	473608	1215535	Q(A)c	60	238	6	H	9.63	10-12-90	--	L
25N/07E-33Q01	473616	1215446	Q(A)c	80	100	6	H	7.56	12-08-90	30	LM
25N/07E-34C01	473654	1215347	Qal	120	52	6	H	27.53	10-11-90	46	L
25N/07E-34E01	473632	1215403	Q(A)f	215	260	6	U	--	--	--	L
25N/07E-34E02	473638	1215404	Qvr	280	220	6	H	196.40	10-04-90	120	LM
25N/07E-34M01	473619	1215408	Q(A)c	140	284	6	H	48.60	10-11-90	.79	LW
25N/07E-34N01	473616	1215418	Qvr	105	87	6	H	19.91	10-16-90	--	L
26N/06E-02B01	474622	1220002	Q(A)c	90	200	8	H	82.50 P	07-06-90	--	L
26N/06E-02E01	474610	1220030	Q(A)c	550	290	6	H	174.39 R	07-06-90	8.9	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/06E-02M01	474603	1220039	Q(A)c	490	229	6	H	168.91	08-06-90	--	LWM
26N/06E-03C01	474623	1220134	Qva	423	79	6	H	-1.26 F	07-12-90	2.8	L
26N/06E-03D01	474629	1220155	Qva	490	120	6	H	13.88	07-05-90	--	L
26N/06E-03D02	474632	1220158	Qva	510	208	6	H	33.90	07-06-90	.13	L
26N/06E-03J01	474605	1220052	Qva	530	148.5	6	H	120.97	11-27-90	--	L
26N/06E-03P01	474547	1220127	Br	510	420	6	P	--	--	--	L
26N/06E-03P02	474548	1220127	Qva	510	226	6	P	--	--	14	L
26N/06E-04J01	474604	1220205	Qva	493	90	6	H	58.21 R	07-12-90	41	L
26N/06E-04J02	474605	1220208	Br	500	200	6	P	135.94 P	07-13-90	430	LMS
26N/06E-09A02	474537	1220208	Qva	460	58	6	H	42.80	07-05-90	19	L
26N/06E-09B02	474532	1220222	Qva	435	90	6	H	11.37	07-06-90	10	LM
26N/06E-09L02	474508	1220246	Qva	370	80	6	H	11.38	11-29-90	--	L
26N/06E-10A01	474539	1220100	Qva	470	112	6	H	97.23 R	07-06-90	25	LMS
26N/06E-10H01	474518	1220046	Q(A)f	330	300	6	U	132.09	07-17-90	2.3	L
26N/06E-10H02	474529	1220055	Multiple	374	301	6	H	111.17 P	07-18-90	--	L
26N/06E-11C01	474538	1220015	Q(A)f	230	273	6	H	153.92	07-05-90	1.4	L
26N/06E-11E01	474524	1220034	Qva	340	63	6	H	22.39 R	07-09-90	46	L
26N/06E-13D03	474443	1215907	Q(A)c	45	215	6	P	-- F	08-01-90	--	LMVP
26N/06E-13D04	474441	1215906	Q(A)c	45	229	6	U	--	--	--	L
26N/06E-13J01	474420	1215813	Qva	405	90	6	H	--	--	--	LM
26N/06E-13N01	474407	1215908	Q(A)c	100	236	6	I	38.90	11-28-90	--	LW
26N/06E-13Q01	474409	1215834	Qva	295	99.5	6	H	--	--	--	L
26N/06E-14D01	474446	1220027	Q(A)c	230	83	6	H	74.43	08-03-90	400	LM
26N/06E-14D02	474448	1220034	Q(A)c	270	305	6	H	79.18	02-11-91	--	L
26N/06E-22K01	474326	1220112	Q(A)f	560	194	6	H	151.38 R	07-18-90	2.3	L
26N/06E-22K02	474325	1220118	Qva	548	190	6	H	137.17	08-01-90	130	LWM
26N/06E-22K03	474322	1220110	Q(A)f	533	337	6	H	192.65	08-03-90	1.8	L
26N/06E-24D01	474345	1215906	Q(A)c	125	251	6	H	76.48 R	08-01-90	--	LM
26N/06E-25A01	474251	1215810	Qva	240	75	6	H	33.87	07-10-90	19	L
26N/06E-25A02	474259	1215812	Qva	261	197	6	H	--	--	37	L
26N/06E-25A03	474256	1215817	Qva	240	76	6	H	19.89	10-31-90	24	L
26N/06E-25C02	474300	1215856	Q(B)c	190	823.5	12	U	114.64	11-16-90	32	LW
26N/06E-25F01	474242	1215857	Qvt	60	58	6	H	4.09 R	07-17-90	--	LMP
26N/06E-25H01	474237	1215812	Qva	260	63	6	H	41.25	08-08-90	120	L
26N/06E-25J02	474228	1215807	Qva	255	60	6	H	19.01	08-10-90	6.0	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/06E-25R01	474216	1215818	Qva	225	217	6	H	35.77	08-03-90	5.6	L
26N/06E-26D01	474300	1220040	Qva	375	118	6	H	67.40	07-11-90	20	L
26N/06E-26D02	474301	1220034	Qva	200	271	6	H	189.18	11-27-90	1.6	L
26N/06E-26D03	474303	1220035	Qva	250	101	6	H	36.10	12-06-90	--	LM
26N/06E-26E01	474245	1220042	Qvt	360	50	6	H	--	--	2.8	L
26N/06E-27G01	474240	1220123	Q(B)c	510	1,010	10	U	435.91	02-11-91	8.6	L
26N/06E-35E01	474153	1220039	Qva	500	100	8	P	--	--	540	L
26N/06E-35L01	474140	1220011	Multiple	510	350	6	H	255.44	11-30-90	--	L
26N/07E-03L01	474557	1215353	Br	848	295	6	U	--	--	360	L
26N/07E-03L02	474557	1215353	Br	850	345	8	P	--	--	--	L
26N/07E-03M01	474557	1215407	Br	778	160	6	H	79.34	07-16-90	3.3	LM
26N/07E-04A01	474621	1215424	Br	890	200	6	H	17.63	08-22-90	--	L
26N/07E-04D01	474624	1215529	Br	920	50	6	H	8.33	11-21-90	8.2	LMS
26N/07E-04F01	474620	1215503	Qvt	740	108	6	H	65.62	08-29-90	--	L
26N/07E-04J01	474557	1215424	Br	730	175	6	H	--	--	--	L
26N/07E-04N01	474540	1215525	Multiple	590	54	6	H	9.75	09-24-90	--	L
26N/07E-04P01	474536	1215457	Br	560	425	8	H	--	--	.01	L
26N/07E-04R01	474547	1215436	Br	690	215	6	U	113.12	10-25-90	--	L
26N/07E-05D01	474624	1215636	Br	820	200	6	U	--	--	--	L
26N/07E-05D02	474624	1215643	Br	850	540	6	U	--	--	--	L
26N/07E-05F01	474618	1215635	Br	800	166	6	H	111.00 R	09-25-90	--	L
26N/07E-05K01	474602	1215558	Br	776	505	8	H	121.36 R	08-23-90	.03	L
26N/07E-05P01	474541	1215634	Br	685	185	6	H	34.30 R	08-23-90	--	L
26N/07E-05P02	474548	1215632	--	700	302	6	H	--	--	--	L
26N/07E-06B01	474630	1215725	Qvt	70	100	6	S	20.89 R	10-22-90	61	L
26N/07E-06F01	474613	1215743	--	35	338	6	Z	--	--	--	--
26N/07E-06G01	474608	1215715	Br	60	58	6	H	28.56 P	10-30-90	75	L
26N/07E-06K01	474603	1215717	Br	50	40	6	S	--	--	150	LMP
26N/07E-08A01	474532	1215558	Br	600	120	6	H	27.98	10-25-90	.94	LM
26N/07E-08D01	474532	1215643	Br	520	260	6	H	102.39	08-29-90	.05	L
26N/07E-09F01	474510	1215456	Br	365	137	6	H	121.45 R	08-24-90	.03	L
26N/07E-09F02	474508	1215508	Br	295	30	6	H	9.30	09-24-90	2.4	LWM
26N/07E-09GO1	474515	1215451	Br	410	340	6	H	--	--	.54	L
26N/07E-09Q01	474454	1215447	Br	270	146	6	H	94.07 R	08-27-90	.00	L
26N/07E-14F01	474423	1215224	Qvt	550	138	6	H	11.54	10-30-90	1.6	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-14G01	474417	1215211	Br	670	300	6	H	62.30	11-01-90	--	L
26N/07E-14G02	474416	1215210	Br	640	182	6	H	18.90	12-08-90	--	LM
26N/07E-14J01	474406	1215146	Br	890	305	6	H	-- F	09-27-90	--	L
26N/07E-14K01	474406	1215218	Br	530	132	6	H	6.72	10-29-90	1.2	L
26N/07E-14L01	474402	1215234	--	582	233	6	H	69.15	08-29-90	--	L
26N/07E-14P01	474358	1215229	Br	560	130	6	H	25.84 R	09-26-90	.01	LW
26N/07E-15E01	474417	1215411	Br	390	360	6	H	--	--	--	L
26N/07E-15F01	474423	1215352	Br	380	300	6	H	--	--	--	L
26N/07E-16A01	474428	1215422	Br	260	96	6	H	--	--	.05	LM
26N/07E-16A02	474428	1215424	Br	280	43	6	H	9.73	10-22-90	.88	L
26N/07E-16H01	474421	1215434	Br	330	195	6	H	--	--	--	L
26N/07E-16L01	474414	1215503	Qvt	420	66.7	6	H	53.91	10-23-90	26	L
26N/07E-16L02	474402	1215459	Qva	450	134	6	H	106.92	10-25-90	3.2	LM
26N/07E-16L03	474410	1215455	Qva	390	118	6	H	84.79	11-15-90	1.8	L
26N/07E-17B01	474438	1215613	Qvr	100	98	6	H	--	--	220	L
26N/07E-17C01	474429	1215622	Q(A)f	80	211	10	H	-- F	09-24-90	2.6	LM
26N/07E-17C02	474436	1215626	Qal	70	35	6	H	11.25	09-24-90	310	L
26N/07E-17N01	474355	1215643	Qva	450	130	6	H	86.63	11-21-90	46	L
26N/07E-18B01	474445	1215712	Qva	60	46	6	P	14.49	09-24-90	200	LM
26N/07E-18M01	474417	1215801	Qva	430	73	6	H	56.78	11-16-90	610	L
26N/07E-18N01	474409	1215800	Q(A)c	418	210	6	H	180.06	08-31-90	330	LM
26N/07E-18R01	474402	1215709	Qva	472	250	6	H	226.45	08-31-90	300	L
26N/07E-19G01	474327	1215719	Qva	455	260	8	H	220.97 R	10-26-90	--	L
26N/07E-19J01	474315	1215652	Q(A)f	470	419	6	H	192.32	09-27-90	--	L
26N/07E-19J02	474313	1215655	Q(A)f	460	416	6	H	296.26	11-07-90	--	LM
26N/07E-19K01	474324	1215724	Qva	470	274	6	U	--	--	--	L
26N/07E-19K02	474325	1215722	Q(A)f	460	322	6	Z	--	--	--	L
26N/07E-19P01	474304	1215743	Qva	305	113	6	H	--	--	28	LMV
26N/07E-20E01	474332	1215647	Qva	485	260	6	H	231.61 R	10-29-90	18	LWM
26N/07E-21P01	474257	1215455	Qva	510	103	6	H	75.88	09-27-90	93	L
26N/07E-22C01	474336	1215353	Qva	520	164	6	U	--	--	--	L
26N/07E-22C02	474335	1215347	Qva	490	60	6	P	--	--	230	L
26N/07E-22D01	474338	1215403	Qva	480	45	6	H	6.68	10-31-90	--	LMS
26N/07E-22E01	474324	1215401	Multiple	440	132	6	H	12.66	09-26-90	--	L
26N/07E-22L01	474315	1215352	Qva	350	109	6	H	43.69	11-16-90	20	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-23E01	474325	1215247	Qva	545	58	6	H	29.61	09-04-90	15	L
26N/07E-23G01	474328	1215216	Br	520	325	6	H	38.28 R	09-25-90	.08	L
26N/07E-23G02	474321	1215202	Br	535	120	6	H	--	--	--	L
26N/07E-23M01	474311	1215244	Br	590	117	6	H	106.50	09-26-90	--	L
26N/07E-26Q01	474208	1215211	Qva	535	57	6	U	10.90	11-28-90	12	L
26N/07E-27F01	474232	1215340	Br	347	225	6	H	--	--	.02	LM
26N/07E-27G01	474231	1215328	Q(A)f	423	118	6	H	--	--	31	L
26N/07E-27G02	474236	1215335	Br	360	220	6	H	-- F	10-30-90	--	L
26N/07E-27M01	474229	1215411	Qva	385	243	8	H	177.13	11-20-90	42	L
26N/07E-27P01	474210	1215347	Qvr	310	40	6	H	4.26	11-01-90	--	L
26N/07E-27P02	474211	1215342	Qvr	325	40	6	H	9.97	11-01-90	--	L
26N/07E-28B01	474245	1215438	Qvr	455	56	6	H	19.90	09-06-90	110	L
26N/07E-28C01	474249	1215500	Qvt	517	122	6	H	112.00	09-06-90	--	L
26N/07E-28E01	474232	1215526	Q(A)f	485	60	6	U	25.20	11-15-90	--	L
26N/07E-28E02	474236	1215521	Qva	500	113	6	H	83.62	10-30-90	330	LWMS
26N/07E-28J01	474218	1215434	Q(A)f	385	253	6	U	140.77	12-08-90	24	L
26N/07E-29C01	474245	1215630	Qvt	450	34	6	U	2.76	09-27-90	56	L
26N/07E-29E01	474237	1215650	Qva	400	95	6	H	41.80	09-06-90	20	L
26N/07E-29G01	474240	1215553	Q(A)f	455	123	6	H	31.98 R	09-28-90	6.7	L
26N/07E-29H01	474234	1215551	Qvt	460	70	6	H	17.01	10-30-90	66	L
26N/07E-30A01	474247	1215653	Qva	445	160	6	H	84.03	09-28-90	5.7	LM
26N/07E-30C01	474257	1215730	Qva	330	43	8	P	.39 R	11-13-90	17	L
26N/07E-30G01	474238	1215712	Qvt	290	53	6	H	32.85 R	11-08-90	46	L
26N/07E-30H01	474244	1215654	Q(A)c	420	302	6	H	212.30	11-19-90	--	L
26N/07E-30M01	474231	1215757	--	280	86	--	Z	--	--	--	L
26N/07E-30M02	474231	1215757	Multiple	280	460	6	H	--	--	--	L
26N/07E-30P01	474207	1215746	Qvt	410	60	6	H	47.48	11-06-90	340	LWM
26N/07E-31B01	474201	1215727	Qva	460	125	6	H	116.63	11-08-90	370	L
26N/07E-31B02	474200	1215727	Qva	480	138	6	H	121.31	09-28-90	150	LM
26N/07E-32E01	474148	1215636	Q(A)c	180	180	6	H	96.77 R	11-08-90	44	L
26N/07E-32J01	474128	1215541	Qva	410	78	6	H	53.60	11-07-90	--	L
26N/07E-32K01	474132	1215604	Q(A)c	445	333	6	H	264.14	11-09-90	--	LM
26N/07E-32M01	474132	1215634	Q(A)f	130	227	6	H	123.62	11-07-90	--	LM
26N/07E-32M02	474129	1215636	Q(A)c	85	116	6	H	--	--	37	L
26N/07E-32R01	474120	1215544	Q(A)c	340	256	6	P	202.69 R	11-09-90	46	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-33M01	474127	1215531	Qvr	365	18	36	H	2.90	11-08-90	--	L
26N/07E-33M02	474127	1215533	--	385	11.4	38	U	.55	11-08-90	--	--
26N/07E-33M03	474127	1215533	--	388	280	6	H	220.06 R	11-08-90	--	--
26N/07E-33N01	474120	1215533	Qvr	320	75	6	H	50.06	11-09-90	8.3	L
26N/07E-33Q01	474117	1215443	Qvr	310	115	6	H	99.68	11-16-90	--	L
26N/07E-33Q02	474116	1215438	Qvr	290	134	6	H	90.63 R	11-28-90	18	LM
26N/07E-34D01	474202	1215415	Qvr	365	9.5	28	H	4.97 R	11-28-90	--	--
26N/07E-34L01	474136	1215345	Qva	470	152	6	P	129.95	11-26-90	12	L
26N/07E-35D01	474200	1215245	Qva	550	138	6	H	57.75	12-04-90	--	LM

APPENDIX B.--WATER-QUALITY DATA TABLES

[deg. C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, not detected at the given concentration; >, concentration is greater than the given value; cols. per 100 mL, colonies per 100 milliliters; --, not determined; Geohydrologic unit: Qal, alluvium; Qvr, Vashon recessional outwash; Qvt, Vashon till; Qva, Vashon advance outwash; Q(A)f, Upper fine-grained unit; Q(A)c, Upper coarse-grained unit; Q(B)f, Lower fine-grained unit; Q(B)c, Lower coarse-grained unit; Br, Bedrock; for more explanation, see figure 10 in the text.]

Table B1.--*Values of field measurements and concentrations of common constituents*

Local well number	Date (month/ day/ year)	Time	Geo- hydro- logic unit	Land surface elev- ation (feet above sea level)	Depth of well below land surface (feet)	Temper- ature, water (deg. C)	Spe- cific con- duct- ance, field (µS/cm)	Spe- cific con- duct- ance, lab (µS/cm)
23N/08E-03L03	07-30-91	1545	Qal	435	230	10.0	121	112
23N/08E-04L01	08-08-91	1215	Qal	430	47	15.0	81	80
23N/08E-05K02	08-16-91	0900	Qal	430	39	9.5	127	103
23N/08E-08K01	08-15-91	0840	Br	680	240	15.5	830	863
23N/08E-10F03	08-15-91	1425	Qal	450	18.5	11.0	115	116
	08-15-91	1430	Qal	450	18.5	11.0	115	118
23N/08E-13N01	07-30-91	1415	Qal	595	194	11.0	98	100
23N/08E-15J06	07-30-91	1115	Qal	482	40	10.5	141	147
23N/08E-16M01	08-08-91	1500	Br	720	750	16.5	374	379
23N/08E-22A01	08-15-91	1015	Qal	494	18.2	10.0	52	52
23N/08E-24J01	08-15-91	1220	Br	580	178	11.0	267	274
23N/08E-25F01	08-15-91	1845	Qal	630	48	9.0	127	133
24N/06E-02E01	08-02-91	1540	Qvt	530	40	11.5	160	161
24N/06E-06A05	08-03-91	1150	Q(A)c	25	87	13.5	169	169
24N/06E-09E03	08-01-91	1440	Qva	385	251	14.5	172	172
24N/06E-09N02	07-31-91	1345	Qva	310	199	10.0	141	147
	07-31-91	1350	Qva	310	199	10.0	141	146
24N/06E-10H02	08-08-91	1110	Qva	455	155.2	11.0	167	167
	08-08-91	1115	Qva	455	155.2	11.0	167	167
24N/06E-10P02	08-08-91	1400	Qva	355	72	16.0	149	149
24N/06E-12B01	08-02-91	1255	Q(A)c	430	160	12.5	141	142
24N/06E-12L01	08-02-91	1410	Q(A)f	440	362	10.5	154	155
24N/06E-22H02	08-02-91	1110	Qvr	425	86	13.0	166	165
24N/07E-03P01	08-05-91	1215	Q(A)c	90	320	18.5	641	636
24N/07E-04E01	08-09-91	1045	Qal	75	65	15.0	256	283
24N/07E-05F01	08-09-91	1335	Br	400	765	10.5	171	190
24N/07E-06B01	08-09-91	1200	Q(A)c	230	106	12.0	171	189
24N/07E-08A02	08-15-91	1025	Qvt	310	39	11.0	157	156
24N/07E-10K01	08-09-91	0855	Qal	85	36	13.0	152	131
24N/07E-12E02	08-07-91	1445	Qvr	815	115	11.0	86	87
	08-07-91	1450	Qvr	815	115	11.0	86	87
24N/07E-12J01	08-15-91	1130	Br	965	700	10.5	151	152
24N/07E-13E01	07-31-91	1030	Br	295	398	12.5	189	195
24N/07E-14G01	08-07-91	1320	Qal	120	65	14.0	120	122
24N/07E-15D01	07-29-91	1435	Qal	105	49.5	10.5	121	125
24N/07E-16F01	08-06-91	1115	Qvr	150	122	12.5	129	132
24N/07E-17B01	08-05-91	1210	Qvr	210	74	15.0	185	191
24N/07E-18F03	08-05-91	1400	Qva	520	80	10.5	117	118
24N/07E-19R02	08-07-91	1130	Br	1,000	220	15.0	271	276
24N/07E-20J02	08-02-91	1325	Br	1,240	100	12.0	424	446

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium, percent
23N/08E-03L03	7.7	7.6	0.1	54	16	3.5	3.1	11
23N/08E-04L01	5.9	6.5	2.3	31	9.7	1.7	3.4	19
23N/08E-05K02	6.9	6.7	.0	43	13	2.5	4.4	18
23N/08E-08K01	8.6	8.4	7.0	22	5.1	2.3	200	95
23N/08E-10F03	7.0	7.1	4.7	54	17	2.7	3.0	11
	7.0	7.0	4.7	54	17	2.8	3.0	11
23N/08E-13N01	8.2	8.0	7.2	47	16	1.7	2.3	10
23N/08E-15J06	6.9	7.1	5.5	64	20	3.5	3.3	10
23N/08E-16M01	9.5	9.4	.6	2	.81	.03	88	99
23N/08E-22A01	6.4	6.7	6.0	21	6.8	.97	2.1	18
23N/08E-24J01	8.4	8.2	.1	95	29	5.4	19	30
23N/08E-25F01	7.8	7.6	6.2	61	18	3.9	3.1	10
24N/06E-02E01	7.3	7.5	5.8	68	12	9.3	6.5	17
24N/06E-06A05	8.3	8.0	.5	72	14	9.1	5.7	14
24N/06E-09E03	6.8	7.1	5.8	70	14	8.6	5.9	15
24N/06E-09N02	7.1	7.2	.6	62	9.2	9.4	5.6	16
	7.1	7.3	.6	61	9.0	9.3	5.5	16
24N/06E-10H02	6.7	7.0	9.0	72	15	8.4	6.0	15
	6.7	7.0	9.0	72	15	8.5	6.1	15
24N/06E-10P02	7.8	7.9	.1	64	15	6.5	5.1	14
24N/06E-12B01	8.3	8.3	.1	61	14	6.2	4.5	14
24N/06E-12L01	8.4	8.4	.1	63	16	5.5	4.8	13
24N/06E-22H02	7.8	7.9	.0	70	16	7.2	5.2	14
24N/07E-03P01	8.4	8.3	.1	170	55	7.6	51	39
24N/07E-04E01	8.1	7.8	.0	100	27	8.0	21	31
24N/07E-05F01	7.3	7.5	2.5	86	18	10	5.6	12
24N/07E-06B01	7.6	7.7	2.7	80	14	11	5.9	13
24N/07E-08A02	6.7	6.9	8.0	64	13	7.6	6.4	18
24N/07E-10K01	6.5	6.6	.2	55	15	4.3	5.7	18
24N/07E-12E02	7.0	7.4	7.8	35	7.4	4.0	3.6	18
	7.0	7.4	7.8	35	7.4	4.0	3.6	18
24N/07E-12J01	8.6	8.3	.3	32	10	1.6	22	60
24N/07E-13E01	8.9	8.6	.0	15	5.3	.51	38	84
24N/07E-14G01	6.2	6.8	3.4	51	10	6.4	4.9	17
24N/07E-15D01	6.3	6.5	5.5	44	12	3.3	7.0	25
24N/07E-16F01	6.5	7.2	6.5	53	13	5.1	5.2	17
24N/07E-17B01	6.8	7.2	3.5	75	19	6.6	9.3	21
24N/07E-18F03	6.0	7.3	7.2	45	11	4.3	5.7	21
24N/07E-19R02	9.3	9.3	2	3	1.1	.05	64	98
24N/07E-20J02	7.5	7.7	1.0	250	54	27	4.5	4

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
23N/08E-03L03	0.2	0.9	52	52	7.4	2.4	0.1	12
23N/08E-04L01	.3	.4	--	28	3.8	2.1	<.1	15
23N/08E-05K02	.3	.8	65	53	.1	1.8	<.1	37
23N/08E-08K01	18	1.8	--	266	170	.3	2.5	9.0
23N/08E-10F03	.2	.8	--	51	4.3	2.0	<.1	12
	.2	.8	--	51	4.4	1.2	<.1	13
23N/08E-13N01	.1	.4	--	45	3.1	1.7	.1	12
23N/08E-15J06	.2	.9	--	65	4.3	1.6	.1	15
23N/08E-16M01	26	.3	--	183	6.2	1.0	.9	8.8
23N/08E-22A01	.2	.4	--	22	1.9	1.1	<.1	8.9
23N/08E-24J01	.8	.7	--	70	43	17	<.1	17
23N/08E-25F01	.2	.5	--	55	5.2	.6	<.1	16
24N/06E-02E01	.3	.9	--	74	2.5	2.8	<.1	29
24N/06E-06A05	.3	2.0	--	80	3.8	2.9	<.1	38
24N/06E-09E03	.3	1.3	--	69	5.0	4.9	<.1	28
24N/06E-09N02	.3	1.9	--	62	6.1	3.8	<.1	25
	.3	1.7	--	62	6.1	4.2	.1	25
24N/06E-10H02	.3	1.3	--	68	4.1	5.0	<.1	27
	.3	1.2	--	68	4.0	4.9	<.1	27
24N/06E-10P02	.3	1.9	--	79	2.0	.7	.1	27
24N/06E-12B01	.3	1.7	--	66	4.6	2.1	<.1	25
24N/06E-12L01	.3	3.6	--	69	6.7	2.3	<.1	24
24N/06E-22H02	.3	1.6	--	73	5.1	3.6	<.1	30
24N/07E-03P01	2	2.4	--	81	6.1	140	.1	18
24N/07E-04E01	.9	2.8	--	113	1.1	24	.1	34
24N/07E-05F01	.3	2.0	--	86	8.3	1.5	.1	27
24N/07E-06B01	.3	2.2	--	86	5.9	1.2	.1	31
24N/07E-08A02	.3	1.0	--	55	3.4	3.3	<.1	28
24N/07E-10K01	.3	1.2	77	65	<.1	1.5	<.1	24
24N/07E-12E02	.3	.5	--	37	2.6	2.2	.1	19
	.3	.5	--	35	2.6	2.2	<.1	19
24N/07E-12J01	2	.8	--	75	1.9	.6	.1	23
24N/07E-13E01	4	.4	--	88	10	1.0	<.1	24
24N/07E-14G01	.3	.9	--	53	4.9	3.1	.1	25
24N/07E-15D01	.5	1.4	--	46	3.6	4.7	.1	23
24N/07E-16F01	.3	1.0	--	53	1.5	3.0	<.1	26
24N/07E-17B01	.5	1.4	--	62	7.1	8.2	<.1	21
24N/07E-18F03	.4	.7	--	35	2.8	4.1	<.1	25
24N/07E-19R02	16	.1	--	133	5.1	.5	.1	8.8
24N/07E-20J02	.1	.5	--	239	6.2	4.1	<.1	14

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
23N/08E-03L03	78	<0.05	1,400	73	<1	<1
23N/08E-04L01	58	1.1	580	8	<1	<1
23N/08E-05K02	109	<.05	9,700	390	<1	<1
23N/08E-08K01	551	.14	6	1	<1	<1
23N/08E-10F03	75	.49	8	<1	<1	<1
	75	.49	8	<1	<1	<1
23N/08E-13N01	66	.40	<3	<1	<1	1
23N/08E-15J06	92	.83	35	4	<1	<1
23N/08E-16M01	216	.10	6	<1	<1	<1
23N/08E-22A01	37	.30	17	<1	<1	7
23N/08E-24J01	173	<.05	55	53	<1	<1
23N/08E-25F01	85	1.0	6	2	<1	<1
24N/06E-02E01	113	1.2	<3	<1	<1	<1
24N/06E-06A05	124	.08	46	130	<1	<1
24N/06E-09E03	118	1.9	8	5	<1	<1
24N/06E-09N02	101	.55	230	23	<1	<1
	101	.56	250	23	<1	<1
24N/06E-10H02	114	1.4	<3	<1	<1	6
	114	1.5	<3	<1	<1	8
24N/06E-10P02	106	<.05	75	110	<1	<1
24N/06E-12B01	98	<.05	110	54	<1	<1
24N/06E-12L01	104	<.05	33	47	<1	<1
24N/06E-22H02	113	<.05	440	270	<1	<1
24N/07E-03P01	329	<.05	48	86	<1	<1
24N/07E-04E01	186	<.05	110	110	<1	<1
24N/07E-05F01	125	.30	<3	<1	<1	<1
24N/07E-06B01	127	.96	5	<1	<1	<1
24N/07E-08A02	115	4.4	8	2	<1	<1
24N/07E-10K01	111	<.05	13,000	410	>60	2
24N/07E-12E02	65	.81	10	3	<1	<1
	64	.82	9	3	<1	<1
24N/07E-12J01	105	<.05	63	39	<1	<1
24N/07E-13E01	132	<.05	11	9	<1	<1
24N/07E-14G01	89	.44	14	1	<1	<1
24N/07E-15D01	91	1.9	12	<1	<1	<1
24N/07E-16F01	97	2.4	5	2	<1	<1
24N/07E-17B01	127	3.8	3	<1	<1	<1
24N/07E-18F03	91	3.8	4	<1	<1	<1
24N/07E-19R02	160	<.05	9	2	<1	<1
24N/07E-20J02	254	.05	47	33	<1	<1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo- hydro- logic unit	Land surface elev- ation (feet above sea level)	Depth of well below land surface (feet)	Temper- ature, water (deg. C)	Spe- cific con- duct- ance, field (µS/cm)	Spe- cific con- duct- ance, lab (µS/cm)
24N/07E-21H01	07-29-91	1625	Br	490	118	9.5	158	163
24N/07E-23D01	08-15-91	1640	Qal	105	44	13.5	264	272
24N/07E-23H03	08-02-91	1105	Br	105	223	12.5	305	313
24N/07E-24Q01	08-06-91	1330	Qva	341	119	10.5	166	172
24N/07E-27D01	08-01-91	1415	Q(A)c	250	91	16.0	567	590
24N/07E-33D01	08-01-91	1035	Qvr	530	80	13.0	143	128
24N/07E-36M01	08-01-91	1245	Q(A)c	850	260	14.5	148	152
24N/07E-36R01	07-31-91	1415	Br	790	338	12.0	132	136
24N/08E-18K02	07-30-91	1505	Qva	575	217	13.5	162	168
	07-30-91	1510	Qva	575	217	13.5	162	161
24N/08E-19M01	08-06-91	1445	Br	160	100	13.0	577	595
24N/08E-20M01	07-29-91	1025	Qvr	560	281	12.5	379	407
24N/08E-20R02	07-29-91	1335	Qvr	700	34	11.0	177	175
24N/08E-24Q01S	07-29-91	1040	Br	680	--	9.0	82	84
24N/08E-26K01	07-30-91	1330	Qal	450	59	11.5	75	77
24N/08E-28E02	07-29-91	1240	Qvr	750	108	9.5	156	163
24N/08E-28H01	07-30-91	1100	Qva	1,025	321	11.0	143	148
24N/08E-30N01	07-31-91	1150	Qal	445	26	15.0	50	49
24N/08E-32F01	08-16-91	1040	Q(A)c	420	544	13.5	185	194
25N/06E-01N01	08-01-91	1155	Qva	560	165	12.0	96	95
25N/06E-10J02	08-01-91	1310	Qva	550	194	12.0	123	121
25N/06E-14M01	07-31-91	1445	Qvt	485	58	12.0	253	219
25N/06E-20E01	07-31-91	1600	Q(B)c	70	122	11.5	199	209
25N/06E-24K01	08-01-91	1100	Qvt	420	120	10.5	154	160
25N/06E-25E01	07-31-91	1300	Q(A)c	190	49	11.5	138	139
25N/06E-25K01	08-01-91	1450	Q(A)c	280	335	11.0	177	186
25N/06E-28H01	07-31-91	1130	Qvr	425	47	12.0	186	188
25N/06E-32F03	08-02-91	1715	Q(A)c	50	116	11.5	274	274
25N/06E-34D01	08-02-91	1130	Qva	360	214	10.0	162	170
25N/06E-34E02	08-08-91	0940	Q(B)c	370	714	12.0	154	151
25N/07E-01N01	08-09-91	1450	Qvt	260	98	12.0	380	377
25N/07E-04J01	08-03-91	1555	Qal	60	108	12.5	300	292
	08-03-91	1600	Qal	60	108	12.5	300	293
25N/07E-06B01	08-06-91	1455	Q(A)c	40	490	13.5	330	329
25N/07E-07E01	08-02-91	1545	Q(A)c	55	647	11.0	156	163
25N/07E-07P01	08-03-91	1435	Qvr	130	39	12.0	144	142
25N/07E-08D02	08-06-91	1325	Q(A)c	135	729	13.0	289	288
25N/07E-10E01	08-02-91	1340	Qal	70	44	11.0	160	168
25N/07E-10J01	08-06-91	1145	Qva	460	150	10.5	127	126
25N/07E-11Q01	08-07-91	1415	Q(A)c	190	177	11.0	170	169

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dis-solved (mg/L)	Hard-ness, total (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Sodium, percent
24N/07E-21H01	8.7	8.3	0.9	31	12	0.29	24	63
24N/07E-23D01	7.3	7.3	.1	110	27	10	15	23
24N/07E-23H03	8.8	8.8	.2	9	3.4	.23	70	94
24N/07E-24Q01	8.2	8.2	.2	76	19	6.9	5.1	12
24N/07E-27D01	8.4	8.2	.2	150	46	8.7	55	44
24N/07E-33D01	6.7	6.9	.1	51	13	4.6	5.5	19
24N/07E-36M01	8.4	8.3	.1	53	17	2.6	11	30
24N/07E-36R01	9.1	9.0	.2	11	4.3	.16	27	84
24N/08E-18K02	8.2	8.2	.1	68	19	5.0	7.7	19
	8.2	8.2	.1	68	19	5.1	8.0	20
24N/08E-19M01	8.3	8.2	.1	80	25	4.3	94	71
24N/08E-20M01	7.0	7.2	3.9	200	47	20	12	11
24N/08E-20R02	6.5	6.8	.1	49	12	4.6	16	41
24N/08E-24Q01S	6.8	7.1	10.6	37	12	1.7	1.9	10
24N/08E-26K01	7.1	7.5	9.4	33	11	1.4	2.0	11
24N/08E-28E02	8.4	8.1	.1	77	21	5.9	2.5	7
24N/08E-28H01	8.5	8.3	5.0	71	20	5.1	2.4	7
24N/08E-30N01	5.6	6.0	.7	18	4.7	1.5	2.4	22
24N/08E-32F01	8.2	8.1	.1	76	23	4.5	9.9	21
25N/06E-01N01	6.0	6.3	4.2	36	8.8	3.3	4.7	22
25N/06E-10J02	7.6	7.7	.1	48	12	4.3	6.2	22
25N/06E-14M01	6.5	6.5	.1	91	20	9.9	8.0	16
25N/06E-20E01	7.5	7.7	.0	87	19	9.6	8.5	17
25N/06E-24K01	6.6	6.8	7.8	61	18	3.9	7.8	22
25N/06E-25E01	7.0	7.5	3.2	56	13	5.8	5.3	17
25N/06E-25K01	8.3	8.1	.0	66	21	3.4	13	29
25N/06E-28H01	6.8	7.3	2.0	83	15	11	6.8	15
25N/06E-32F03	6.6	6.8	5.0	120	22	16	8.6	13
25N/06E-34D01	7.2	7.3	2.3	74	15	8.9	5.7	14
25N/06E-34E02	8.2	8.2	.1	61	18	3.9	7.6	20
25N/07E-01N01	7.7	7.8	2.1	41	11	3.2	77	80
25N/07E-04J01	8.7	8.1	.1	37	9.4	3.3	54	74
	8.7	8.1	.1	37	9.3	3.3	51	73
25N/07E-06B01	8.2	8.2	.2	71	21	4.4	44	55
25N/07E-07E01	8.6	8.2	.1	65	17	5.5	8.9	23
25N/07E-07P01	7.4	7.2	5.1	59	11	7.6	5.3	16
25N/07E-08D02	8.2	8.2	.1	100	26	8.4	21	30
25N/07E-10E01	6.7	6.9	6.0	71	14	8.7	6.5	16
25N/07E-10J01	7.6	7.7	2.1	56	13	5.8	4.5	14
25N/07E-11Q01	8.2	8.1	.6	56	16	3.8	13	32

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium ad-sorp-tion ratio	Potas-sium, dis-solved (mg/L as K)	Alka-linity, field (mg/L as $CaCO_3$)	Alka-linity, lab (mg/L as $CaCO_3$)	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
24N/07E-21H01	2	0.1	--	77	5.4	1.0	0.1	11
24N/07E-23D01	.6	2.6	141	141	.6	1.8	<.1	31
24N/07E-23H03	10	.7	--	132	2.8	17	.4	30
24N/07E-24Q01	.3	2.6	--	79	6.5	3.0	.1	28
24N/07E-27D01	2	2.0	--	107	<.1	130	.1	17
24N/07E-33D01	.3	1.0	58	51	8.3	3.7	<.1	20
24N/07E-36M01	.7	1.5	--	76	1.1	.8	<.1	15
24N/07E-36R01	3	.1	--	67	2.7	.9	.1	11
24N/08E-18K02	.4	1.0	--	77	7.6	2.3	.1	19
	.4	1.0	--	77	7.6	2.2	.1	19
24N/08E-19M01	5	1.4	--	139	5.3	100	.2	27
24N/08E-20M01	.4	1.3	--	202	9.6	4.7	<.1	25
24N/08E-20R02	1	1.6	58	58	3.9	19	.1	24
24N/08E-24Q01S	.1	.3	--	34	3.7	.7	<.1	8.5
24N/08E-26K01	.2	.3	--	30	4.5	1.4	.1	9.4
24N/08E-28E02	.1	.4	--	68	12	1.0	<.1	13
24N/08E-28H01	.1	.4	--	62	7.9	3.2	<.1	14
24N/08E-30N01	.2	.2	20	20	1.6	1.9	<.1	16
24N/08E-32F01	.5	4.0	--	96	.8	4.9	.1	30
25N/06E-01N01	.3	.4	--	36	4.4	3.3	<.1	15
25N/06E-10J02	.4	1.1	--	59	1.3	1.3	.1	35
25N/06E-14M01	.4	1.1	103	84	20	3.9	.1	35
25N/06E-20E01	.4	1.5	--	93	8.5	4.2	<.1	22
25N/06E-24K01	.4	.7	--	61	1.9	3.7	<.1	30
25N/06E-25E01	.3	1.3	--	54	6.4	2.6	<.1	21
25N/06E-25K01	.7	1.4	--	91	.9	1.7	<.1	19
25N/06E-28H01	.3	1.3	--	85	5.0	4.0	.1	31
25N/06E-32F03	.3	1.5	--	98	11	8.6	<.1	32
25N/06E-34D01	.3	1.4	--	79	3.9	5.7	<.1	30
25N/06E-34E02	.4	2.8	--	77	.2	3.2	.1	30
25N/07E-01N01	5	1.5	--	197	<.1	7.3	.2	15
25N/07E-04J01	4	2.9	--	139	6.5	7.7	.2	26
	4	3.3	--	139	6.7	7.8	.2	27
25N/07E-06B01	2	7.0	--	159	1.3	11	.2	27
25N/07E-07E01	.5	.9	--	79	3.3	3.1	.1	19
25N/07E-07P01	.3	1.6	--	58	6.4	2.1	<.1	31
25N/07E-08D02	.9	6.7	--	135	11	.7	.1	31
25N/07E-10E01	.3	.9	--	76	4.4	3.1	<.1	28
25N/07E-10J01	.3	1.3	--	54	7.1	2.5	.1	23
25N/07E-11Q01	.8	3.2	--	89	2.3	.6	.2	33

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
24N/07E-21H01	100	0.07	<3	2	<1	<1
24N/07E-23D01	174	<.05	1,500	370	<1	<1
24N/07E-23H03	204	<.05	6	7	<1	<1
24N/07E-24Q01	119	<.05	33	82	<1	<1
24N/07E-27D01	324	<.05	440	64	<1	<1
24N/07E-33D01	97	<.05	5,700	160	<1	<1
24N/07E-36M01	95	<.05	35	32	<1	<1
24N/07E-36R01	86	<.05	11	3	<1	<1
24N/08E-18K02	108	<.05	91	61	<1	<1
	108	<.05	91	60	--	--
24N/08E-19M01	341	<.05	250	83	<1	<1
24N/08E-20M01	245	.89	8	<1	<1	<1
24N/08E-20R02	118	<.05	620	920	<1	<1
24N/08E-24Q01S	52	.55	<3	<1	<1	1
24N/08E-26K01	50	.49	6	<1	<1	1
24N/08E-28E02	97	<.05	22	19	<1	<1
24N/08E-28H01	95	1.0	<3	<1	<1	<1
24N/08E-30N01	41	.07	230	10	<1	<1
24N/08E-32F01	135	<.05	94	80	<1	<1
25N/06E-01N01	65	.52	370	36	<1	<1
25N/06E-10J02	97	<.05	540	160	<1	<1
25N/06E-14M01	174	<.05	14,000	230	<1	<1
25N/06E-20E01	130	<.05	720	230	<1	<1
25N/06E-24K01	117	3.3	8	2	<1	<1
25N/06E-25E01	96	1.7	<3	1	<1	<1
25N/06E-25K01	115	<.05	110	48	<1	<1
25N/06E-28H01	128	.71	13	2	<1	<1
25N/06E-32F03	180	4.9	<3	4	<1	<1
25N/06E-34D01	120	.53	5	<1	<1	1
25N/06E-34E02	112	<.05	23	38	<1	<1
25N/07E-01N01	234	.12	130	26	<1	<1
25N/07E-04J01	193	<.05	39	35	<1	<1
	192	<.05	42	36	<1	<1
25N/07E-06B01	211	<.05	25	35	<1	<1
25N/07E-07E01	105	<.05	43	40	<1	<1
25N/07E-07P01	106	1.4	18	1	<1	<1
25N/07E-08D02	186	<.05	18	41	<1	<1
25N/07E-10E01	114	.67	4	4	<1	<1
25N/07E-10J01	92	.42	14	13	<1	<1
25N/07E-11Q01	126	<.05	58	43	<1	<1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
25N/07E-15C01	08-07-91	1300	Q(A)c	65	103	12.5	262	262
25N/07E-15R02	08-05-91	1245	Qvr	240	115	11.0	135	141
25N/07E-17A01	08-01-91	1255	Qva	425	247	10.5	111	115
25N/07E-20P01	08-05-91	1600	Q(A)c	160	269	11.5	316	312
25N/07E-21C01	08-05-91	1500	Qal	70	35	8.5	57	59
25N/07E-23Q01S	08-16-91	1530	Qvt	450	--	9.5	119	120
25N/07E-26F01S	08-07-91	1600	Qvr	380	--	17.5	111	109
25N/07E-27D01	08-09-91	1240	Qvr	100	95	10.5	245	244
25N/07E-28Q01	08-05-91	1425	Qal	85	25	13.5	127	127
25N/07E-29H02	08-07-91	1135	Q(A)c	70	214	12.0	312	307
25N/07E-30F01	08-03-91	1325	Q(A)c	425	241	10.5	148	148
25N/07E-31D01	08-09-91	1045	Qal	115	95	13.0	147	147
25N/07E-31J01	08-05-91	1800	Q(A)c	315	241	16.5	233	230
25N/07E-33Q01	08-05-91	1320	Q(A)c	80	100	12.5	178	178
25N/07E-34E02	08-16-91	0930	Qvr	280	220	14.5	130	129
26N/06E-02M01	08-07-91	1300	Q(A)c	490	229	10.0	158	163
26N/06E-04J02	08-08-91	1020	Br	500	200	12.5	142	156
26N/06E-09B02	08-08-91	0900	Qva	435	90	11.0	188	207
26N/06E-10A01	08-06-91	1000	Qva	470	112	13.0	199	220
26N/06E-13D03	08-05-91	1320	Q(A)c	45	215	11.0	267	296
26N/06E-13J01	08-16-91	1250	Qva	405	90	14.5	148	147
	08-16-91	1255	Qva	405	90	14.5	148	147
26N/06E-14D01	08-05-91	1145	Q(A)c	230	83	12.0	209	232
26N/06E-22K02	08-07-91	1525	Qva	548	190	11.0	82	84
26N/06E-24D01	08-06-91	0830	Q(A)c	125	251	12.0	263	296
26N/06E-25F01	08-07-91	1510	Qvt	60	58	17.0	240	266
26N/06E-26D03	08-14-91	1450	Qva	250	101	15.5	216	214
26N/07E-03M01	08-06-91	1205	Br	778	160	12.5	435	489
26N/07E-04D01	08-06-91	1435	Br	920	50	11.0	233	255
	08-06-91	1440	Br	920	50	11.0	233	254
26N/07E-06K01	08-14-91	1320	Br	50	40	15.5	260	258
26N/07E-08A01	08-05-91	1620	Br	600	120	11.0	194	216
26N/07E-09F02	08-07-91	1100	Br	295	30	11.0	108	111
26N/07E-14G02	08-16-91	1115	Br	640	182	16.5	220	206
26N/07E-16A01	08-06-91	1640	Br	260	96	10.5	194	216
26N/07E-16L02	08-08-91	1405	Qva	450	134	13.0	109	121
26N/07E-17C01	08-07-91	1130	Q(A)f	80	211	12.5	228	253
26N/07E-18B01	08-07-91	1635	Qva	60	46	11.0	98	111
26N/07E-18N01	08-07-91	1400	Q(A)c	418	210	11.0	201	217
26N/07E-19J02	08-08-91	1125	Q(A)f	460	416	14.0	291	322

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dis-solved (mg/L)	Hard-ness, total (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Sodium, percent
25N/07E-15C01	8.2	8.2	0.1	44	12	3.4	43	66
25N/07E-15R02	7.3	7.7	6.2	58	15	4.9	5.5	17
25N/07E-17A01	7.5	7.5	1.7	47	6.1	7.7	4.1	15
25N/07E-20P01	8.1	8.1	.1	150	39	12	7.6	10
25N/07E-21C01	6.5	6.8	4.2	23	7.1	1.4	2.0	15
25N/07E-23Q01S	6.6	7.5	8.6	46	11	4.5	4.2	16
25N/07E-26F01S	6.5	6.7	10.3	38	8.7	3.9	5.9	25
25N/07E-27D01	8.6	8.4	.2	67	18	5.4	27	46
25N/07E-28Q01	6.0	6.3	2.5	45	12	3.6	6.5	22
25N/07E-29H02	8.1	8.0	.1	120	32	8.7	19	25
25N/07E-30F01	7.8	7.5	8.3	59	11	7.7	5.1	15
25N/07E-31D01	8.3	8.1	.3	64	15	6.5	4.5	13
25N/07E-31J01	8.0	8.0	.1	100	22	11	8.5	15
25N/07E-33Q01	6.8	7.1	5.6	75	17	7.8	7.0	17
25N/07E-34E02	7.1	7.5	9.1	39	10	3.4	12	40
26N/06E-02M01	8.3	8.0	.1	73	18	6.8	5.1	13
26N/06E-04J02	7.3	7.5	6.6	64	16	5.8	5.8	16
26N/06E-09B02	7.9	8.1	.0	79	24	4.7	12	24
26N/06E-10A01	7.0	7.2	1.7	95	20	11	11	20
26N/06E-13D03	8.6	8.4	.3	83	25	5.0	36	48
26N/06E-13J01	6.4	7.3	5.4	62	13	7.2	4.9	14
	6.4	7.8	5.4	62	13	7.2	4.9	14
26N/06E-14D01	8.6	8.4	.2	33	10	1.9	43	73
26N/06E-22K02	7.9	7.7	7.2	32	7.1	3.4	4.7	24
26N/06E-24D01	8.6	8.5	.5	54	18	2.2	48	65
26N/06E-25F01	8.2	8.1	.1	110	26	11	12	18
26N/06E-26D03	8.2	8.2	.2	100	27	8.8	5.7	11
26N/07E-03M01	8.9	8.7	.1	7	1.8	.55	120	97
26N/07E-04D01	6.9	7.0	1.2	89	24	7.0	17	29
	6.9	7.0	1.2	90	24	7.2	18	30
26N/07E-06K01	6.6	6.9	6.1	110	25	12	12	19
26N/07E-08A01	6.9	7.1	6.4	82	25	4.7	15	28
26N/07E-09F02	6.0	6.3	8.2	45	15	1.8	5.1	20
26N/07E-14G02	8.4	9.1	1.8	3	1.0	.12	44	94
26N/07E-16A01	8.6	8.3	--	2	.79	.11	52	97
26N/07E-16L02	8.2	8.0	.0	50	14	3.7	4.4	16
26N/07E-17C01	8.6	8.3	.5	45	12	3.6	41	64
26N/07E-18B01	6.8	7.1	6.2	45	9.9	5.0	3.8	15
26N/07E-18N01	7.9	7.8	.0	90	21	9.0	11	20
26N/07E-19J02	8.4	8.4	.2	61	19	3.2	54	65

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
25N/07E-15C01	3	2.9	--	133	6.6	0.7	0.2	20
25N/07E-15R02	.3	.9	--	59	8.4	4.1	<.1	21
25N/07E-17A01	.3	1.5	--	48	4.9	2.8	<.1	29
25N/07E-20P01	.3	3.7	--	128	34	3.2	<.1	29
25N/07E-21C01	.2	.4	--	23	4.3	1.6	<.1	9.5
25N/07E-23Q01S	.3	.9	--	49	5.4	2.1	<.1	20
25N/07E-26F01S	.4	.4	--	24	1.4	2.8	<.1	24
25N/07E-27D01	1	1.6	--	122	3.8	6.4	<.1	17
25N/07E-28Q01	.4	4.1	--	47	7.9	4.0	<.1	17
25N/07E-29H02	.8	6.7	--	148	12	7.4	.2	34
25N/07E-30F01	.3	1.9	--	63	3.7	4.4	<.1	29
25N/07E-31D01	.2	1.5	--	59	16	1.2	<.1	21
25N/07E-31J01	.4	3.8	--	121	<.1	3.2	.2	43
25N/07E-33Q01	.4	1.2	--	68	4.3	4.5	<.1	28
25N/07E-34E02	.8	.8	--	52	8.2	3.5	<.1	20
26N/06E-02M01	.3	1.6	--	71	9.5	2.8	.1	18
26N/06E-04J02	.3	2.8	--	63	12	2.1	.1	43
26N/06E-09B02	.6	4.4	--	97	9.9	.7	.2	36
26N/06E-10A01	.5	1.0	--	105	8.1	7.1	.2	21
26N/06E-13D03	2	2.5	--	149	1.7	6.3	<.1	15
26N/06E-13J01	.3	1.1	--	61	7.2	3.1	<.1	21
	.3	1.1	--	61	7.3	3.1	<.1	21
26N/06E-14D01	3	.9	--	116	3.5	1.4	.1	17
26N/06E-22K02	.4	.6	--	38	.8	2.1	.1	27
26N/06E-24D01	3	1.9	--	143	6.6	6.8	<.1	14
26N/06E-25F01	.5	5.5	--	126	12	3.8	.1	30
26N/06E-26D03	.2	1.6	--	96	16	2.8	<.1	20
26N/07E-03M01	20	.9	--	242	9.7	8.3	.3	21
26N/07E-04D01	.8	.3	--	78	50	2.7	.1	38
	.8	.2	--	74	50	2.7	.1	38
26N/07E-06K01	.5	.2	--	105	7.8	9.5	<.1	37
26N/07E-08A01	.7	.4	--	98	5.1	3.3	.1	25
26N/07E-09F02	.3	.5	--	40	2.2	3.9	<.1	21
26N/07E-14G02	11	2.3	--	96	4.2	6.1	<.1	23
26N/07E-16A01	15	.4	--	111	2.0	3.0	.2	15
26N/07E-16L02	.3	1.0	--	54	4.8	.6	.1	20
26N/07E-17C01	3	4.0	--	131	.1	3.4	<.1	24
26N/07E-18B01	.2	1.2	--	42	5.9	3.6	.1	23
26N/07E-18N01	.5	3.3	--	110	.2	3.5	.2	32
26N/07E-19J02	3	2.5	--	175	<.1	4.2	<.1	15

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
25N/07E-15C01	169	<0.05	34	34	<1	<1
25N/07E-15R02	96	.18	23	1	--	--
25N/07E-17A01	89	.80	39	43	<1	<1
25N/07E-20P01	205	<.05	47	130	<1	<1
25N/07E-21C01	42	.32	13	2	--	--
25N/07E-23Q01S	82	1.1	6	5	<1	<1
25N/07E-26F01S	89	6.3	15	3	<1	<1
25N/07E-27D01	152	<.05	10	22	<1	<1
25N/07E-28Q01	89	1.2	92	2	<1	<1
25N/07E-29H02	209	<.05	55	100	<1	<1
25N/07E-30F01	104	.65	8	2	<1	<1
25N/07E-31D01	101	<.05	24	110	<1	<1
25N/07E-31J01	165	<.05	210	180	<1	<1
25N/07E-33Q01	124	3.1	4	4	<1	<1
25N/07E-34E02	92	.64	13	6	<1	8
26N/06E-02M01	105	<.05	180	66	<1	<1
26N/06E-04J02	126	.12	25	50	<1	<1
26N/06E-09B02	150	<.05	150	52	<1	<1
26N/06E-10A01	144	.28	44	25	<1	<1
26N/06E-13D03	181	<.05	21	24	<1	<1
26N/06E-13J01	99	1.1	11	5	<1	<1
	99	1.1	9	4	<1	<1
26N/06E-14D01	147	<.05	12	11	<1	<1
26N/06E-22K02	71	.42	16	4	<1	<1
26N/06E-24D01	183	<.05	14	15	<1	<1
26N/06E-25F01	176	<.05	23	54	<1	<1
26N/06E-26D03	140	<.05	180	77	--	--
26N/07E-03M01	308	<.05	84	7	<1	1
26N/07E-04D01	186	<.05	70	290	<1	<1
	185	<.05	74	290	--	--
26N/07E-06K01	178	2.7	15	<1	5	7
26N/07E-08A01	145	1.6	15	5	<1	1
26N/07E-09F02	86	2.8	86	6	<1	<1
26N/07E-14G02	139	.10	47	3	<1	2
26N/07E-16A01	140	.07	5	1	<1	<1
26N/07E-16L02	81	<.05	200	91	<1	<1
26N/07E-17C01	167	<.05	70	29	<1	<1
26N/07E-18B01	83	1.3	5	12	<1	<1
26N/07E-18N01	147	<.05	500	260	<1	<1
26N/07E-19J02	203	<.05	130	28	<1	17

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
26N/07E-19P01	08-08-91	1240	Qva	305	113	11.5	160	174
26N/07E-20E01	08-06-91	1530	Qva	485	260	10.5	177	178
26N/07E-22D01	08-07-91	0955	Qva	480	45	11.0	103	115
26N/07E-27F01	08-07-91	1230	Br	347	225	12.5	593	653
26N/07E-28E02	08-08-91	1130	Qva	500	113	9.0	128	133
26N/07E-30A01	08-08-91	1600	Qva	445	160	10.0	164	173
26N/07E-30P01	08-06-91	1325	Qvt	410	60	9.5	96	99
26N/07E-31B02	08-06-91	1145	Qva	480	138	9.5	140	146
26N/07E-32K01	08-09-91	1200	Q(A)c	445	333	11.0	175	180
26N/07E-32M01	08-08-91	1410	Q(A)f	130	227	12.0	173	181
26N/07E-33Q02	08-09-91	1220	Qvr	290	134	9.0	172	178
26N/07E-35D01	08-15-91	1335	Qva	550	138	11.5	417	413
BLANK - Deionized water	07-30-91	1530	--	--	--	--	--	1
	08-03-91	1630	--	--	--	--	--	4
	08-06-91	1505	--	--	--	--	--	3
	08-07-91	1330	--	--	--	--	--	2
	08-07-91	1515	--	--	--	--	--	1
	08-08-91	1140	--	--	--	--	--	2
	08-15-91	1455	--	--	--	--	--	2
	08-16-91	1320	--	--	--	--	--	3

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dis- solved (mg/L)	Hard- ness, total (mg/L as $CaCO_3$)	Calcium, dis- solved (mg/L as Ca)	Magne- sium, dis- solved (mg/L as Mg)	Sodium, dis- solved (mg/L as Na)	Sodium, percent
26N/07E-19P01	7.9	7.7	0.1	77	21	5.9	6.3	15
26N/07E-20E01	8.0	7.9	7.4	79	20	7.1	7.3	16
26N/07E-22D01	7.4	7.7	3.8	47	12	4.1	5.7	21
26N/07E-27F01	8.0	8.0	.3	95	35	1.9	100	69
26N/07E-28E02	7.4	7.5	4.8	57	11	7.1	4.1	13
26N/07E-30A01	8.2	8.0	.1	73	21	5.1	6.9	17
26N/07E-30P01	6.7	7.0	7.6	40	8.6	4.6	4.1	18
26N/07E-31B02	7.5	7.6	6.9	62	11	8.3	6.1	17
26N/07E-32K01	8.5	8.2	.0	58	17	3.8	14	33
26N/07E-32M01	8.5	8.1	.0	68	20	4.5	11	25
26N/07E-33Q02	6.9	7.1	5.0	79	19	7.6	6.1	14
26N/07E-35D01	7.8	7.9	.1	160	40	15	33	30
BLANK - Deionized water	--	7.5	--	0	.04	.04	<.2	--
	--	7.4	--	--	<.02	<.01	<.2	--
	--	6.9	--	0	.07	.04	<.2	--
	--	6.4	--	--	<.02	<.01	<.2	--
	--	7.2	--	--	<.02	.03	<.2	--
	--	6.6	--	0	.05	.07	<.2	--
	--	6.5	--	0	.04	.06	<.2	--
	--	7.2	--	0	.03	.02	<.2	--

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium ad-sorp-tion ratio	Potas-sium, dis-solved (mg/L as K)	Alka-linity, field (mg/L as $CaCO_3$)	Alka-linity, lab (mg/L as $CaCO_3$)	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
26N/07E-19P01	0.3	2.8	--	87	1.5	0.7	0.2	24
26N/07E-20E01	.4	2.8	--	86	6.6	3.1	.2	21
26N/07E-22D01	.4	.7	--	49	6.8	2.3	.1	18
26N/07E-27F01	4	1.2	--	219	.7	77	.2	18
26N/07E-28E02	.2	.8	--	49	3.9	3.0	.1	21
26N/07E-30A01	.4	2.0	--	85	1.2	.7	.2	19
26N/07E-30P01	.3	.6	--	34	4.8	2.9	.1	22
26N/07E-31B02	.3	1.1	--	66	6.5	3.0	.1	26
26N/07E-32K01	.8	2.7	--	90	4.7	.6	<.1	25
26N/07E-32M01	.6	2.6	--	87	4.9	.7	.1	27
26N/07E-33Q02	.3	1.1	--	69	5.8	5.3	<.1	25
26N/07E-35D01	1	1.6	--	231	.9	3.5	.1	22
BLANK - Deionized water	--	<.1	--	2.0	.1	<.1	<.1	<.1
	--	<.1	--	2.7	<.1	.4	<.1	.1
	--	<.1	--	2.5	.2	.4	<.1	.3
	--	<.1	--	2.1	.1	.5	<.1	.1
	--	<.1	--	1.3	<.1	<.1	<.1	.1
	--	<.1	--	3.0	.1	.8	<.1	.1
	--	<.1	--	2.0	<.1	<.1	<.1	<.1
	--	<.1	--	2.5	<.1	<.1	<.1	.1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
26N/07E-19P01	115	<0.05	230	340	<1	<1
26N/07E-20E01	122	.40	6	1	<1	2
26N/07E-22D01	80	22	24	33	<1	<1
26N/07E-27F01	366	<.05	200	46	<1	<1
26N/07E-28E02	92	2.5	7	2	<1	<1
26N/07E-30A01	107	<.05	120	56	<1	<1
26N/07E-30P01	77	1.9	20	1	<1	<1
26N/07E-31B02	103	.29	13	<1	<1	<1
26N/07E-32K01	122	<.05	32	48	<1	<1
26N/07E-32M01	123	<.05	32	86	<1	<1
26N/07E-33Q02	123	2.7	9	<1	<1	1
26N/07E-35D01	255	<.05	210	180	<1	2
BLANK - Deionized water	--	<.05	<3	<1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	14	1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	4	<1	--	--
	--	<.05	5	<1	--	--
	--	<.05	3	<1	--	--

Table B2.--*Concentrations of selected trace elements*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
23N/08E-03L03	07-30-91	1545	Qal	3	7	<1	<1	<1
23N/08E-04L01	08-08-91	1215	Qal	<1	<2	<1	<1	6
23N/08E-05K02	08-16-91	0900	Qal	19	6	<1	<1	<1
23N/08E-08K01	08-15-91	0840	Br	<1	10	<1	<1	61
23N/08E-10F03	08-15-91	1425	Qal	<1	5	<1	<1	<1
	08-15-91	1430	Qal	1	5	<1	<1	<1
23N/08E-13N01	07-30-91	1415	Qal	3	<2	<1	<1	<1
23N/08E-15J06	07-30-91	1115	Qal	<1	3	<1	<1	1
23N/08E-16M01	08-08-91	1500	Br	1	21	<1	<1	<1
23N/08E-22A01	08-15-91	1015	Qal	<1	2	<1	<1	2
23N/08E-24J01	08-15-91	1220	Br	5	6	<1	<1	<1
23N/08E-25F01	08-15-91	1845	Qal	2	2	<1	<1	<1
24N/06E-02E01	08-02-91	1540	Qvt	2	3	<1	5	<1
24N/06E-06A05	08-03-91	1150	Q(A)c	<1	8	<1	<1	<1
24N/06E-09E03	08-01-91	1440	Qva	1	4	<1	<1	13
24N/06E-09N02	07-31-91	1345	Qva	1	6	<1	<1	<1
	07-31-91	1350	Qva	1	6	<1	<1	<1
24N/06E-10H02	08-08-91	1110	Qva	1	2	<1	1	6
	08-08-91	1115	Qva	1	<2	<1	<1	6
24N/06E-10P02	08-08-91	1400	Qva	9	3	<1	<1	13
24N/06E-12B01	08-02-91	1255	Q(A)c	4	6	<1	<1	<1
24N/06E-12L01	08-02-91	1410	Q(A)f	9	6	<1	<1	<1
24N/06E-22H02	08-02-91	1110	Qvr	2	5	<1	1	<1
24N/07E-03P01	08-05-91	1215	Q(A)c	11	28	<1	<1	<1
24N/07E-04E01	08-09-91	1045	Qal	5	14	<1	<1	<1
24N/07E-05F01	08-09-91	1335	Br	2	2	<1	2	1
24N/07E-06B01	08-09-91	1200	Q(A)c	2	3	<1	3	2
24N/07E-08A02	08-15-91	1025	Qvt	<1	2	<1	<1	1
24N/07E-10K01	08-09-91	0855	Qal	10	8	<1	<1	<1
24N/07E-12E02	08-07-91	1445	Qvr	<1	<2	<1	<1	4
	08-07-91	1450	Qvr	<1	<2	<1	2	2
24N/07E-12J01	08-15-91	1130	Br	8	2	<1	<1	<1
24N/07E-13E01	07-31-91	1030	Br	9	<2	<1	<1	<1
24N/07E-14G01	08-07-91	1320	Qal	<1	5	<1	<1	6
24N/07E-15D01	07-29-91	1435	Qal	10	4	<1	<1	2
24N/07E-16F01	08-06-91	1115	Qvr	<1	2	<1	<1	76
24N/07E-17B01	08-05-91	1210	Qvr	1	3	<1	<1	2
24N/07E-18F03	08-05-91	1400	Qva	<1	2	<1	<1	7
24N/07E-19R02	08-07-91	1130	Br	<1	<2	<1	<1	2
24N/07E-20J02	08-02-91	1325	Br	2	75	<1	1	1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
23N/08E-03L03	<1	<0.1	<1	<1.0	71	--
23N/08E-04L01	<1	<.1	<1	<1	100	450
23N/08E-05K02	<1	<.1	<1	<1	19	--
23N/08E-08K01	5	<.1	<1	<1	99	180
23N/08E-10F03	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	6	--
23N/08E-13N01	<1	<.1	<1	<1	<3	--
23N/08E-15J06	<1	<.1	<1	<1	170	--
23N/08E-16M01	<1	<.1	<1	<1	<3	--
23N/08E-22A01	<1	<.1	<1	<1	9	--
23N/08E-24J01	<1	<.1	<1	<1	10	<80
23N/08E-25F01	<1	<.1	<1	<1	4	--
24N/06E-02E01	<1	<.1	<1	<1	<3	--
24N/06E-06A05	<1	.2	<1	<1	<3	--
24N/06E-09E03	<1	<.1	<1	<1	150	--
24N/06E-09N02	<1	<.1	<1	<1	20	--
	<1	<.1	<1	<1	18	--
24N/06E-10H02	<1	<.1	<1	<1	15	260
	<1	<.1	<1	<1	14	220
24N/06E-10P02	<1	<.1	<1	<1	10	--
24N/06E-12B01	<1	<.1	<1	<1	23	--
24N/06E-12L01	<1	<.1	<1	<1	3	--
24N/06E-22H02	<1	<.1	<1	<1	11	--
24N/07E-03P01	<1	<.1	<1	<1	3	--
24N/07E-04E01	<1	<.1	<1	<1	9	--
24N/07E-05F01	<1	<.1	<1	<1	14	260
24N/07E-06B01	<1	<.1	<1	<1	33	--
24N/07E-08A02	<1	.1	<1	<1	55	--
24N/07E-10K01	<1	<.1	<1	<1	62	--
24N/07E-12E02	<1	<.1	<1	<1	130	190
	<1	<.1	<1	<1	130	240
24N/07E-12J01	<1	<.1	<1	<1	120	--
24N/07E-13E01	<1	<.1	<1	<1	<3	--
24N/07E-14G01	<1	<.1	<1	<1	43	--
24N/07E-15D01	<1	<.1	<1	<1	7	530
24N/07E-16F01	<1	<.1	<1	<1	21	210
24N/07E-17B01	<1	<.1	<1	<1	76	--
24N/07E-18F03	<1	<.1	<1	<1	4	--
24N/07E-19R02	<1	<.1	<1	<1	<3	--
24N/07E-20J02	<1	<.1	<1	<1	70	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
24N/07E-21H01	07-29-91	1625	Br	5	<2	<1	<1	<1
24N/07E-23D01	08-15-91	1640	Qal	11	17	<1	<1	<1
24N/07E-23H03	08-02-91	1105	Br	<1	<2	<1	<1	<1
24N/07E-24Q01	08-06-91	1330	Qva	8	7	<1	<1	1
24N/07E-27D01	08-01-91	1415	Q(A)c	8	10	<1	<1	2
24N/07E-33D01	08-01-91	1035	Qvr	1	8	<1	<1	<1
24N/07E-36M01	08-01-91	1245	Q(A)c	1	3	<1	<1	<1
24N/07E-36R01	07-31-91	1415	Br	4	<2	<1	<1	<1
24N/08E-18K02	07-30-91	1505	Qva	8	5	<1	<1	<1
	07-30-91	1510	Qva	9	6	<1	<1	<1
24N/08E-19M01	08-06-91	1445	Br	3	9	<1	<1	<1
24N/08E-20M01	07-29-91	1025	Qvr	2	7	<1	<1	3
24N/08E-20R02	07-29-91	1335	Qvr	2	11	<1	1	<1
24N/08E-24Q01S	07-29-91	1040	Br	<1	4	<1	<1	2
24N/08E-26K01	07-30-91	1330	Qal	<1	2	<1	<1	<1
24N/08E-28E02	07-29-91	1240	Qvr	6	7	<1	<1	<1
24N/08E-28H01	07-30-91	1100	Qva	6	9	<1	<1	<1
24N/08E-30N01	07-31-91	1150	Qal	<1	<2	<1	<1	4
24N/08E-32F01	08-16-91	1040	Q(A)c	3	14	<1	<1	<1
25N/06E-01N01	08-01-91	1155	Qva	<1	2	<1	<1	61
25N/06E-10J02	08-01-91	1310	Qva	10	6	<1	<1	<1
25N/06E-14M01	07-31-91	1445	Qvt	<1	15	<1	<1	<1
25N/06E-20E01	07-31-91	1600	Q(B)c	2	13	<1	<1	<1
25N/06E-24K01	08-01-91	1100	Qvt	<1	4	<1	1	2
25N/06E-25E01	07-31-91	1300	Q(A)c	2	<2	<1	<1	14
25N/06E-25K01	08-01-91	1450	Q(A)c	19	9	<1	<1	<1
25N/06E-28H01	07-31-91	1130	Qvr	1	5	<1	<1	17
25N/06E-32F03	08-02-91	1715	Q(A)c	<1	6	<1	<1	8
25N/06E-34D01	08-02-91	1130	Qva	2	3	<1	<1	<1
25N/06E-34E02	08-08-91	0940	Q(B)c	<1	8	<1	<1	12
25N/07E-01N01	08-09-91	1450	Qvt	9	21	<1	<1	<1
25N/07E-04J01	08-03-91	1555	Qal	26	10	<1	<1	<1
	08-03-91	1600	Qal	26	10	<1	<1	<1
25N/07E-06B01	08-06-91	1455	Q(A)c	31	15	<1	<1	6
25N/07E-07E01	08-02-91	1545	Q(A)c	<1	<2	<1	<1	<1
25N/07E-07P01	08-03-91	1435	Qvr	2	3	<1	2	24
25N/07E-08D02	08-06-91	1325	Q(A)c	19	12	<1	<1	<1
25N/07E-10E01	08-02-91	1340	Qal	<1	3	<1	<1	3
25N/07E-10J01	08-06-91	1145	Qva	2	5	<1	<1	2
25N/07E-11Q01	08-07-91	1415	Q(A)c	9	11	<1	<1	<1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
24N/07E-21H01	<1	<0.1	<1	<1	18	--
24N/07E-23D01	<1	<.1	<1	<1	19	--
24N/07E-23H03	<1	<.1	<1	<1	<3	--
24N/07E-24Q01	<1	<.1	<1	<1	15	--
24N/07E-27D01	<1	<.1	<1	<1	5	--
24N/07E-33D01	<1	<.1	<1	<1	62	--
24N/07E-36M01	<1	<.1	<1	<1	18	--
24N/07E-36R01	<1	<.1	<1	<1	7	--
24N/08E-18K02	<1	<.1	<1	<1	28	--
	<1	<.1	<1	<1	28	--
24N/08E-19M01	<1	<.1	<1	<1	<3	--
24N/08E-20M01	<1	<.1	<1	<1	150	--
24N/08E-20R02	<1	<.1	<1	<1	11	--
24N/08E-24Q01S	<1	<.1	<1	<1	6	--
24N/08E-26K01	<1	<.1	<1	<1	<3	--
24N/08E-28E02	<1	<.1	<1	<1	32	--
24N/08E-28H01	<1	<.1	<1	<1	66	190
24N/08E-30N01	<1	.2	<1	<1	140	--
24N/08E-32F01	<1	<.1	<1	<1	<3	--
25N/06E-01N01	<1	<.1	<1	<1	510	--
25N/06E-10J02	<1	.1	<1	<1	77	--
25N/06E-14M01	<1	<.1	<1	<1	10	440
25N/06E-20E01	<1	<.1	<1	<1	48	--
25N/06E-24K01	<1	.1	<1	<1	22	--
25N/06E-25E01	<1	<.1	<1	<1	270	--
25N/06E-25K01	<1	<.1	<1	<1	5	150
25N/06E-28H01	<1	<.1	<1	<1	81	--
25N/06E-32F03	<1	<.1	<1	<1	5	--
25N/06E-34D01	<1	<.1	<1	<1	5	--
25N/06E-34E02	<1	<.1	<1	<1	<3	--
25N/07E-01N01	<1	<.1	<1	<1	<3	--
25N/07E-04J01	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--
25N/07E-06B01	<1	.8	<1	<1	<3	--
25N/07E-07E01	<1	<.1	<1	<1	<3	--
25N/07E-07P01	<1	<.1	<1	<1	4	280
25N/07E-08D02	<1	<.1	<1	<1	5	--
25N/07E-10E01	<1	<.1	<1	<1	<3	--
25N/07E-10J01	<1	<.1	<1	<1	15	--
25N/07E-11Q01	<1	<.1	<1	<1	29	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo- hydro- logic unit	Arsenic, dis- solved (µg/L as As)	Barium, dis- solved (µg/L as Ba)	Cadmium, dis- solved (µg/L as Cd)	Chro- mium, dis- solved (µg/L as Cr)	Copper, dis- solved (µg/L as Cu)
25N/07E-15C01	08-07-91	1300	Q(A)c	30	9	<1	<1	<1
25N/07E-15R02	08-05-91	1245	Qvr	2	<2	<1	1	3
25N/07E-17A01	08-01-91	1255	Qva	2	4	<1	<1	1
25N/07E-20P01	08-05-91	1600	Q(A)c	14	10	<1	<1	4
25N/07E-21C01	08-05-91	1500	Qal	<1	<2	<1	<1	6
25N/07E-23Q01S	08-16-91	1530	Qvt	1	<2	<1	3	4
25N/07E-26F01S	08-07-91	1600	Qvr	<1	3	<1	1	<1
25N/07E-27D01	08-09-91	1240	Qvr	2	8	<1	<1	<1
25N/07E-28Q01	08-05-91	1425	Qal	<1	7	<1	2	10
25N/07E-29H02	08-07-91	1135	Q(A)c	9	19	<1	<1	3
25N/07E-30F01	08-03-91	1325	Q(A)c	1	4	<1	2	1
25N/07E-31D01	08-09-91	1045	Qal	2	6	<1	<1	<1
25N/07E-31J01	08-05-91	1800	Q(A)c	<1	14	<1	<1	3
25N/07E-33Q01	08-05-91	1320	Q(A)c	<1	4	<1	2	1
25N/07E-34E02	08-16-91	0930	Qvr	<1	2	<1	<1	<1
26N/06E-02M01	08-07-91	1300	Q(A)c	3	4	<1	<1	<1
26N/06E-04J02	08-08-91	1020	Br	2	24	<1	<1	35
26N/06E-09B02	08-08-91	0900	Qva	12	14	<1	<1	6
26N/06E-10A01	08-06-91	1000	Qva	<1	5	<1	2	15
26N/06E-13D03	08-05-91	1320	Q(A)c	37	23	<1	<1	2
26N/06E-13J01	08-16-91	1250	Qva	<1	2	<1	<1	3
	08-16-91	1255	Qva	<1	2	<1	<1	1
26N/06E-14D01	08-05-91	1145	Q(A)c	77	4	<1	<1	13
26N/06E-22K02	08-07-91	1525	Qva	<1	<2	<1	<1	3
26N/06E-24D01	08-06-91	0830	Q(A)c	33	10	<1	<1	3
26N/06E-25F01	08-07-91	1510	Qvt	19	12	<1	<1	3
26N/06E-26D03	08-14-91	1450	Qva	8	12	<1	<1	<1
26N/07E-03M01	08-06-91	1205	Br	<1	<2	<1	<1	1
26N/07E-04D01	08-06-91	1435	Br	<1	<2	<1	<1	3
	08-06-91	1440	Br	<1	<2	<1	<1	2
26N/07E-06K01	08-14-91	1320	Br	<1	<2	<1	<1	9
26N/07E-08A01	08-05-91	1620	Br	<1	<2	<1	<1	4
26N/07E-09F02	08-07-91	1100	Br	<1	<2	<1	<1	9
26N/07E-14G02	08-16-91	1115	Br	<1	<2	<1	2	180
26N/07E-16A01	08-06-91	1640	Br	<1	<2	<1	<1	1
26N/07E-16L02	08-08-91	1405	Qva	<1	<2	<1	<1	<1
26N/07E-17C01	08-07-91	1130	Q(A)f	14	8	<1	<1	1
26N/07E-18B01	08-07-91	1635	Qva	<1	<2	<1	1	2
26N/07E-18N01	08-07-91	1400	Q(A)c	<1	7	<1	<1	<1
26N/07E-19J02	08-08-91	1125	Q(A)f	29	7	<1	<1	1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
25N/07E-15C01	<1	<0.1	<1	<1	4	--
25N/07E-15R02	<1	<.1	<1	<1	55	--
25N/07E-17A01	<1	<.1	<1	<1	200	--
25N/07E-20P01	<1	<.1	<1	<1	14	--
25N/07E-21C01	<1	<.1	<1	<1	150	250
25N/07E-23Q01S	<1	<.1	<1	<1	6	--
25N/07E-26F01S	<1	<.1	<1	<1	15	--
25N/07E-27D01	<1	<.1	<1	<1	<3	--
25N/07E-28Q01	<1	<.1	<1	<1	61	--
25N/07E-29H02	<1	<.1	<1	<1	5	--
25N/07E-30F01	<1	.2	<1	<1	310	--
25N/07E-31D01	<1	<.1	<1	<1	3	--
25N/07E-31J01	<1	<.1	<1	<1	270	--
25N/07E-33Q01	<1	<.1	<1	<1	24	--
25N/07E-34E02	<1	<.1	<1	<1	550	--
26N/06E-02M01	<1	<.1	<1	<1	88	--
26N/06E-04J02	<1	<.1	<1	<1	45	--
26N/06E-09B02	<1	<.1	<1	<1	14	--
26N/06E-10A01	<1	<.1	<1	<1	57	--
26N/06E-13D03	<1	<.1	<1	<1	6	<80
26N/06E-13J01	<1	<.1	<1	<1	67	--
	<1	<.1	<1	<1	40	--
26N/06E-14D01	<1	<.1	<1	<1	10	--
26N/06E-22K02	<1	<.1	<1	<1	67	--
26N/06E-24D01	<1	<.1	<1	<1	10	--
26N/06E-25F01	2	<.1	<1	<1	37	--
26N/06E-26D03	<1	.2	<1	<1	140	--
26N/07E-03M01	<1	<.1	<1	<1	8	--
26N/07E-04D01	<1	<.1	<1	<1	17	320
	<1	<.1	<1	<1	20	320
26N/07E-06K01	1	<.1	<1	<1	<3	--
26N/07E-08A01	<1	<.1	<1	<1	210	--
26N/07E-09F02	<1	<.1	<1	<1	44	360
26N/07E-14G02	<1	<.1	<1	<1	29	--
26N/07E-16A01	<1	<.1	<1	<1	10	--
26N/07E-16L02	<1	<.1	<1	<1	5	--
26N/07E-17C01	<1	<.1	<1	<1	10	--
26N/07E-18B01	<1	<.1	<1	<1	28	--
26N/07E-18N01	<1	<.1	<1	<1	190	--
26N/07E-19J02	<1	<.1	<1	<1	22	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
26N/07E-19P01	08-08-91	1240	Qva	18	7	<1	<1	<1
26N/07E-20E01	08-06-91	1530	Qva	6	4	<1	3	<1
26N/07E-22D01	08-07-91	0955	Qva	<1	<2	<1	<1	1
26N/07E-27F01	08-07-91	1230	Br	<1	26	<1	<1	<1
26N/07E-28E02	08-08-91	1130	Qva	2	<2	<1	<1	1
26N/07E-30A01	08-08-91	1600	Qva	9	3	<1	<1	8
26N/07E-30P01	08-06-91	1325	Qvt	<1	2	<1	<1	52
26N/07E-31B02	08-06-91	1145	Qva	1	5	<1	2	1
26N/07E-32K01	08-09-91	1200	Q(A)c	13	9	<1	<1	<1
26N/07E-32M01	08-08-91	1410	Q(A)f	10	9	<1	<1	13
26N/07E-33Q02	08-09-91	1220	Qvr	2	4	<1	<1	2
26N/07E-35D01	08-15-91	1335	Qva	<1	23	<1	<1	<1
BLANK - Deionized water	07-30-91	1530	--	<1	<2	<1	<1	<1
	08-03-91	1630	--	<1	<2	<1	<1	<1
	08-06-91	1505	--	<1	<2	<1	<1	<1
	08-07-91	1330	--	<1	<2	<1	2	<1
	08-07-91	1515	--	<1	<2	<1	<1	2
	08-08-91	1140	--	<1	<2	<1	<1	<1
	08-15-91	1455	--	<1	<2	<1	<1	<1
	08-16-91	1320	--	<1	<2	<1	<1	2

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
26N/07E-19P01	<1	<0.1	<1	<1	5	--
26N/07E-20E01	<1	<.1	<1	<1	130	--
26N/07E-22D01	<1	<.1	<1	<1	67	--
26N/07E-27F01	<1	<.1	<1	<1	11	--
26N/07E-28E02	<1	<.1	<1	<1	48	150
26N/07E-30A01	<1	<.1	<1	<1	15	--
26N/07E-30P01	<1	<.1	<1	<1	40	--
26N/07E-31B02	<1	<.1	<1	<1	76	--
26N/07E-32K01	<1	<.1	<1	<1	5	--
26N/07E-32M01	2	<.1	<1	<1	27	--
26N/07E-33Q02	<1	<.1	<1	<1	4	--
26N/07E-35D01	<1	<.1	<1	<1	5	--
BLANK - Deionized water	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	11	110
	<1	<.1	<1	<1	7	--
	<1	<.1	<1	<1	<3	<80
	<1	<.1	<1	<1	5	100
	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--

Table B3.--*Concentrations of volatile organic compounds*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	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)
23N/08E-04L01	08-08-91	1215	Qal	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	08-16-91	0900	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	08-15-91	1425	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	08-15-91	1015	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	08-08-91	1110	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	08-08-91	1115	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	08-09-91	0855	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	07-29-91	1435	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	08-05-91	1500	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	08-09-91	1240	Qvr	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	08-05-91	1320	Q(A)c	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	08-08-91	1240	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	08-08-91	1140	--	<.2	.2	<.2	<.2	<.2	<.2	<.2

Local well number	Bromo-di-chloro-methane, total (µg/L)	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)	1,1,1,2-Tetra-chloro-ethane, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Table B3.--*Concentrations of volatile organic compounds--Continued*

Local well number	1,1,2,2-Tetra-chloro-ethane, total (µg/L)	1,2-Dibromo-ethane, total (µg/L)	Chloro-ethene, total (µg/L)	1,1-Di-chloro-ethene, total (µg/L)	1,2-Di-chloro-ethene, total (µg/L)	Tri-chloro-ethene, total (µg/L)	Tetra-chloro-ethene, total (µg/L)	1,2-Di-chloro-propane, total (µg/L)	1,3-Di-chloro-propane, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Local well number	2,2-Di-chloro-propane, total (µg/L)	1,2,3-Tri-chloro-propane, total (µg/L)	1,1-Di-chloro-propene, total (µg/L)	cis 1,3-Di-chloro-propene, total (µg/L)	trans 1,3-Di-chloro-propene, total (µg/L)	Benzene, total (µg/L)	Chloro-benzene, total (µg/L)	1,2-Di-chloro-benzene, total (µg/L)	1,3-Di-chloro-benzene, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Table B3.--*Concentrations of volatile organic compounds--Continued*

Local well number	1,4-Dichloro-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)	Dimethyl-benzene, total (µg/L)	Ethyl-benzene, total (µg/L)	Ethenyl-benzene, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	.3	<.2	<.2	<.2	<.2	<.2

Table B4.--*Concentrations of selected pesticides*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	2,4-D, total (µg/L)	2,4-DP, total (µg/L)	2,4,5-T, total (µg/L)	Silvex, total (µg/L)	Dicamba, total (µg/L)
23N/08E-04L01	08-08-91	1215	Qal	<0.01	<0.01	<0.01	<0.01	<0.01
24N/06E-10H02	08-08-91	1110	Qva	<.01	<.01	<.01	<.01	<.01
	08-08-91	1115	Qva	--	--	--	--	--
24N/07E-04E01	08-09-91	1045	Qal	<.01	<.01	<.01	<.01	<.01
24N/07E-08A02	08-15-91	1025	Qvt	.02	<.01	<.01	<.01	<.01
24N/07E-10K01	08-09-91	0855	Qal	<.01	<.01	<.01	<.01	<.01
25N/07E-21C01	08-05-91	1500	Qal	<.01	<.01	<.01	<.01	.01
25N/07E-28Q01	08-05-91	1425	Qal	<.01	<.01	<.01	<.01	.01
25N/07E-29H02	08-07-91	1135	Q(A)c	<.01	<.01	<.01	<.01	<.01
25N/07E-31D01	08-09-91	1045	Qal	<.01	<.01	<.01	<.01	<.01
26N/06E-13D03	08-05-91	1320	Q(A)c	<.01	<.01	<.01	<.01	.01
26N/06E-25F01	08-07-91	1510	Qvt	<.01	<.01	<.01	<.01	<.01
26N/07E-06K01	08-14-91	1320	Br	<.01	<.01	<.01	<.01	<.01
BLANK- Deionized water	08-08-91	1140	--	<.01	<.01	<.01	<.01	<.01

Local well number	Piclo-ram, total (µg/L)	Ala-chlor, dis-solved (µg/L)	Ame-tryn, dis-solved (µg/L)	Atra-zine, dis-solved (µg/L)	Cyana-zine, dis-solved (µg/L)	De-ethyl atra-zine, dis-solved (µg/L)	De-iso-propyl atra-zine, dis-solved (µg/L)
23N/08E-04L01	<0.01	<0.05	<0.05	<0.05	<0.20	<0.05	<0.05
24N/06E-10H02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
	--	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-04E01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-08A02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-10K01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-21C01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-28Q01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-29H02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-31D01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/06E-13D03	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/06E-25F01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/07E-06K01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
BLANK - Deionized water	<.01	<.05	<.05	<.05	<.20	<.05	<.05

Table B4.--*Concentrations of selected pesticides--Continued*

Local well number	Metolachlor, dissolved (µg/L)	Metribuzin sencor, dissolved (µg/L)	Prometon, dissolved (µg/L)	Prometryn, dissolved (µg/L)	Propazine, dissolved (µg/L)	Simazine, dissolved (µg/L)
23N/08E-04L01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
24N/06E-10H02	<.05	<.05	<.05	<.05	<.05	<.05
	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-04E01	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-08A02	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-10K01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-21C01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-28Q01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-29H02	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-31D01	<.05	<.05	<.05	<.05	<.05	<.05
26N/06E-13D03	<.05	<.05	<.05	<.05	<.05	<.05
26N/06E-25F01	<.05	<.05	<.05	<.05	<.05	<.05
26N/07E-06K01	<.05	<.05	<.05	<.05	<.05	<.05
BLANK - Deionized water	<.05	<.05	<.05	<.05	<.05	<.05

Table B5.--*Concentrations of septage-related compounds*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Nitrate plus nitrite, dis-solved (mg/L as N)	Boron, dis-solved (µg/L as B)	Carbon, organic, dis-solved (mg/L as C)	Methy-lene blue active sub-stances (mg/L)
23N/08E-05K02	08-16-91	0900	Qal	<0.05	20	1.6	<0.02
23N/08E-10F03	08-15-91	1425	Qal	.49	10	.2	<.02
23N/08E-22A01	08-15-91	1015	Qal	.30	10	.3	<.02
24N/06E-02E01	08-02-91	1540	Qvt	1.2	<10	.5	<.02
24N/06E-10H02	08-08-91	1110	Qva	1.4	<10	.5	<.02
	08-08-91	1115	Qva	1.5	<10	.4	<.02
24N/06E-10P02	08-08-91	1400	Qva	<.05	10	.6	<.02
24N/07E-15D01	07-29-91	1435	Qal	1.9	30	.6	<.02
24N/08E-20R02	07-29-91	1335	Qvr	<.05	<10	1.5	<.02
24N/08E-30N01	07-31-91	1150	Qal	.07	<10	1.4	<.02
25N/06E-34D01	08-02-91	1130	Qva	.53	<10	.4	<.02
25N/07E-15C01	08-07-91	1300	Q(A)c	<.05	120	.8	<.02
25N/07E-17A01	08-01-91	1255	Qva	.80	<10	.5	<.02
25N/07E-21C01	08-05-91	1500	Qal	.32	<10	.4	<.02
25N/07E-29H02	08-07-91	1135	Q(A)c	<.05	60	.8	<.02
26N/06E-04J02	08-08-91	1020	Br	.12	20	.5	<.02
26N/06E-10A01	08-06-91	1000	Qva	.28	20	.5	<.02
26N/07E-04D01	08-06-91	1435	Br	<.05	20	.7	<.02
	08-06-91	1440	Br	<.05	<10	.7	<.02
26N/07E-22D01	08-07-91	0955	Qva	.22	10	.4	<.02
26N/07E-28E02	08-08-91	1130	Qva	2.5	10	.4	<.02
BLANK - Deionized water	08-06-91	1505	--	<.05	<10	.5	<.02
	08-08-91	1140	--	<.05	<10	.5	<.02

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

The quality-assurance plan for this study (G. L. Turney, U.S. Geological Survey, written commun., 1991) calls for quality-control procedures at all levels of data collection and analysis. Whereas many of the procedures address only methodology, some require the collection and analysis of quality-control samples. The resulting data are reviewed to determine the quality of the project data.

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

In the following sections, data from standard reference samples, sample duplicates, blanks, cation-anion balance, field alkalinity, and checks on field values are discussed. The data are included in the tables of Appendix B.

Standard Reference Samples

Standard reference samples of various concentrations for selected inorganic constituents were inserted as blind samples into the laboratory sample runs at the National Water Quality Laboratory (NWQL). Each standard sample was submitted several times to obtain enough data to be statistically meaningful. The results were summarized and are available through computer programs maintained by the U.S. Geological Survey's Branch of Quality Assurance (BQA). The summary provides the mean concentration determined by the NWQL for each standard during a given period, along with the standard deviation of the laboratory concentrations, coefficient of variation, and number of times the standard was submitted and analyzed. These data for standards submitted from July 15 to August 31, 1991, were used to assess the error in the analytical accuracy of samples collected from 124 east King County wells and springs during that period. The standards used in the assessment were only those that enclosed the range of the sample concentrations; that is, the range of standards just exceeded the range of samples. In cases where that was not possible, those standards that best represented the sample concentrations were used.

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

$$s_i = \sqrt{s_s{}^2 + (\bar{u}_s - MPV_s)^2} \qquad (1)$$

where

s_i = standard deviation of the estimated true standard concentration;

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

$\bar{u}_s$ = mean concentration of the standard as determined by the NWQL; and

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

Equation 2 was used to determine the coefficient of variation (CV_i) for the analysis of each standard:

$$CV_i = \frac{s_i}{MPV_s} \qquad (2)$$

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

$$CV_o = \sqrt{\frac{\sum_{i=1}^{m} (n_i - 1) CV_i^2}{\sum_{i=1}^{m} (n_i - 1)}} \qquad (3)$$

where

CV_0 = overall coefficient of variation of all standards for a constituent;

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

m = number of standards.

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

$$E = (1.96 \times CV_0)\,100 \quad , \qquad (4)$$

where E = overall error of analysis, in percent.

This error is a representation of the average percent error in analytical accuracy of the samples from east King County and is shown in table C1 for each constituent. It also includes a degree of analytical precision. However, the accuracy and precision are difficult to separate in the given data, and, in the interest of conservation, the error is considered to be entirely in the accuracy.

The average absolute standard deviation (s_0) for each constituent, in units based on concentration, was calculated using equation 5 and is also shown in table C1.

$$s_0 \sqrt{\frac{\sum_{i=1}^{m} (n_i - 1)\, s_s^2}{\sum_{i=1}^{m} (n_i - 1)}} \qquad (5)$$

The estimated errors for the cations and anions determined in this study were generally reasonable. Quality-assurance goals for this study called for an error of 10 percent or less for cations, anions, and nutrients. The errors for magnesium, sodium, alkalinity, and chloride met this goal. The errors for calcium, potassium, and silica, just barely exceeded the goal and ranged from 11 to 12 percent. The errors for sulfate and nitrate were 19 and 14 percent, respectively, and are probably representative. The largest error was 53 percent, for fluoride, and was a result of errors in small concentrations that were close to the detection limit. At these low concentrations, acceptable small absolute errors, as represented by the absolute standard deviation, produce large percent errors. For example, an absolute error of 0.2 mg/L is a 20-percent error for a concentration of 1.0 mg/L, but is only a 2-percent error for a concentration of 10 mg/L.

Errors for metals ranged from 11 to 111 percent. In a few instances, the error was within the goal of 20 percent. However, the generally large percent errors associated with metals were usually from concentrations that were at or near detection limits. Even though the percentages themselves were large at these low levels, the absolute errors were reasonable.

The average absolute error, as represented by the average absolute standard deviations, was generally reasonable. Even in instances where it seemed large, such as for sulfate or zinc, the absolute error was good when compared with the range of standards from which it was derived. Only for cadmium and chromium did the average absolute error seem large. Because cadmium and chromium were not present in significant quantities in east King County ground water, this is not considered a problem. Furthermore, the absolute standard deviation of the actual samples was probably smaller than that listed in table C1 for the standards. This is because the overall error as derived usually overemphasizes standards at larger concentrations when the concentration ranges over several standards. Although the standards were submitted in approximately equal numbers over the entire concentration range, the constituent concentrations in the ground-water samples were mostly near the smaller end of the range; only a small percentage of samples were near the larger end of the concentration range. In fact, in most cases the median ground-water concentration was smaller than the smallest standard, even though the sample concentration range covered several standards. In extreme cases, such as for cadmium and chromium, the smallest standard concentration was larger than the largest ground-water concentration. The standard deviation tends to increase with concentration, so the average standard deviation of the standards will be larger than the average standard deviation of the samples due to the difference in concentration distribution.

Internal surrogate standards were injected into each sample to be analyzed for concentrations of volatile organic compounds or pesticides. The standards were used to determine percent recoveries, and those that were not detected within a certain percentage of the known concentrations (variable, dependent upon the compound)

Table C1.--*Estimated error in analysis of inorganic constituents*

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

Constituent	Number of standards	Number of times standards submitted	Median concentration in ground-water samples	Range of concentrations in ground-water samples	Range of concentration of standards	Average absolute standard deviation of standards	Average[a] percent error in analysis
Calcium	6	34	15	0.79 - 55	8.31 - 63.2	1.6	11
Magnesium	6	34	5.0	.03 - 27	2.04 - 41.8	.82	7.2
Sodium	6	34	6.6	1.9 - 200	27.5 - 101	2.8	9.0
Potassium	5	22	1.3	.1 - 7	1.60 - 3.53	.12	12
Alkalinity	5	22	76	20 - 266	16.8 - 88.5	2.3	8.8
Sulfate	5	22	4.8	<.1 - 170	12.5 - 314	6.9	19
Chloride	5	22	3.0	.3 - 140	23.0 - 54.3	1.7	9.8
Fluoride	4	19	<.1	<.1 - 2.5	.33 - 1.05	.14	53
Silica	3	11	23	8.5 - 43	5.53 - 12.3	.59	11
Nitrate	2	73	.07	<.05 - 6.3	.41 - 1.42	.05	14
Iron (μg/L)	2	17	24	<3 - 14,000	38.2 - 122	6.7	14
Manganese (μg/L)	1	3	17	<1 - 920	46.3	2.6	11
Arsenic (μg/L)	2	18	2	<1 - 77	2.75 - 5.97	.80	53
Barium (μg/L)	3	20	5	<2 - 75	56.8 - 126	6.8	12
Boron (μg/L)	4	18	10	<10 - 120	11.0 - 66.2	5.9	47
Cadmium (μg/L)	2	7	<1	<1 - <1	3.99 - 11.5	4.0	74
Chromium (μg/L)	2	6	<1	<1 - 5	6.17 - 18.2	4.7	52
Copper (μg/L)	2	7	1	<1 - 180	5.45 - 7.06	1.3	39
Lead (μg/L)	2	7	<1	<1 - 5	9.40 - 11.5	1.3	25
Mercury (μg/L)	2	7	<.1	<.1 - .8	.11 - .16	.07	111
Selenium (μg/L)	1	12	<1	<1 - <1	3.95	1.1	56
Silver (μg/L)	2	6	<1	<1 - <1	.69 - 4.20	.47	65
Zinc (μg/L)	3	20	15	<3 - 550	68.2 - 198	9.6	19

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

were identified by the NWQL. No samples were reported to have substandard volatile organic compound or pesticide recoveries.

Duplicate Samples

Duplicate pairs of samples were collected for all types of analyses performed. Precision criteria were a 10-percent maximum difference for cations, anions, silica, dissolved solids, and nutrients and a 20-percent maximum difference for metals, trace elements, and organic compounds. A difference for each pair was computed as a percentage of the average concentration for the pair. The average difference of all pairs and the number of pairs exceeding the difference criteria are listed for each constituent in table C2.

For most constituents, the average percent difference was well within the criteria presented above. Only boron and copper had percent differences exceeding the criteria, although the differences for potassium, chloride, and zinc were relatively large also. In almost all cases, the larger percent errors were a result of small absolute differences in small concentrations near the detection limit, and were therefore considered acceptable. One exception was zinc, where a pair of samples from well 26N/06E-13J01 had concentrations of 67 and 40 μg/L, well above the detection limit of 3 μg/L. This disparity may reflect a sampling or analytical problem, but the overall difference for zinc is 19 percent (including these pairs) and the problem was probably isolated.

Blanks

Blanks of deionized water were processed in the same manner as water samples and sent to the NWQL for analysis. Although no criteria were set for constituent concentrations in blanks, the significance of any constituent present in a blank was based on how close the constituent concentration was to the detection limit and how small it was compared with the median sample concentration. Also important was the number of times the constituent was detected in blank samples. These data are presented in table C3 and, when compared with these criteria, concentrations in blanks were insignificant for all constituents except iron, zinc, and dissolved organic carbon. Even though iron was detected in four blanks, and the maximum concentration was 14 μg/L, the average blank concentration was 5 μg/L. Excluding the largest value, the average blank concentration was just over 3 μg/L, which was acceptable. Likewise, zinc was present in four blanks, and the average concentration in all blanks was 5 μg/L. Excluding the largest value of 11 μg/L, the average blank concentration was 4 μg/L, which was reasonable. For dissolved organic carbon, both blank concentrations were equal to the sample median concentration of 0.5 mg/L. However, the concentrations of concern in the study were 1.0 mg/L or larger, so interpretations were not affected.

Cation-Anion Balance

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

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

$$\frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} , \qquad (6)$$

where

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

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

Ideally, this value is zero, but nonzero values are common and may be large when a cation or anion concentration is in error or when an ion present in large concentrations (often a metal) is not analyzed for. The acceptable percent difference varies with the total sum of cations and anions, as shown in figure C1. For most of the samples collected in east King County, the cation-anion balance was acceptable; only six analyses exceeded the allowable percent difference. Of these, five still had cation-anion balances of less than 3 percent, and four of the five exceeded the allowable percent difference by less than 1 percent. The error in these five analyses was therefore minimal. The remaining sample, from well 24N/07E-10K01, had a cation-anion balance of 8.6 percent, and it is likely that the error was in the alkalinity. This sample was one of the eight for which a field alkalinity was determined and for these eight, field alkalinities were used in calculating the cation-anion

Table C2.--*Average differences in constituent values and concentrations determined for duplicate samples*

Constituents	Number of duplicate pairs	Average difference in percent	Number[a] of pairs exceeding difference criteria
Calcium	8	0.4	0
Magnesium	8	1.3	0
Sodium	8	2.3	0
Potassium	8	9.0	3
Alkalinity	8	1.4	0
Sulfate	8	1.2	0
Chloride	8	8.5	1
Fluoride	8	.0	0
Silica	8	1.5	0
Dissolved solids	8	.3	0
Nitrate	8	1.2	0
Iron	8	5.5	1
Manganese	8	3.3	1
Arsenic	8	1.5	0
Barium	8	2.3	0
Boron	2	33	1
Cadmium	8	.0	0
Chromium	8	8.3	1
Copper	8	26	3
Lead	8	.0	0
Mercury	8	.0	0
Selenium	8	.0	0
Silver	8	.0	0
Zinc	8	19	2
Radon-222	3	13	1
Dissolved organic carbon	2	11	1
Methylene blue active substances	2	.0	0
All organic[b]	1	.0	0

[a] Difference criterion is 10 percent for cations, anions, silica, dissolved solids, and nutrients. Percent-difference criterion is 20 percent for all metals, trace elements, radiochemicals, and organic compounds. No percent-difference criterion was established for bacteria.

[b] Organic compounds were not detected in any of the duplicate samples, therefore all differences for these compounds are zero. The duplicate analysis for the chlorophenoxy pesticides was lost during analysis.

Table C3.--*Summary of constituent values and concentrations determined for blank samples*

[Concentrations in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; pCi/L, picocuries per liter; cols. per 100 mL, colonies per 100 milliliters]

Constituent	Number of blanks	Detection limit	Number of blanks equal to or exceeding detection limit	Maximum blank concentration	Median sample concentration
Calcium	8	0.02	5	0.07	15
Magnesium	8	.01	6	.07	5.0
Sodium	8	.2	0	<.2	6.6
Potassium	8	.1	0	<.1	1.3
Alkalinity	8	1	8	3.0	76
Sulfate	8	.1	4	.2	4.8
Chloride	8	.1	4	.8	3.0
Fluoride	8	.1	0	<.1	<.1
Silica	8	.1	6	.3	23
Nitrate	8	.05	0	<.05	.07
Iron (µg/L)	8	3	4	14	24
Manganese (µg/L)	8	1	1	1	17
Arsenic (µg/L)	8	1	0	<1	2
Barium (µg/L)	8	2	0	<2	5
Boron (µg/L)	2	10	0	<10	10
Cadmium (µg/L)	8	1	0	<1	<1
Chromium (µg/L)	8	1	1	2	<1
Copper (µg/L)	8	1	2	2	1
Lead (µg/L)	8	1	0	<1	<1
Mercury (µg/L)	8	.1	0	<.1	<.1
Selenium (µg/L)	8	1	0	<1	<1
Silver (µg/L)	8	1	0	<1	<1
Zinc (µg/L)	8	3	3	11	15
Radon-222 (pCi/L)	3	80	2	110	250
Dissolved organic carbon	2	.1	2	.5	.5
Methylene blue active substances	2	.02	0	<.02	<.02
Dichloromethane (µg/L)	1	.2	1	.2	<.2
Toluene (µg/L)	1	.2	1	.3	<.2
All other organics, by class [1]					
Volatiles (µg/L)	1	.2	0	<.2	<.2
Chlorophenoxy acid pesticides (µg/L)	1	.01	0	<.01	<.01
Triazine pesticides (µg/L)	1	.05	0	<.05	<.05
Fecal coliform (cols. per 100 mL)	38	1	0	0	<1
Fecal streptococci (cols. per 100 mL)	38	1	2	4	<1

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[1] Organic compounds other than those listed individually were not detected in the blanks.

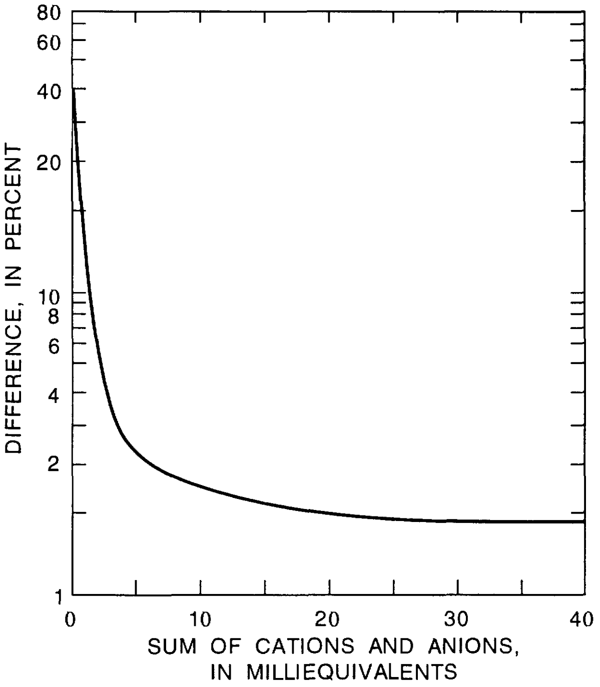

Figure C1.--Cation and anion percent difference curve.

balance because they provided a better balance. Nevertheless, the field alkalinity determined for this sample may have been low because some iron carbonate may have already precipitated, as discussed in the next section. All six analyses with excessive cation-anion balances were kept and used, because the indicated error was not large enough to affect any interpretations of the data. Also, when the error could be attributed to a likely constituent, such as the alkalinity, there was no way to determine the extent of error and the correct concentration.

Field Alkalinity

Alkalinity consists primarily of bicarbonate and a minor amount of carbonate and hydroxide in most natural ground-water systems. Alkalinity can be determined by titration either in the laboratory or in the field, but there are drawbacks with each. Field alkalinity analyses are time-consuming and are performed onsite in a field vehicle, often under less than ideal conditions. As a result, errors in analyses are more frequent than for laboratory analyses. The laboratory procedure is automated; however, the samples are not preserved, so any changes in sample chemistry, especially mineral precipitation or dissolution, can affect the alkalinity. One of the best indicators of the accuracy of an alkalinity value is the cation-anion balance. If field and laboratory alkalinity values differ greatly, the one that provides the better cation-anion balance is likely more accurate.

For this study, field alkalinities were determined only for samples that had a dissolved oxygen value of 1.0 mg/L or less and had an iron concentration of 800 µg/L or more, as determined with a field screening method. This approach was taken after making the following general observations during several other studies in Washington. First, in studies where field alkalinities were determined for every sample (Turney, 1986a, 1986b, 1986c, 1990) the difference in field and laboratory alkalinities was insignificant in most cases. Furthermore, when differences were significant, almost always the laboratory value was more accurate, as judged by the cation-anion balance. Most differences were therefore attributable to error in the field analysis. The most notable exceptions occurred when dissolved oxygen values were less than 0.5 mg/L and iron concentrations were larger than 1,000 µg/L. In these cases, the laboratory alkalinity was usually substantially smaller than the field alkalinity, probably because the unpreserved sample became oxygenated and iron carbonate precipitated out of solution, reducing the total alkalinity. The iron concentration was determined in the laboratory from an acid-preserved sample, so a corresponding drop in the iron concentration was not observed. This was evident during a study (Dion and others, 1994) where field alkalinities were not determined, and most of the samples with poor cation-anion balances had small dissolved-oxygen concentrations and large iron concentrations.

As mentioned in the report, only eight samples met the criteria for determining the alkalinity in the field. Of the eight samples, the field and laboratory alkalinities were identical for four of them. Of the remaining four, the laboratory alkalinity was lower than the field alkalinity by an average of 18 percent. Furthermore, these 4 samples had by far the 4 largest iron concentrations of all 124 samples, ranging from 5,700 to 14,000 µg/L. The cation-anion balance was acceptable in three of these four samples when calculated with the field alkalinity in place of the laboratory alkalinity. The sample with the unacceptable cation-anion balance, from well 24N/07E-10K01, was the only sample in the entire study with a cation-anion balance greatly exceeding that allowable (see previous section). In all four samples with the large iron concentrations, it is evident that iron carbonate was precipitating. For well 24N/07E-10K01, it simply appears that the precipitation began even before the field alkalinity could be determined. Given the overall good cation-anion balances observed for the east King County samples, and the results of the field alkalinities, the approach taken in this study for deciding when to determine field alkalinities seems reasonable.

Checks on Field Values

The primary controls on the determinations of field values of pH, specific conductance, dissolved oxygen, and temperature are proper instrument calibration and field procedures. However, pH and specific conductance are also determined in the laboratory as standard procedure. Values of laboratory and field specific conductance differed by more than 5 percent for 31 of 124 samples, and of these 31, exceeded 10 percent for 19 samples. Field and laboratory pH differed by more than 0.3 units for 18 of 124 samples, but only 8 of these differed by more than 0.5 units; the maximum difference was 1.3 units. Because pH and specific conductance values can change during the time between the field and laboratory determinations, these comparisons must be considered approximations at best, but the good agreement generally serves to confirm the field values.