



Prepared in cooperation with the
GRAND COUNTY BOARD OF COUNTY COMMISSIONERS

Water-Quality Characteristics and Ground- Water Quantity of the Fraser River Watershed, Grand County, Colorado, 1998–2001



Water-Resources Investigations Report 03–4275

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

Front and back covers: Fraser River Valley
Photographs by Jeffrey B. Bails, U.S. Geological Survey

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By Nancy J. Bauch and Jeffrey B. Bails

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CONVERSION FACTORS, DATUMS, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
centimeter per second (cm/s)	0.394	inch per second
cubic foot (ft ³)	0.02832	cubic meter
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon per day per foot (gpd/ft)	0.000207	cubic meter per second per meter
inch per year (in/yr)	25.4	millimeter per year
microgram per liter (µg/L)	1.0	part per billion
mile (mi)	1.609	kilometer
milligram per liter (mg/L)	1.0	part per million
milliliter (mL)	0.0338	ounce, fluid
pound per square inch (lb/in ²)	6.895	kilopascal

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

$$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$$

Datums: Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Abbreviations and Acronyms

col/100 mL	colonies per 100 milliliters
pCi/L	picocuries per liter
µm	micrometer
AMCL	alternative maximum contaminant level
CDPHE	Colorado Department of Public Health and Environment
<i>E. coli</i>	<i>Escherichia coli</i>
GIS	geographic information system
HA	health advisory
ISDS	individual septic disposal system
LOWESS	LOcally WEighted Scatterplot Smooth
LT-MDL	long-term method detection level
LRL	laboratory reporting level
MBAS	methylene blue active substances
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MRL	minimum reporting level

Abbreviations and Acronyms—Continued

NTU	nephelometric turbidity units
NWQL	National Water Quality Laboratory
PMCL	proposed maximum contaminant level
POC	particulate organic carbon
QC	quality control
SDWR	secondary drinking-water regulation
TT	treatment technique
TVS	table value standard
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WY	water year (a 12-month period beginning October 1 and ending September 30 of the following year. A water year is designated as the year in which it ends.)

Water-Quality Characteristics and Ground-Water Quantity of the Fraser River Watershed, Grand County, Colorado, 1998–2001

Nancy J. Bauch and Jeffrey B. Bails

Abstract

The U.S. Geological Survey, in cooperation with the Grand County Board of County Commissioners, conducted a 4-year study to assess ground- and surface-water-quality conditions and ground-water quantity in the 302-square-mile Fraser River watershed in north-central Colorado. The Fraser River flows north about 28 miles from the headwaters near the Continental Divide, through the towns of Winter Park, Fraser, Tabernash, and Granby, and is one of the major tributaries to the Upper Colorado River. Increasing urban development, as well as the seasonal influx of tourists, is placing more demands on the water resources in the Fraser River watershed.

A ground-water sampling network of 11 wells was established to represent different aquifer systems (alluvial, Troublesome Formation, Precambrian granite), land uses (urban, nonurban), and areas with or without individual septic disposal system use. The well network was sampled for ground-water quality on a semiannual basis from August 1998 through September 2001. The sampling included field properties and the collection of water samples for analysis of major ions, trace elements, nutrients, dissolved organic carbon, bacteria, methylene blue active substances, and radon-222. One surface-water site, on the Fraser River just downstream from the town of Tabernash, Colorado, was sampled bimonthly from August 1998 through September 2001 to assess the cumulative effects of natural and human processes on water quality in the upper part of the Fraser River watershed. Surface-water-quality sampling included field properties and the collection of water-quality samples for analysis of major ions, trace elements, nutrients, organic carbon, and bacteria.

Ground water was a calcium-bicarbonate type water and is suitable as a drinking-water, domestic, municipal, industrial, and irrigation source. In general, no widespread ground-water-quality problems were indicated. All pH values and concentrations of dissolved solids, chloride, fluoride, sulfate, nitrite, and nitrate in the ground-water samples met or were substantially less than U.S. Environmental Protection Agency drinking-water standards and health advisories or State of Colorado water-quality standards. Federal standards for turbidity and concentrations of iron, manganese, methylene blue active sub-

stances, and radon-222 were not met in water samples from at least one well. The only ground-water-quality concern assessed by this study is radon-222, which was detected in all radon-analyzed samples from 10 wells at levels exceeding the proposed U.S. Environmental Protection Agency drinking-water standard of 300 picocuries per liter.

Concentrations of chloride, magnesium, and sulfate were statistically different (higher) in ground-water samples from wells completed in the alluvial aquifer, urbanized areas, and areas with individual septic disposal system use than those from wells completed in the Troublesome Formation, nonurban areas, and areas without individual septic disposal system use. Dissolved organic carbon concentrations were statistically higher in ground-water samples from wells completed in the alluvial aquifer and areas without individual septic disposal system use than those from wells completed in the Troublesome Formation and areas with individual septic disposal system use. Differences in dissolved organic-carbon concentrations between the latter category and areas without septic systems likely had no environmental significance.

Surface water at the site Fraser River below Crooked Creek at Tabernash was a calcium-bicarbonate type water and is suitable as a drinking-water, residential, commercial, and irrigation resource. All pH values and concentrations of dissolved oxygen were within the State of Colorado instream water-quality standards, and all concentrations of chloride, sulfate, iron, manganese, un-ionized ammonia, nitrite, nitrate, and fecal coliform bacteria met State standards. Seasonal changes in the values or concentrations of field properties and constituents in the surface water were detected. For most constituents, maximum concentrations typically occurred during winter with low streamflow conditions, and minimums typically occurred during spring as a result of dilution by snowmelt runoff.

Ground-water quantity was estimated for the alluvial and Troublesome Formation aquifers in the upper portion of the Fraser River watershed, the most likely area for future ground-water use. The estimated average volume of available ground water in the alluvial aquifer was about 150,000 acre-feet, with seasonal fluctuations of about 7 percent. The Troublesome Formation aquifer, which consists of siltstone and interbedded sandstone and conglomerate, has approximately 370,000 acre-feet of available water in the upper 500 feet of the aquifer.

Introduction

Many small towns and rural areas in the Western United States had substantial population growth and related land-use changes during the last 2 decades of the 20th century and the beginning of the 21st century. Outdoor recreation and tourism, second-home development, and proximity to resort and mountain areas have been major factors affecting growth and the steady urban development of rangeland, forests, and agricultural lands. Many of the communities affected by population growth and urban development are in rural areas where little or

no information is available on the quality of ground water or surface water.

One area in Colorado that has seen population growth and increased urban development is the Fraser River watershed in Grand County (fig. 1), where population increased by more than 56 percent in the 1990's (U.S. Census Bureau, 2002). Located in north-central Colorado, the Fraser River watershed encompasses about 302 mi² (square miles) and contains the towns of Winter Park, Fraser, Tabernash, and Granby. Two ski areas are within the watershed, along with sites for many year-round recreational and tourism-based activities. The effect of the rapid development of the watershed on the quality of the local water resources largely is unknown. Except for some tributaries and

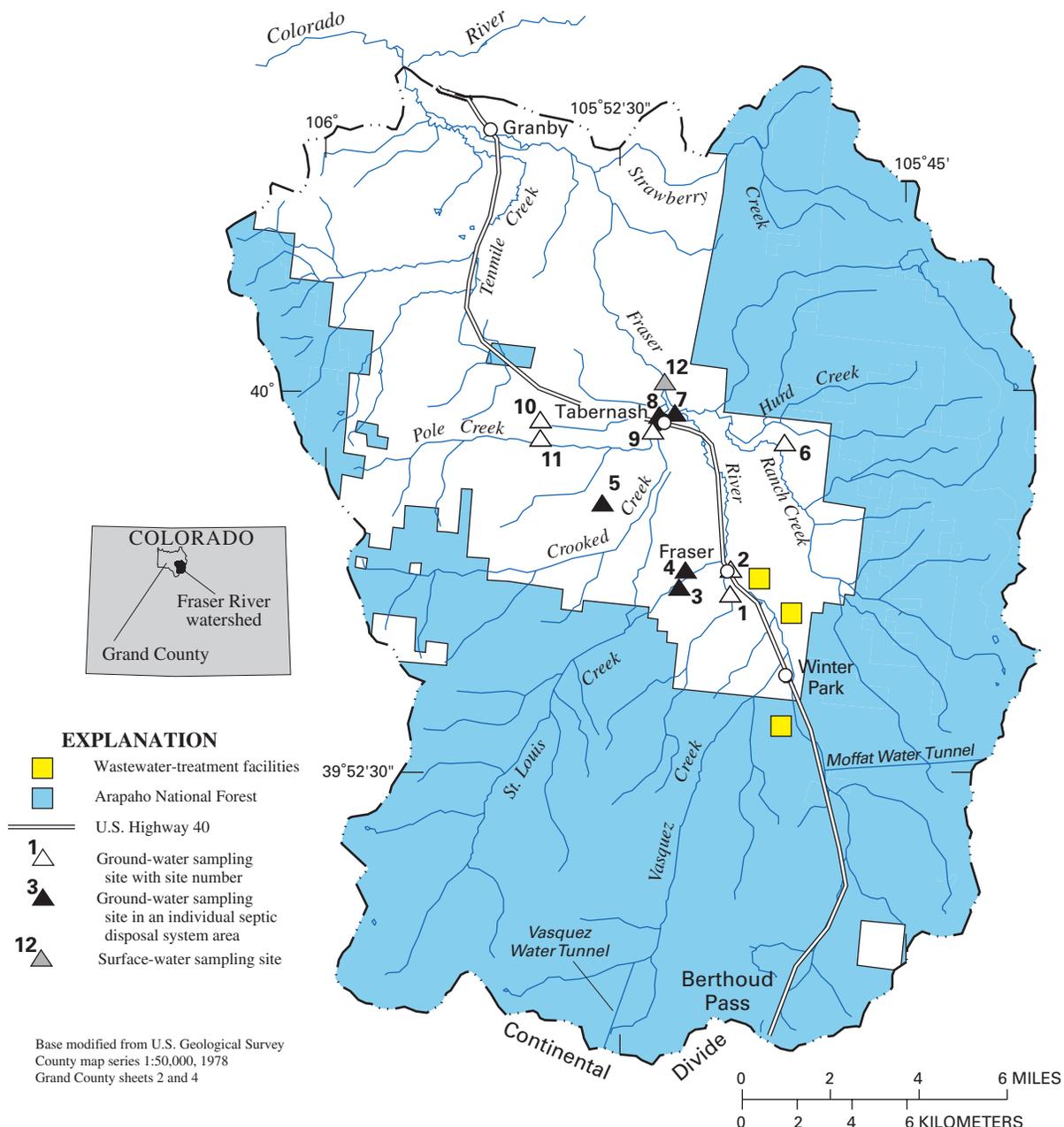


Figure 1. Location of ground- and surface-water sample-collection sites in the Fraser River watershed (Arapaho National Forest boundary from Colorado Department of Transportation, 1998).

the Fraser River itself (Bails, 2003), little historical information is available on ground- and surface-water quality in the Fraser River watershed. An assessment of available water-quality data in the watershed through water year 1997 revealed few ground- and surface-water-quality data (Apodaca and Bails, 1999).

The effects of population growth and the conversion of rangeland and forests to urban land uses on ground-water quality in the Fraser River watershed were first studied in 1997 as part of the Upper Colorado River Basin study unit of the U.S. Geological Survey (USGS) National Water-Quality Assessment Program (Apodaca and Bails, 2000; Apodaca and others, 2002). Recognizing the lack of baseline water-quality data for the Fraser River watershed, the Grand County Board of County Commissioners indicated a need to further characterize and monitor water quality in the watershed. In 1998, the USGS, in cooperation with the Grand County Board of County Commissioners, began a detailed water-quality study in the area. The objectives of the study were to (1) assess current ground-water quality and quantity in areas with present-day development and potential future development in the Fraser River watershed, (2) determine the effects of individual septic disposal systems (ISDS's) on ground-water quality, and (3) assess current surface-water quality and quantity at a site on the Fraser River downstream from the town of Tabernash to determine the effects of present-day growth in the watershed and to support assessment of future growth. This study provides baseline ground- and surface-water information for the Fraser River watershed. Water-quality sampling began in August 1998 and continued through September 2001. Results from the initial sampling in August 1998 relating the effects of ISDS's on ground-water quality were described by Apodaca and others (2000).

Purpose and Scope

This report presents an assessment of ground- and surface-water-quality data and ground-water-quantity data collected by the USGS from August 1998 through September 2001 in the Fraser River watershed. Ground-water-quality data include field properties and concentrations of dissolved solids, major ions, selected trace elements, nutrients, organic carbon, bacteria, methylene blue active substances (MBAS), and radon-222 for water from 11 wells. These data are related to aquifer type (alluvial, Troublesome Formation), land use (urban, nonurban), and location in ISDS and non-ISDS areas. Ground-water-quality data also are examined for changes over time. The surface-water data include field properties and concentrations of dissolved solids, major ions, selected trace elements, nutrients, organic carbon, and fecal coliform bacteria for water from one site on the Fraser River. This report also presents an estimate of the quantity of water available in the alluvial aquifer of the Fraser River and in the Troublesome Formation.

Description of the Fraser River Watershed

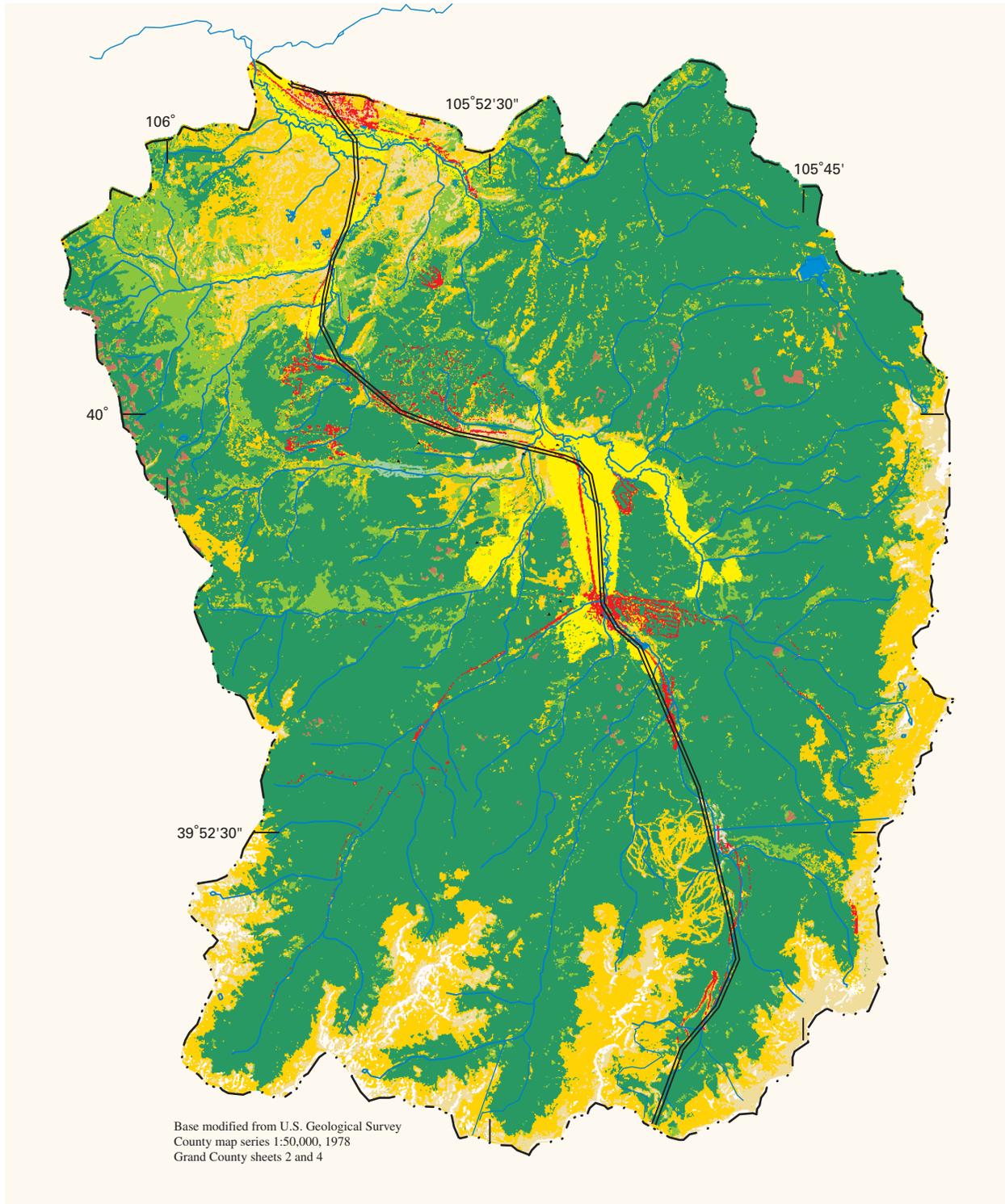
The Fraser River watershed is in north-central Colorado in Grand County (fig. 1) and lies within the Southern Rocky Mountains physiographic province (Hunt, 1974). The watershed comprises about 302 mi² in the southeastern part of Grand County and constitutes about 16 percent of the total area (1,869 mi²) of the county. The terrain within the watershed is flat in the valleys to mountainous in the southern and eastern boundaries, with land-surface altitudes ranging between about 8,000 and 12,800 ft. The Fraser River flows northerly about 28 mi from its headwaters along the Continental Divide in the Arapaho National Forest through the towns of Winter Park, Fraser, Tabernash, and Granby to its confluence with the Colorado River (fig. 1). The primary tributaries to the Fraser River are Vasquez, St. Louis, Crooked, Ranch, Tenmile, and Strawberry Creeks (fig. 1).

Land use/land cover in the Fraser River watershed is 64 percent evergreen forest; 8 percent deciduous forest; 24 percent pasture, shrubland, and grassland; less than 2 percent urban, less than 2 percent perennial ice/snow or bare rock; and less than 1 percent open water (fig. 2) (U.S. Environmental Protection Agency, 2002a). For purposes of this report, the land use/land cover is classified as "urban" or "nonurban" (forests, rangeland, grassland) and "ISDS" or "non-ISDS" area, based on a visual examination of land use around a well and well location in an area of historical or new ISDS use or in an area without ISDS use.

Daily average temperature ranges between 13°F and 55°F. Average annual precipitation ranges from 20 inches per year north and west of Fraser to more than 40 inches per year in the higher peaks along the Continental Divide in the eastern and southern portions of the watershed.

The geology of the Fraser River watershed varies from rocks of Precambrian age to unconsolidated alluvium of Quaternary age (fig. 3). Igneous and metamorphic rocks (granite, gneiss, and schist) of Precambrian age are exposed in the north-eastern, eastern, and southern areas of the watershed. Fractured rocks of this age generally produce small quantities of water that are suitable only for domestic uses. Sedimentary rocks of Triassic, Jurassic, and Cretaceous age in the northwestern area of the watershed yield little water; however, yields probably are sufficient for most domestic purposes. Rocks of Tertiary age or younger, including the Troublesome Formation and alluvium, have the largest yields for wells in the watershed (Voegeli, 1965). The Troublesome Formation of Tertiary age is primarily siltstone with some interbedded sandstones and conglomerates and is as much as 1,000 ft thick. Alluvium consists of unconsolidated sand and gravel and glacial drift and is as much as 200 ft thick. Recharge is derived mostly from snowmelt (Apodaca and others, 2000).

Aquifers in the Fraser River watershed include the alluvial aquifer composed of alluvium, the Troublesome Formation aquifer composed of rocks of the Troublesome Formation, and the Precambrian granite aquifer composed of fractured granite.



EXPLANATION			
	Evergreen forest		Urban
	Grassland		Open water
	Rangeland		Perennial ice and snow
	Shrubland		
	Deciduous forest		

Figure 2. Land-use/land-cover classifications for the Fraser River watershed (U.S. Environmental Protection Agency, 2002a).

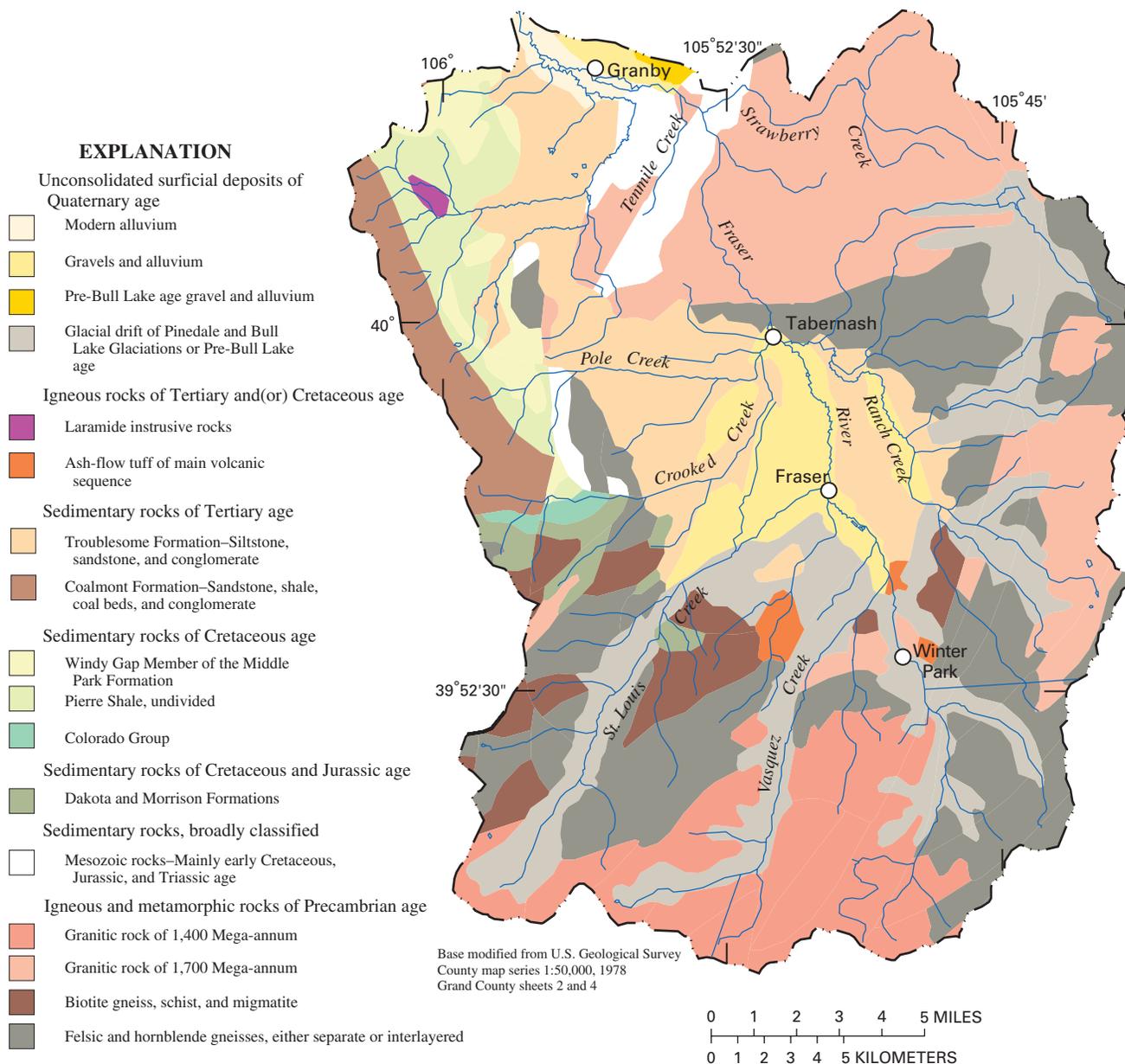


Figure 3. Generalized geology of the Fraser River watershed (Green, 1992; Tweto, 1979).

Water from the alluvial and Troublesome Formation aquifers is used for residential and municipal purposes.

The population of Grand County in 2000 was 12,442, an increase of more than 56 percent since 1990 and more than 300 percent since 1970 (U.S. Census Bureau, 2002). In addition, the county receives large seasonal influxes of visitors related to recreational and tourism-related activities, which add to the demand on water resources of the area. Three wastewater-treatment facilities (fig. 1) and public water supplies that service the larger population centers are located upstream from Tabernash. The wastewater facilities serve the Winter Park ski area and the towns of Winter Park and Fraser and discharge to the Fraser River. Discharge from the facilities is highest in winter and early spring because of recreational activities. Outside of

Fraser, well water is used for water supply and ISDS's are used for post-use treatment of sewage.

Acknowledgments

The authors thank the Grand County Board of County Commissioners for their support throughout the study described in this report. We also thank the individuals, businesses, and agencies that permitted access to their wells for ground-water sampling. The authors acknowledge the efforts of Lori Apodaca, Rick Arnold, Steve Char, Jason Gurdak, and C. Michelle Smith of the USGS in collecting the ground-water-quality data presented in this report, and Jim Martinez and Clay Thompson

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of the USGS in collecting the surface-water-quality data. Thanks also are extended to Lori Apodaca and Daniele Chafin for technical review of the manuscript, Mary Kidd for editorial review, Sharon Powers for illustrations, John Evans for cover design, and Alene Brogan for manuscript preparation and layout.

Data Collection and Analysis

Water-quality data were collected from August 1998 through September 2001 at 11 ground-water sites, including 2 sites that were sampled for only a portion of the study, and 1 surface-water site (fig. 1, table 1). The 11 ground-water sites were selected to represent different aquifers, different land-use settings, and varying depths to ground water within the Fraser River watershed. Well selection was based on well availability, location in areas with historical or new ISDS use or non-ISDS use, and areal distribution throughout the study area. Well 1, currently in a nonurban and non-ISDS area, was added to the sample-collection network in 2000 upon the request of the cooperator, the Grand County Board of County Commissioners, because of impending development in the area. Data collection

at well 3 was discontinued after 1999 because it represented a ground-water resource that was sufficiently represented by other wells in the same area. Wells were located in fractured granite (one well), in the sedimentary Troublesome Formation (four wells), and in alluvium (six wells) and ranged in depth from 18 to 295 ft. The single surface-water site (site 12, Fraser River below Crooked Creek at Tabernash) was selected to represent the integration of the effects of natural and human factors on surface-water quality in the Fraser River watershed upstream from Tabernash.

Ground-water quantity was evaluated for the surficial alluvial aquifer and the Troublesome Formation aquifer. The areal extent of the aquifers was derived from geologic maps of Colorado (Green, 1992; Tweto, 1979). Information on aquifer thickness was gathered from lithologic well logs obtained at the Colorado Division of Water Resources. Aquifer properties were derived from available aquifer-test information as well as comparison to similar aquifer systems. A more detailed discussion of the estimation of ground-water quantity, or the amount of water available to be withdrawn by wells, in the alluvial and Troublesome Formation aquifers can be found in the “Ground-Water Quantity” section of this report.

Table 1. Description of 11 ground-water wells and one surface-water sampling site in the Fraser River watershed, August 1998–September 2001.

[USGS, U.S. Geological Survey; ft, feet; ISDS, individual septic disposal system; CFC, chlorofluorocarbon; M, monitoring; Muni, municipal; D, domestic; Fm, Formation; NU, nonurban; U, urban]

Site number (fig. 1)	USGS station number	Altitude (ft)	Well type	Aquifer ¹	Well depth below land surface (ft)	Land use	Location in ISDS area	CFC estimated recharge date ²	Data-collection period for well
Ground-water-quality wells									
1	395623105481000	8,619	M	Alluvial	18	NU	No	³ 1989	2000–01
2	395658105485400	8,568	Muni	Troublesome Fm	110	U	No	1983 or younger	1998–2001
3	395642105500700	8,685	D	Troublesome Fm	145	U	Yes	1968	1998–99
4	395657105495300	8,610	D	Alluvial	85	U	Yes	1980	1998–2001
5	395750105515800	8,665	D	Troublesome Fm	120	NU	Yes	1979	1998–2001
6	395921105472300	8,531	D	Alluvial	75	NU	No	1991	1998–2001
7	395942105502000	8,332	D	Alluvial	65	U	Yes	1969 or younger	1998–2001
8	395937105500500	8,342	D	Alluvial	25	U	Yes	1990's	1998–2001
9	395929105510300	8,320	M	Alluvial	28	U	No	1976	1998–2001
10	395928105533500	8,592	D	Troublesome Fm	295	NU	No	1968	1998–2001
11	395907105540100	8,582	D	Precambrian granite	105	NU	No	1955	1998–2001
Surface-water-quality site									
12	09033300	8,270	Station name: Fraser River below Crooked Creek at Tabernash, Colorado						

¹From Tweto (1979) and Green (1992).

²From Apodaca and others (2000), unless otherwise noted.

³From Apodaca and others (2002).

Data Collection

Ground-water samples were collected from the 11 wells semiannually during the spring and fall, following procedures outlined in Koterba and others (1995). Well water was sampled using either a submersible pump (no pressure tanks) or through an outside household spigot (all downstream from pressure tanks). During each sampling visit, field properties (water temperature, specific conductance, dissolved-oxygen concentration, pH, turbidity, and acid-neutralizing capacity) were measured, and ground-water samples were collected for laboratory analysis.

Surface-water samples from site 12 (Fraser River) were collected bimonthly following procedures outlined in the USGS National Field Manual (U.S. Geological Survey, 1997 to present). Discharge and field properties (water temperature, specific conductance, dissolved-oxygen concentration, and pH) were measured, and surface-water samples were collected for laboratory analysis using the equal-width-increment method.

Ground- and surface-water samples collected for analysis of dissolved solids, major ions, trace elements, and nutrients were filtered onsite through a 0.45- μm cellulose filter. Samples collected for analysis of dissolved organic carbon were filtered through a 0.45- μm silver filter. The silver filter was saved for analysis of particulate organic carbon. Samples collected for the analysis of suspended sediment and total recoverable phosphorus were not filtered. Samples collected for nutrient and dissolved and particulate organic carbon analysis were chilled to 4°C, and all samples except suspended sediment were transported to and analyzed at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo. Suspended-sediment samples were analyzed for suspended-sediment concentration at the USGS Iowa Sediment Laboratory in Iowa City, Iowa. The procedures used for processing and preservation of the water-quality samples are described in Koterba and others (1995) and in the USGS National Field Manual (U.S. Geological Survey, 1997 to present).

Unfiltered samples for the analysis of bacteria (total coliform, *Escherichia coli* [*E. coli*], and fecal coliform) were collected in the field using sterilized equipment. Bacteria samples were collected last, and the samples were processed within 6 hours of collection. Collection and processing were done using m-ENDO and NA-MUG media for ground water and m-FC media for surface water (Britton and Greeson, 1989; U.S. Environmental Protection Agency, 1991; American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1999).

For MBAS, unfiltered water samples were collected and chilled until analyzed. Samples for the analysis of radon-222 were collected by withdrawing 10 mL of water into a glass syringe and injecting this water into a glass scintillation vial beneath mineral oil (U.S. Geological Survey, 1997 to present).

After sampling at each site, all equipment except that for bacteria sampling was cleaned with a 0.1-percent nonphosphate detergent solution and then rinsed with tap water and distilled water. Tubing was stored in clean, sealable plastic bags, and

organic carbon and radon equipment was reassembled, wrapped in aluminum foil, and stored in clean containers. Bacteria sampling equipment was washed, wrapped in craft paper, and then sterilized in the laboratory by autoclaving at 121°C at 15 lb/in² for 20 minutes.

Data Analysis

Analysis of ground- and surface-water data collected for this study was conducted in a two-step process. First, ground- and surface-water samples were analyzed at the USGS NWQL. Then these results, along with the ground- and surface-water field properties, were analyzed using various statistical methods.

Laboratory Analysis

At the USGS NWQL, the ground- and surface-water samples were analyzed for concentrations of dissolved solids, major ions, trace elements (iron and manganese), nutrients (ammonia [un-ionized ammonia (NH_3) plus ammonium (NH_4^+)], total and/or dissolved ammonia plus organic nitrogen, nitrite, nitrate plus nitrite (hereinafter nitrate), total or dissolved phosphorus, and orthophosphate), and dissolved organic carbon. The nutrients represent concentrations as either nitrogen or phosphorus. Ground-water samples also were analyzed for MBAS and radon-222, and surface-water samples also were analyzed for particulate organic carbon. Except for these latter three constituents plus bacteria and constituents as total concentrations, all samples were in the dissolved form. Samples for major ions and nutrients were extracted and analyzed by various methods (Fishman and Friedman, 1989; Fishman, 1993; U.S. Environmental Protection Agency, 1993). Samples for dissolved organic carbon were analyzed by UV-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993), and samples for particulate organic carbon were analyzed by wet-chemical oxidation and infrared spectrometry (Burkhardt and others, 1997). Samples for MBAS were analyzed using procedures described by Burkhardt and others (1995), and samples for radon-222 were analyzed by liquid scintillation counting (American Society for Testing and Materials, 1999).

The analytical results from the NWQL were reported as either the minimum reporting level (MRL) or laboratory reporting level (LRL), along with the long-term method detection level (LT-MDL). The minimum reporting level is defined by the NWQL as the smallest measured concentration of a constituent that may be reliably measured using a given analytical method (Timme, 1995). For some constituents, the reporting level was changed at the beginning of a water year from the MRL to the LT-MDL and LRL (Childress and others, 1999). The LT-MDL is the lowest concentration of a constituent that is reported by the NWQL and represents that value at which the probability of a false positive is statistically limited to less than or equal to 1 percent. The LRL is calculated as 2 times the LT-MDL and represents the value at which the probability of a

false negative is less than or equal to 1 percent. Concentrations detected between the LT-MDL and LRL are reported as estimated (E) concentrations. Concentrations detected at values less than the MRL, LT-MDL, or undetected are reported with a “less than” (<) symbol at the MRL or the LRL (Childress and others, 1999). The LT-MDL and LRL for a constituent may change annually on a water-year basis.

Statistical Methods

Water-quality data were analyzed using nonparametric statistical methods. Nonparametric methods were used because they do not require data sets to be normally distributed, are resistant to outliers, and are appropriate for use with small data sets (Helsel and Hirsch, 1992). The two-tailed Wilcoxon rank-sum test was used to determine if the distribution of the ground-water-quality data was significantly different among aquifer types (alluvial, Troublesome Formation), land use (urban, non-urban), and ISDS and non-ISDS areas. Results of the test are expressed in terms of *p*-values—the probability of rejecting or not rejecting the hypothesis that the data sets of the comparison categories are similar. The test does not prove that the data sets are similar, only that similarity in data sets can be rejected or not rejected. Test results were considered to be statistically significant when the *p*-value of the respective test was less than or equal to 0.05, indicating that there was at least a 95-percent probability that there were differences in water-quality data and related median values between the comparison categories. The case against similarity in data increased as *p*-values got smaller and smaller. For results with *p*-values greater than 0.05, the hypothesis of similarity in data sets could not be rejected. Data for the Precambrian granite aquifer were excluded from the comparison of aquifer types because of the small size of the data set (seven samples). Water temperature and radon-222 data were excluded from comparisons for land use and ISDS/non-ISDS areas because processes on or near the land surface should have no effect on water temperature and radon-222 concentrations in ground water. Data that were reported with a less-than (<) symbol were given a value equal to one-half the respective MRL or LRL for comparison testing. Results of the two-tailed Wilcoxon rank-sum tests for some constituents were excluded from discussion in this report because elevated concentrations in one or more wells biased the results. Additional information on the Wilcoxon rank-sum test is found in Helsel and Hirsch (1992) and Ott (1993).

With statistical testing such as the Wilcoxon rank-sum test, differences in water-quality data between categories can be statistically significant but not environmentally significant. For example, statistically significant differences in nitrate concentrations between two land uses would not be environmentally important if nitrate concentrations were centered around 1.50 mg/L for one land use and 0.090 mg/L for the other land use. Nitrate concentrations in the water for both land uses would be considered low and would not be of concern environmentally.

Changes in ground-water quality with time were qualitatively examined by graphing individual constituents for a site against time, fitting a LOWESS smooth curve (Helsel and Hirsch, 1992) to the data, and visually examining the graphs for changes. Quantitative analyses of changes with time or trends were not used because the time periods of the data sets were of insufficient length (maximum of 4 years), and the data sets were of insufficient size (maximum of seven samples) to perform statistical tests for trend analysis, such as the Mann-Kendall test or the seasonal Kendall test. Also, data collection only occurred in 2 months of each year. Graphs of changes with time were developed for most water-quality constituents, including water temperature, specific conductance, pH, turbidity, dissolved-oxygen concentration, acid-neutralizing capacity, dissolved solids, major ions (calcium, magnesium, sodium, potassium, chloride, and sulfate), silica, nutrients (nitrate and orthophosphate), and dissolved organic carbon. Manganese was included when most or all manganese concentrations for a given well were greater than the reporting level. Graphs were not developed for bromide, fluoride, ammonia, ammonia plus organic nitrogen, nitrite, iron, total coliform bacteria, and MBAS because most concentrations for these constituents were less than the respective laboratory reporting levels. Phosphorus was excluded because of its similarity in concentration to orthophosphate. Radon-222 and data for wells 1 and 3 also were excluded because only four or fewer samples were collected at each site or from the two wells.

Water-Quality Standards

Ground-water data were compared to U.S. Environmental Protection Agency (USEPA) primary, secondary, proposed, and alternative drinking-water standards and treatment techniques (U.S. Environmental Protection Agency, 2002b) and State of Colorado water-quality standards, where applicable (Colorado Department of Public Health and Environment, 2001). Primary drinking-water standards consist of maximum contaminant levels (MCL's), which are the highest values or concentrations of contaminants allowed in public water-supply systems to protect human health. MCL's are legally enforceable standards. Secondary drinking-water regulations (SDWR) are related to the esthetic and cosmetic qualities of the water, such as taste and odor or tooth and skin discoloration, and are not legally enforceable. The USEPA-proposed MCL and proposed alternative MCL (AMCL) that are applicable to this report are under review and are not currently (2003) enforceable. USEPA treatment techniques are required processes that aim to lower the levels of contaminants in drinking water.

Instream water-quality standards have been established for selected field properties and water-quality constituents for the Fraser River and its tributaries by the Colorado Department of Public Health and Environment (Colorado Department of Public Health and Environment, 2002). The water-quality standards are numeric values or table value standards (TVS). The Fraser

River and its tributaries are given the highest (class 1) aquatic life and recreational qualifications allowable.

In 2000, USEPA established recommended nutrient criteria for rivers and streams in ecoregion II—Western Forested Mountains, including the Fraser River watershed. The intent of these criteria is to identify baseline conditions for rivers and streams that are minimally affected by human activities and protect against nutrient enrichment from cultural eutrophication (U.S. Environmental Protection Agency, 2000a). These criteria are guidance that States and tribes may use as a starting point in establishing their water-quality standards (U.S. Environmental Protection Agency, 2000a). For ecoregion II, the recommended criterion for total phosphorus in rivers and streams is 0.010 mg/L (U.S. Environmental Protection Agency, 2000a). Because the total phosphorus criterion only is a guidance for establishing standards and is not a legally enforceable criterion, it will be excluded from the discussions about ground- and surface-water quality in the Fraser River watershed.

Water Quality

Water-quality data for ground water and surface water include field properties, dissolved solids and(or) major ions, selected trace elements, nutrients, organic carbon, and bacteria. Ground-water data also include MBAS and radon-222. Ground-water data are related to aquifer type, type of land use, and the presence or absence of ISDS's and are examined for changes over time. To the extent required, interpretation of water-quality data is limited or qualified by quality-control factors, as described in Appendix II—"Quality-Control Methods and Analysis" at the end of this report.

Ground Water

All water-quality constituents for ground water are in the dissolved form except for total coliform bacteria, MBAS, and radon-222. A statistical summary of selected ground-water data, USEPA and State of Colorado water-quality standards, and NWQL reporting levels is listed in table 2. A full listing of ground-water-quality data is in table 5 in Appendix I.

Field Properties

Water temperature for 86 percent of the wells was less than 10°C. Temperatures above 10°C were measured only in two wells (sites 5 and 11) near Tabernash. Well 5 is 120 ft deep in the Troublesome Formation, and well 11 is 105 ft deep in the Precambrian fractured granite. Water temperature from site 5 generally was about two times higher than temperatures from the other wells. Sample collection for this well took place at an outside household spigot, and the temperature of the water may have increased as the water traveled through the pressure tank and plumbing system. There is no known hydrothermal activity

in the area. No statistical relation was detected between well depth and water temperature. There was a statistically significant difference in water temperature between the alluvial and the Troublesome Formation aquifers (table 3); the median water temperature was cooler in the alluvial aquifer.

Specific conductance, defined as the ability of water to conduct an electric current at 25°C, provides an indication of ion concentration. As ion concentrations increase, specific conductance increases (Hem, 1992). Specific conductance for ground water in the Fraser River watershed was low to moderate, ranging between 88 and 430 $\mu\text{S}/\text{cm}$ (table 2). Median values of specific conductance were lowest in the vicinity of Fraser and Winter Park and were highest in the Tabernash area. Well 8 had the highest median specific conductance, 392 $\mu\text{S}/\text{cm}$.

Most (76 percent) dissolved-oxygen concentrations measured in ground water for this study were greater than 1.0 mg/L. Dissolved-oxygen concentrations less than 1.0 mg/L, which can be indicative of reducing conditions, were measured in three wells, one in the Troublesome Formation aquifer near Fraser (well 2) and two in the alluvial aquifer near Tabernash (wells 7 and 9). Some metals such as iron and manganese are more soluble under reducing conditions (Hem, 1992). Dissolved-oxygen concentrations in sites 7 and 9 were particularly low—less than or equal to 0.7 mg/L for all samples. Dissolved-oxygen concentrations below 1.0 mg/L are considered low for the Fraser River watershed (Apodaca and Bails, 1999). Statistically significant differences in dissolved-oxygen concentrations were detected for aquifer type and land use (table 3); median dissolved-oxygen concentrations were lower in the alluvial aquifer and in urban areas than in the Troublesome Formation aquifer and nonurban areas. Ground water is supplied with dissolved oxygen through recharge and the movement of air through the unsaturated zone above the water table (Hem, 1992). Low dissolved-oxygen concentrations may result from the interaction of ground water with oxidizable materials (organic matter and reduced minerals) along the flow path of the water and(or) from microbiological activities. The lower dissolved-oxygen concentrations in the alluvial aquifer and urban wells may represent natural conditions or may indicate the addition of organic matter through human activities, including fertilizers or septic systems. Of the three wells with low dissolved-oxygen concentrations, only site 7 is in an ISDS area.

Almost all pH values were within the USEPA SDWR of 6.5 to 8.5 (table 2). The exception was site 1, where pH in the water samples ranged from 6.1 to 6.5. A pH of 7.0 indicates neutral pH, less than 7.0 indicates the water is acidic, and pH greater than 7.0 indicates the water is basic. Site 1 is very shallow—only 18 ft deep, and ground water is frequently in contact with the soil horizon. Humic acids from the soil horizon decrease pH in the ground water. Values of pH were statistically different for aquifer types and land use (table 3). Median pH was lower in alluvial aquifer and urban well-water samples than in water samples from the Troublesome Formation aquifer and nonurban areas. It is not known why urban wells had a generally lower pH than did nonurban wells.

Table 2. Statistical summary of selected ground-water data for the Fraser River watershed, 1998–2001, with U.S. Environmental Protection Agency and State of Colorado water-quality standards and U.S. Geological Survey National Water Quality Laboratory reporting levels.

[All water-quality constituents are in the dissolved form except for total coliform bacteria, methylene blue active substances, and radon-222. USEPA, U.S. Environmental Protection Agency; USEPA water-quality standards and health advisory are from U.S. Environmental Protection Agency (2002b) unless otherwise noted; WY, water year; MRL, minimum reporting level; LT-MDL, long-term method detection level; LRL, laboratory reporting level; °C, degrees Celsius; --, no standard determined; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; SDWR, USEPA secondary drinking-water regulation; NTU, nephelometric turbidity units; TT, treatment techniques; WQS, water-quality standard; <, less than; µg/L, micrograms per liter; E, estimated; N, nitrogen; HA, health advisory; MCL, maximum contaminant level; nitrate is nitrate plus nitrite; P, phosphorus; C, carbon; col/100 mL, colonies per 100 milliliters; MCLG, maximum contaminant level goal; pCi/L, picocuries per liter; AMCL, alternative maximum contaminant level]

Field properties, constituents, and reporting units	Number of samples	USEPA water-quality standard or health advisory			WY 1998		WY 1999		WY 2000		WY 2001	
		Minimum	Median	Maximum	MRL	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	LT-MDL
Field properties												
Water temperature (°C)	70	4.0	7.3	15.0	0.1	--	0.1	*0.1	*0.1	*0.1	*0.1	*0.1
Specific conductance (µS/cm)	70	88	260	430	1.0	--	1.0	*1.0	*1.0	*1.0	*1.0	*1.0
Oxygen, dissolved (mg/L)	70	0.1	3.8	10.1	0.1	--	0.1	*0.1	*0.1	*0.1	*0.1	*0.1
pH (standard units)	70	6.1	7.6	8.5	6.5–8.5 (SDWR)		0.1	*0.1	*0.1	*0.1	*0.1	*0.1
Turbidity (NTU)	69	0.1	0.3	7.7	1.5 (TT)		1.0	*1.0	*1.0	*1.0	*1.0	*1.0
Dissolved solids, major ions, and trace elements												
Dissolved solids (mg/L)	67	55	165	269	2400 mg/L or 1.25 times background level (WQS)	Computed concentration ³						
Chloride (mg/L)	70	0.3	2.6	24.7	250 (SDWR)	0.1		*0.1	0.14	0.29	0.04	0.08
Sulfate (mg/L)	67	<0.3	2.9	16.0	250 (SDWR)	0.1		*0.1	0.15	0.31	0.05	0.11
Iron (µg/L)	70	<10	<10	310	300 (SDWR)	10	5	10	5	10	5	10
Manganese (µg/L)	70	E 2.0	<3.2	510	50 (SDWR)	4	1.5	3	1.1	2.2	1.6	3.2
Nutrients and dissolved organic carbon												
Ammonia, ⁴ as N (mg/L)	70	<0.002	<0.002	0.040	30 (HA)	0.002		*0.002		*0.002		*0.002
Nitrite, as N (mg/L)	69	<0.001	<0.001	0.004	1 (MCL)	0.001		*0.001		*0.001		*0.001
Nitrate, as N (mg/L)	70	<0.005	0.208	4.72	10 (MCL)	0.005		*0.005		*0.005		*0.005
Orthophosphate, as P (mg/L)	70	E 0.005	0.047	0.137	--	0.001		*0.001		*0.001	0.004	0.007
Dissolved organic carbon, as C (mg/L)	70	0.2	0.91	4.0	--	0.1		*0.1	0.16	0.33	0.16	0.33

Total coliform bacteria, methylene blue active substances, and radon-222

Table 2. Statistical summary of selected ground-water data for the Fraser River watershed, 1998–2001, with U.S. Environmental Protection Agency and State of Colorado water-quality standards and U.S. Geological Survey National Water Quality Laboratory reporting levels.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, methylene blue active substances, and radon-222. USEPA, U.S. Environmental Protection Agency; USEPA water-quality standards and health advisory are from U.S. Environmental Protection Agency (2002b) unless otherwise noted; WY, water year; MRL, minimum reporting level; LT-MDL, long-term method detection level; LRL, laboratory reporting level; °C, degrees Celsius; --, no standard determined; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; SDWR, USEPA secondary drinking-water regulation; NTU, nephelometric turbidity units; TT, treatment techniques; WQS, water-quality standard; <, less than; µg/L, micrograms per liter; E, estimated; N, nitrogen; HA, health advisory; MCL, maximum contaminant level; nitrate is nitrate plus nitrite; P, phosphorus; C, carbon; col/100 mL, colonies per 100 milliliters; MCLG, maximum contaminant level goal; pCi/L, picocuries per liter; AMCL, alternative maximum contaminant level]

Field properties, constituents, and reporting units	Number of samples	Minimum	Median	Maximum	USEPA water-quality standard or health advisory	WY 1998		WY 1999		WY 2000		WY 2001	
						MRL	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	
Total coliform bacteria (col/100 mL)	68	<1	<1	E 140	55% (MCLG)	1		*1		*1		*1	
Methylene blue active substances (mg/L)	69	<0.02	<0.02	3.82	0.5 (SDWR)	0.02		*0.02		*0.02		*0.02	0.02
Radon-222, total (pCi/L)	30	365	760	6,380	6,300 (proposed MCL) 7,400 (proposed AMCL)	*26		*26		*26		*26	*26

¹Treatment techniques are U.S. Environmental Protection Agency required processes, from U.S. Environmental Protection Agency (2002b).

²Maximum allowable dissolved-solids concentration in ground water is the value that is less restrictive; applies to “agricultural use—quality,” “surface-water quality protection,” and “potentially usable quality” classes of ground water, from Colorado Department of Public Health and Environment (2001).

³Dissolved solids (sum of constituents) is computed as the sum of calcium, magnesium, sodium, potassium, silica, chloride, sulfate, and carbon (as carbonate equivalent) plus any other constituents, such as dissolved iron, if they are present in the water.

⁴Un-ionized ammonia [NH₃] plus ammonium [NH₄⁺].

⁵No more than 5 percent of samples can be total coliform-positive in a month. Every sample that has total coliforms must be analyzed for fecal coliforms; no fecal coliforms are allowed. From U.S. Environmental Protection Agency (2002b).

⁶Under review, from U.S. Environmental Protection Agency (2000b).

⁷Applies to those States that create Multimedia Mitigation programs to address radon in indoor air. Under review, from U.S. Environmental Protection Agency (2000b).

Table 3. Results of two-tailed Wilcoxon rank-sum tests for comparison of selected field properties and water-quality constituents in wells by aquifer type, land use, and individual septic disposal system (ISDS) or non-ISDS area, Fraser River watershed, 1998–2001.

[All water-quality constituents are in the dissolved form except for total coliform bacteria, methylene blue active substances, and radon-222. n, number of samples; Troubl. Fm., Troublesome Formation; p-value is the significance level of the two-tailed Wilcoxon rank-sum test. A p-value less than or equal to 0.05 (shown in bold type) indicates that the hypothesis of similarities in values or concentrations between the tested groups is rejected, and there is a statistically significant difference between the tested groups. ISDS, individual septic disposal system; °C, degrees Celsius; NA, not applicable; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; NTU, nephelometric turbidity units; µg/L, micrograms per liter; E, estimated; N, nitrogen; nitrate is nitrate plus nitrite; P, phosphorus; C, carbon; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter]

Field properties, constituents, and reporting units	Aquifer			Land use			Septic disposal		
	Alluvial median, (n)	Troubl. Fm. median, (n)	p-value	Urban median, (n)	Nonurban median, (n)	p-value	ISDS median, (n)	Non-ISDS median, (n)	p-value
Temperature (°C)	6.6, (39)	7.3, (24)	0.024	6.6, (38)	8.0, (32)	NA	6.7, (31)	7.3, (39)	NA
Specific conductance (µS/cm)	256, (39)	256, (24)	0.343	258, (38)	260, (32)	0.981	260, (31)	256, (39)	0.244
Dissolved oxygen (mg/L)	1.9, (39)	4.8, (24)	<0.001	1.0, (38)	4.6, (32)	<0.001	4.3, (31)	3.4, (39)	0.892
pH (standard units)	7.3, (39)	7.8, (24)	0.048	7.2, (38)	7.9, (32)	<0.001	7.6, (31)	7.5, (39)	0.385
Turbidity (NTU)	0.3 (38)	0.2 (24)	0.016	0.3, (37)	0.3, (32)	0.732	0.3, (31)	0.22, (38)	0.285
Dissolved solids (mg/L)	168, (38)	158, (22)	0.342	168, (37)	160, (30)	0.668	162, (31)	166, (36)	0.349
Chloride (mg/L)	4.5, (39)	1.5, (24)	0.002	4.6, (38)	1.5, (32)	<0.001	4.8, (31)	1.8, (39)	0.021
Magnesium (mg/L)	4.39, (39)	3.41, (24)	0.005	4.40, (38)	2.10, (32)	<0.001	3.53, (31)	2.44, (39)	<0.001
Sulfate (mg/L)	4.5, (38)	2.7, (22)	<0.001	4.0, (37)	2.5, (30)	<0.001	3.1, (31)	2.7, (36)	0.004
Iron (µg/L)	<10 (39)	<10, (24)	0.006	<10, (38)	<10, (32)	0.075	<10, (31)	<10, (39)	NA
Manganese (µg/L)	<4.0, (39)	<3.0, (24)	0.008	E 6.2, (38)	<3.0, (32)	NA	3.9, (31)	<3.0, (39)	<0.001
Ammonia, ¹ as N (mg/L)	0.002, (39)	<0.002, (24)	0.311	<0.002, (38)	<0.002, (32)	0.761	<0.002, (31)	0.003, (39)	0.522
Nitrate, as N (mg/L)	0.110, (39)	0.216, (24)	0.590	0.222, (38)	0.204, (32)	0.444	0.206, (31)	0.214, (39)	0.328
Orthophosphate, as P (mg/L)	0.047, (39)	0.121, (24)	<0.001	0.048, (38)	0.048, (32)	0.288	0.028, (31)	0.061, (39)	<0.001
Dissolved organic carbon, as C (mg/L)	1.8, (39)	0.69, (24)	0.010	1.1, (38)	0.83, (32)	0.878	0.70, (31)	1.0, (39)	0.008
Total coliform bacteria (col/100 mL)	<1, (37)	<1, (24)	0.057	<1, (36)	1, (32)	0.983	<1, (30)	<1, (38)	0.557
Methylene blue active substances (mg/L)	<0.02, (39)	<0.02, (23)	0.006	<0.02, (38)	<0.02, (31)	0.681	<0.02, (31)	<0.02, (38)	0.834
Radon-222, total (pCi/L)	710, (15)	1074, (12)	0.479	1096, (18)	661, (12)	NA	784, (15)	752, (15)	NA

¹Un-ionized ammonia [NH₃ plus ammonium [NH₄⁺].

Turbidity, the cloudiness of water, can foster the growth of microbes and impede the water-disinfection process (Apodaca and Bails, 2000). Turbidity for water samples from all wells except site 1 was less than 5.0 nephelometric turbidity units (NTU), the USEPA treatment technique value for public-supply water (table 2); most were less than or equal to 2.4 NTU. Higher turbidity for water samples from site 1 probably was due to the shallowness of the well and its location in a field that frequently has standing water. The median turbidity for water samples from alluvial aquifer wells was statistically higher than the median turbidity for water samples from wells in the Troublesome Formation aquifer (table 3).

Dissolved Solids, Major Ions, and Trace Elements

Dissolved solids, major ions, and trace elements in uncontaminated ground water are the result of the natural dissolution of materials along the ground-water flow path in soil and rock. Dissolved-solids concentration is used as one indicator of the suitability of water for drinking, residential, and industrial use, and irrigation purposes. The concentrations of dissolved solids in water samples from wells in the Fraser River watershed were low to moderate, ranging from 55 to 269 mg/L (table 2) and indicated that the water is suitable for domestic, municipal, industrial, and agricultural uses. Median dissolved-solids concentrations were lowest in the vicinity of Fraser and Winter Park and were highest around and to the west of Tabernash. Water samples from site 8 had the greatest median dissolved-solids concentration, 252 mg/L. All dissolved-solids concentrations were less than the State of Colorado water-quality standard of 400 mg/L (table 2).

The dominant water type in the ground-water samples was calcium-bicarbonate type water (fig. 4). Only in samples from site 1 was the water type a mixed-cation (calcium-potassium or calcium-sodium) -bicarbonate type water or a mixed-cation (calcium-potassium or calcium-sodium) -mixed-anion (bicarbonate-chloride) type water.

There were differences among the wells in the concentrations of the major ions that formed the calcium-bicarbonate type water. Median concentrations of most major ions were greatest for wells in the Tabernash area, especially site 8. The median chloride concentration for water samples from site 8 was 3 times greater than the median concentrations for samples from the other wells, and all sulfate concentrations in samples from site 8 were greater than 10 mg/L. Site 7, located just east of site 8, was the only other well with a sulfate concentration greater than 10 mg/L. The Tabernash area, including sites 7 and 8, is the most downgradient part of the study area. Because of this, the ground water would have had a longer residence time, which could cause the increase in specific conductance and higher concentrations of dissolved solids and major ions. Chloride and sulfate concentrations in water samples from all wells were substantially less than the USEPA SDWR of 250 mg/L for each constituent (table 2). Concentrations of chloride, magnesium, and sulfate in water samples from wells in the alluvial

aquifer and urban and ISDS areas were statistically higher than those from wells in the Troublesome Formation aquifer and nonurban and non-ISDS areas, as indicated by median concentrations of the three ions (table 3).

Sources of chloride in ground water can include natural processes (evaporative concentrations in precipitation, brines, dissolution of halite, fluid inclusions in rock) and human activities (fertilizers, septic-system effluent, road salt). In other areas of the Southern Rocky Mountains physiographic province, chloride concentrations have been higher in urban than non-urban areas (Apodaca and Bails, 2000). Magnesium can be a major constituent of igneous and metamorphic rocks, depending on the presence or alteration of ferromagnesian minerals in the rocks, and is present in minerals such as dolomite in sedimentary rocks. Most sulfate in ground-water samples from the 11 wells probably resulted from the oxidation of sulfide minerals in igneous and sedimentary rocks in the watershed. Greater magnesium and sulfate concentrations in urban wells as compared to the nonurban wells probably resulted from the greater exposure of the ground water to more igneous and metamorphic rocks and sulfide minerals in the more areally extensive watershed draining to the urban areas.

Concentrations of iron in the ground-water samples ranged from less than 10 to 310 $\mu\text{g/L}$ (table 2). Concentrations greater than the reporting level of 10 $\mu\text{g/L}$ only were detected in samples from sites 4, 6, and 7. The highest concentrations occurred in water samples from site 7 (median of 210 $\mu\text{g/L}$), with one sample exceeding the USEPA SDWR for iron of 300 $\mu\text{g/L}$ (table 2). Manganese concentrations ranged from an estimated 2 $\mu\text{g/L}$ to 510 $\mu\text{g/L}$ (table 2), with water samples from four wells having concentrations greater than the laboratory reporting levels. Elevated concentrations occurred in samples from site 7 (median of 457 $\mu\text{g/L}$) and site 9 (median of 73.8 $\mu\text{g/L}$). All seven samples from site 7 had manganese concentrations greater than the USEPA SDWR for manganese of 50 $\mu\text{g/L}$ (table 2), as did four of seven samples for site 9. As discussed in "Field Properties," the solubility of iron and manganese increases when reducing conditions (characterized by very low dissolved-oxygen concentrations) are present in an aquifer. Median dissolved-oxygen concentrations for water samples from sites 7 and 9 were low, 0.2 and 0.5 mg/L, respectively, and indicated the presence of reducing conditions. Manganese concentrations in water samples from wells in the alluvial aquifer and ISDS areas were significantly higher than those in water samples from wells in the Troublesome Formation aquifer and non-ISDS areas, as indicated by median manganese concentrations (table 3).

Nutrients and Dissolved Organic Carbon

Nutrients (nitrogen and phosphorus) can occur in ground water as a result of natural and anthropogenic factors. Nitrogen is a naturally occurring element in crustal rocks, plants, soil, and the atmosphere, whereas phosphorus is common in igneous rocks and occurs in mineral form as apatite (Hem, 1992).

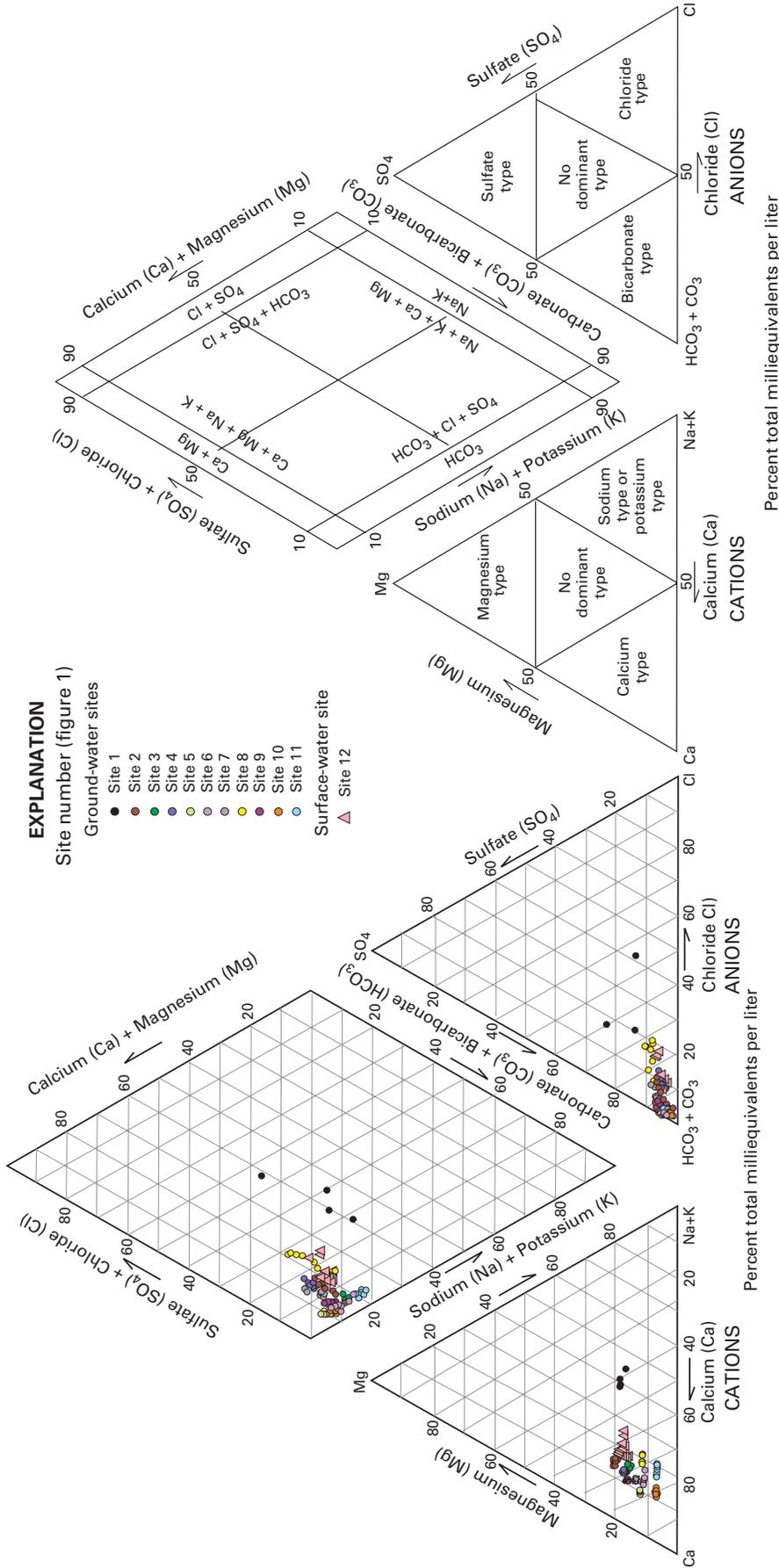


Figure 4. Dissolved major-ion composition of ground- and surface-water samples collected in the Fraser River watershed, 1998–2001.

Anthropogenic sources of nitrogen and phosphorus include synthetic fertilizers, animal waste, and septic-system effluent. Nitrogen also is a by-product of the combustion of fossil fuels. Nitrogen and phosphorus are essential nutrients for plant growth, but high concentrations of either nutrient in a water body can cause unwanted, dense algal blooms. High concentrations of nitrate in drinking water can cause methemoglobinemia (blue-baby syndrome) in small children (Hem, 1992). Drinking-water standards or health advisories have been established for ammonia (un-ionized ammonia $[\text{NH}_3]$ plus ammonium $[\text{NH}_4^+]$), nitrite, and nitrate (table 2).

Ground-water samples were analyzed for the dissolved forms of ammonia (un-ionized ammonia plus ammonium), ammonia plus organic nitrogen, nitrite, nitrate, phosphorus, and orthophosphate.

Ammonia (un-ionized ammonia plus ammonium) was detected in low concentrations in water samples from the 11 wells (table 2). Most (60 of 70) ammonia concentrations were less than 0.01 mg/L (table 5, Appendix I). Ammonia also was detected in 32 percent (7 of 22) of the blank samples, primarily at low concentrations (0.002–0.005 mg/L); one sample had a concentration of 0.021 mg/L (table 9, Appendix II). The presence of ammonia in some blanks indicates that small amounts of ammonia were introduced during sampling and/or laboratory analysis in a few samples. Also, variability in reported ammonia concentrations was within the concentration range of the environmental data, and there was inconsistency in the detection of ammonia in replicate-pair samples (table 7, Appendix II). Because of these factors, the exact concentration of ammonia in the ground-water samples collected during the sampling period is uncertain. It is known, however, that only small amounts of ammonia were present in the samples, and all concentrations were less than or equal to about 0.040 mg/L (table 2).

In surface or ground water, nitrite usually is undetected or detected at very low concentrations because it is rapidly converted to nitrate in the presence of oxygen. During this study, nitrite concentrations were undetected or were less than or equal to the reporting level of 0.001 mg/L in all ground-water samples but one (0.004 mg/L for site 8 on 09/13/2000). Detected concentrations of nitrite were much lower than the USEPA MCL for nitrite of 1 mg/L in drinking water (table 2).

Nitrate plus nitrite concentrations in the ground-water samples were essentially nitrate, and will be considered as such in this report, because of the very low or undetected concentrations of nitrite. Nitrate concentrations in the ground-water samples ranged from less than 0.005 to 4.72 mg/L, with a median concentration of 0.208 mg/L (table 2). Most (54 of 70) nitrate concentrations were very low, less than 0.3 mg/L. Nitrate concentrations for all water samples from site 7, completed in the alluvial aquifer in Tabernash, were less than or equal to 0.008 mg/L. Nitrate in this well probably was denitrified to reduced species of nitrogen; reducing conditions for this well were indicated by low dissolved-oxygen concentrations and elevated iron and manganese concentrations. Nitrate concentrations were elevated (greater than 1 mg/L) in water samples from

three alluvial aquifer wells (sites 1, 4, and 8). Nitrate concentrations greater than 2 mg/L may indicate nitrate introduced by human activities (U.S. Geological Survey, 1999). Nitrate concentrations for all seven water samples from site 8 were above 2 mg/L, the estimated national background concentration of nitrate in ground water (Mueller and Helsel, 1996). These concentrations may indicate that recent land-use practices have affected water quality, as water in site 8 has an estimated chlorofluorocarbon recharge date of the 1990's (table 1). Results of the Wilcoxon rank-sum test indicated that the hypotheses of similarities in nitrate concentrations between urban and non-urban areas and between ISDS and non-ISDS areas could not be rejected (table 3). Similarities in nitrate concentrations between aquifer types also could not be rejected statistically (table 3) because of comparable median values, although nitrate concentrations were elevated in water samples from some alluvial aquifer wells (fig. 5). No nitrate concentrations were greater than the USEPA MCL for nitrate in drinking water of 10 mg/L (table II). Variability and uncertainty in nitrate concentrations (table 8, Appendix II) had little, if any effect, on the nitrate results.

Orthophosphate was the primary component of dissolved phosphorus in water from the 11 wells in the study area, as indicated by the similarities in concentrations of the two constituents. For some ground-water samples, the dissolved phosphorus concentration was slightly less than the orthophosphate concentration. Small differences in these two constituents may be a reflection of analytical precision or variability in phosphorus concentrations, as discussed in "Quality-Control Methods and Analysis" in Appendix II. Orthophosphate concentrations in the ground-water samples ranged from an estimated value of about 0.005 to 0.137 mg/L, and the median concentration was 0.047 mg/L (table 2). Minimum concentrations were detected in water samples from three alluvial aquifer wells (sites 1, 4, and 7). All samples for sites 2 and 10, completed in the Troublesome Formation aquifer, had orthophosphate concentrations greater than 0.1 mg/L. Orthophosphate concentrations were higher in water samples from the Troublesome Formation aquifer and non-ISDS areas than in samples from the alluvial aquifer and ISDS areas, as indicated by median concentrations (table 3). The most common geologic source of phosphorus is

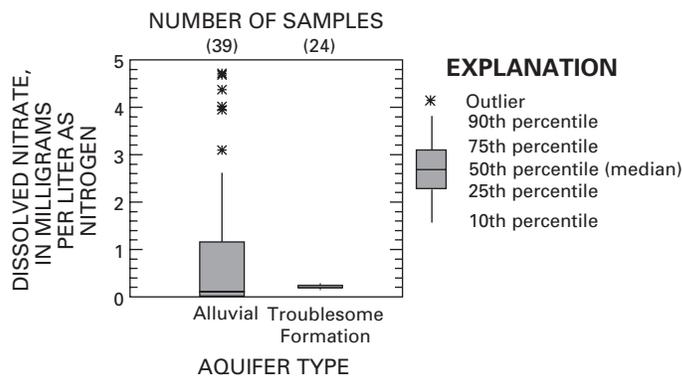


Figure 5. Distribution of dissolved nitrate concentrations by aquifer type for wells in the Fraser River watershed, 1998–2001.

the mineral apatite (Hem, 1992). Although little information is available on the mineralogy of the Troublesome Formation, significantly higher concentrations of orthophosphate in water samples from the Troublesome Formation aquifer could indicate that apatite is the major source of orthophosphate in the study area.

Naturally occurring dissolved organic carbon in ground water is the result of biological and biochemical decay and degradation processes in soil and, as such, usually is assumed to be similar to the organic material present in soils in the ground-water recharge area (Hem, 1992). Anthropogenic sources of dissolved organic carbon include organic amendments to soil, such as animal manure, and leachate from landfills or septic-disposal systems. The naturally occurring and anthropogenically derived organic solutes that constitute dissolved organic carbon can function as nutrients for microbiota, affect metal solubility, participate in oxidation/reduction reactions, and affect physical and chemical properties of solid/liquid or liquid/gas interfaces. Certain organic solutes are toxic to aquatic and other life forms and can cause water to be unusable for human activities (Hem, 1992).

Dissolved organic carbon concentrations in ground-water samples from the wells in the Fraser River watershed ranged from 0.2 to 4.0 mg/L, and the median concentration was 0.91 mg/L (table 2). The highest concentrations, 3.0 mg/L and greater, were detected in all four water samples from site 1, the very shallow (18 ft) alluvial aquifer well located between Winter Park and Fraser. Samples from site 6, east-southeast of Tabernash, and from sites 7, 8, and 9, near Tabernash, had median dissolved organic carbon concentrations exceeding 1.0 mg/L. All four wells also were alluvial aquifer wells.

Dissolved organic carbon concentrations were higher in water samples from wells completed in the alluvial aquifer and in non-ISDS areas than those from wells completed in the Troublesome Formation aquifer and in ISDS areas (table 3). There was, however, some overlap between dissolved organic carbon concentrations in samples from ISDS and non-ISDS areas (fig. 6). The concentration differences between these two areas likely have no environmental significance. High concentrations of dissolved organic carbon in ground water likely are the result of the decay of organic compounds associated with natural vegetation in the area. Concentrations in water samples from site 1, which is in a pasture, also could reflect the effects of animal waste.

Bacteria, Methylene Blue Active Substances, and Radon-222

Total coliform bacteria are used as indicator bacteria to assess the sanitary quality of water and the potential public health risk from waterborne diseases. They typically do not cause disease themselves but are correlated to the presence of several waterborne organisms or pathogens that do cause disease (Myers and Sylvester, 1997). Coliform bacteria can be

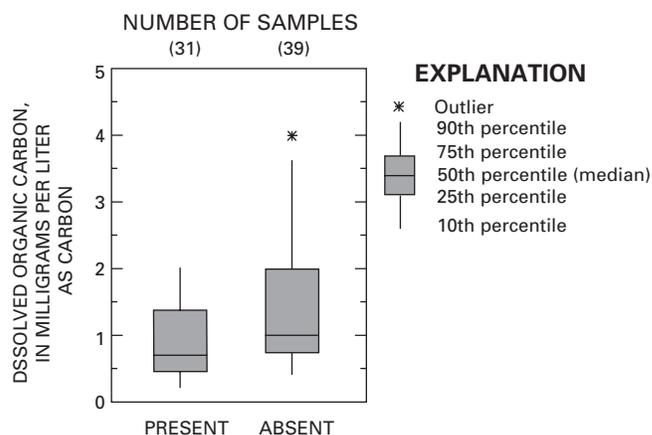


Figure 6. Distribution of dissolved organic carbon concentrations by presence or absence of individual septic disposal systems for wells in the Fraser River watershed, 1998–2001.

present in soil naturally or may occur as a result of animal or human waste.

For the 11 wells, total coliform bacteria were detected in one or two water samples from each of six wells (sites 1, 3, 4, 6, 7, and 8). Overall, the bacteria were detected in 9 of 68 ground-water samples, or 13 percent. All but two samples (both for site 1) had bacteria concentrations less than or equal to 4 col/100 mL (colonies per 100 milliliters). Soil was the most likely source for the low concentrations of total coliform bacteria in water samples from sites 3, 4, 6, 7, and 8, and animal waste was the likely source of the bacteria in samples from site 1. Of these six wells, all were completed in the alluvial aquifer, except for site 3, which was completed in the Troublesome Formation aquifer. All nine samples with detections of total coliform bacteria also were analyzed for *E. coli*, an indication of fecal contamination; *E. coli* were not detected. Because each well was sampled only once in each month that sampling occurred, insufficient data were available to compare the total coliform counts for each well to the USEPA MCLG, which specifies no more than 5 percent of the samples in a month test positive for total coliform (table 2). Except for site 1, total coliform bacteria were not a ground-water-quality issue.

MBAS are natural or synthetic anionic surfactants; the synthetic surfactants are present in many types of soaps and detergents (Burkhardt and others, 1995). Detection of MBAS in water samples can be an indicator of contamination by wastewater. Most (57 of 69) water samples from the 11 wells did not contain detectable concentrations of MBAS, including all samples from the 4 wells completed in the Troublesome Formation aquifer. All detected concentrations except one were in water samples from alluvial aquifer wells. MBAS concentrations ranged from less than 0.02 to 3.82 mg/L (table 2), and all but the maximum concentration were less than or equal to 0.10 mg/L. The maximum concentration, detected in a sample from site 8 in an ISDS area, was the only concentration higher than the

USEPA SDWR for MBAS of 0.5 mg/L (table 2). This exceedance may indicate the local contamination of ground water by waste from an ISDS. Detection of anthropogenic surfactants probably relates more to the failure of individual ISDS's rather than being representative of the entire ISDS area. Other detected concentrations of MBAS were too low to discern whether the surfactants were naturally occurring or had an anthropogenic source.

Radon is a naturally occurring radioactive gas that is formed from the decay of uranium. Major sources of radon include rocks containing uranium minerals, soils derived from such rocks, and ground water that has been in contact with uranium-bearing rocks and soils. Uranium decays to radium (and other products) and then to radon, which is soluble in water and occurs in ground water as a gas. Radon can be present in indoor air as a result of seepage from soils underneath a building (the primary mechanism) or through the use of well water (through aeration) that contains radon. The primary public health risk associated with radon is the breathing of radon from indoor air in homes (U.S. Environmental Protection Agency, 2000b). The National Research Council estimated that the radon in indoor air resulting from the breakdown of uranium in soils has contributed to about 20,000 lung cancer deaths each year in the United States (National Research Council, 1999). Only a small portion of radon in indoor air is derived from the aeration of radon-containing well water through household use of the water. This source can, however, increase a person's risk of lung cancer over a lifetime. Drinking water that contains radon presents a risk of internal-organ cancers, particularly stomach cancer (U.S. Environmental Protection Agency, 2000b). Radon can be removed from well water through the use of carbon filters or aeration devices (U.S. Environmental Protection Agency, 2000b).

Different isotopes of radon are produced by the decay of radium, but only one, radon-222, has environmental importance (Hem, 1992). Excluding site 1, which was sampled only in 2000 and 2001, three of the water samples collected from each well in 1998 and 1999 were analyzed for radon-222. Concentrations ranged from 365 to 6,380 pCi/L (picocuries per liter), and the median concentration was 760 pCi/L (table 2). All concentrations exceeded the USEPA-proposed MCL for radon-222 in drinking water of 300 pCi/L (table 2), which is under review. When variability and uncertainty in radon-222 concentrations were taken into account (table 8, Appendix II), part of the concentration range for one sample was less than the USEPA-proposed MCL. Among the 10 wells, water samples from site 4, an alluvial aquifer well immediately west of Fraser, had the highest median radon-222 concentration (6,170 pCi/L). This concentration was more than three times higher than the next highest median concentration (fig. 7). All radon-222 concentrations for site 4 were greater than the USEPA-proposed alternative MCL for radon-222 in drinking water of 4,000 pCi/L (table 2), which also is under review. Statistically significant

differences in radon-222 concentrations were not indicated for samples from wells completed in the alluvial aquifer and wells completed in the Troublesome Formation aquifer (table 3). Radon-222 concentrations in ground-water samples from wells in the Fraser River watershed were similar to concentrations in ground-water samples from wells in other areas of the Upper Colorado River Basin in Colorado, which ranged from 305 to 4,030 pCi/L in 1997 (Apodaca and others, 2000).

Changes Over Time

For each well except sites 1 and 3, data for field properties and water-quality constituents for ground-water samples were examined qualitatively for changes over time by using LOWESS smooth curves. Insufficient data were available for wells 1 and 3 to be included in the analysis. Properties and constituents that were graphed included water temperature, specific conductance, dissolved-oxygen concentration, pH, turbidity, alkalinity, dissolved solids, major ions (calcium, chloride, magnesium, potassium, silica, sodium, and sulfate), manganese, nutrients (nitrate and orthophosphate), and dissolved organic carbon. For most constituents from most wells, changes in the data over time were not apparent. Changes were apparent, however, for samples from site 7, an alluvial aquifer well in the Tabernash area. Specific conductance and calcium, magnesium, chloride, and sulfate concentrations appeared to increase over time (fig. 8). These changes are qualitative changes only and are not legitimate statistical trends because of the short time periods of the data collection, the small sample sizes, and data collection only occurring in 2 months of each year. The change in specific conductance probably was a function of higher concentrations of calcium, magnesium, chloride, and sulfate over portions of the sampling period. Calcium and magnesium concentrations generally increased between May 1999 and May 2001, whereas chloride and sulfate concentrations increased after May 2000, respectively (fig. 8). The apparent increases in specific conductance and calcium, magnesium, chloride, and sulfate concentrations for site 7 had little effect on water quality of the well, but the changes indicate that shallow ground water could be susceptible to changes in land use in the watershed. Specific conductance remained moderate, and the water remained suitable for use. Chloride and sulfate concentrations remained well below the USEPA drinking-water standard of 250 mg/L for each constituent (table 2).

Surface Water

As stated previously, field properties for the surface-water site Fraser River below Crooked Creek at Tabernash (hereinafter Fraser River at Tabernash) were measured bimonthly between August 1998 and September 2001, and water samples were collected for laboratory analyses during each site visit. The resulting data for WY's 1999, 2000, and

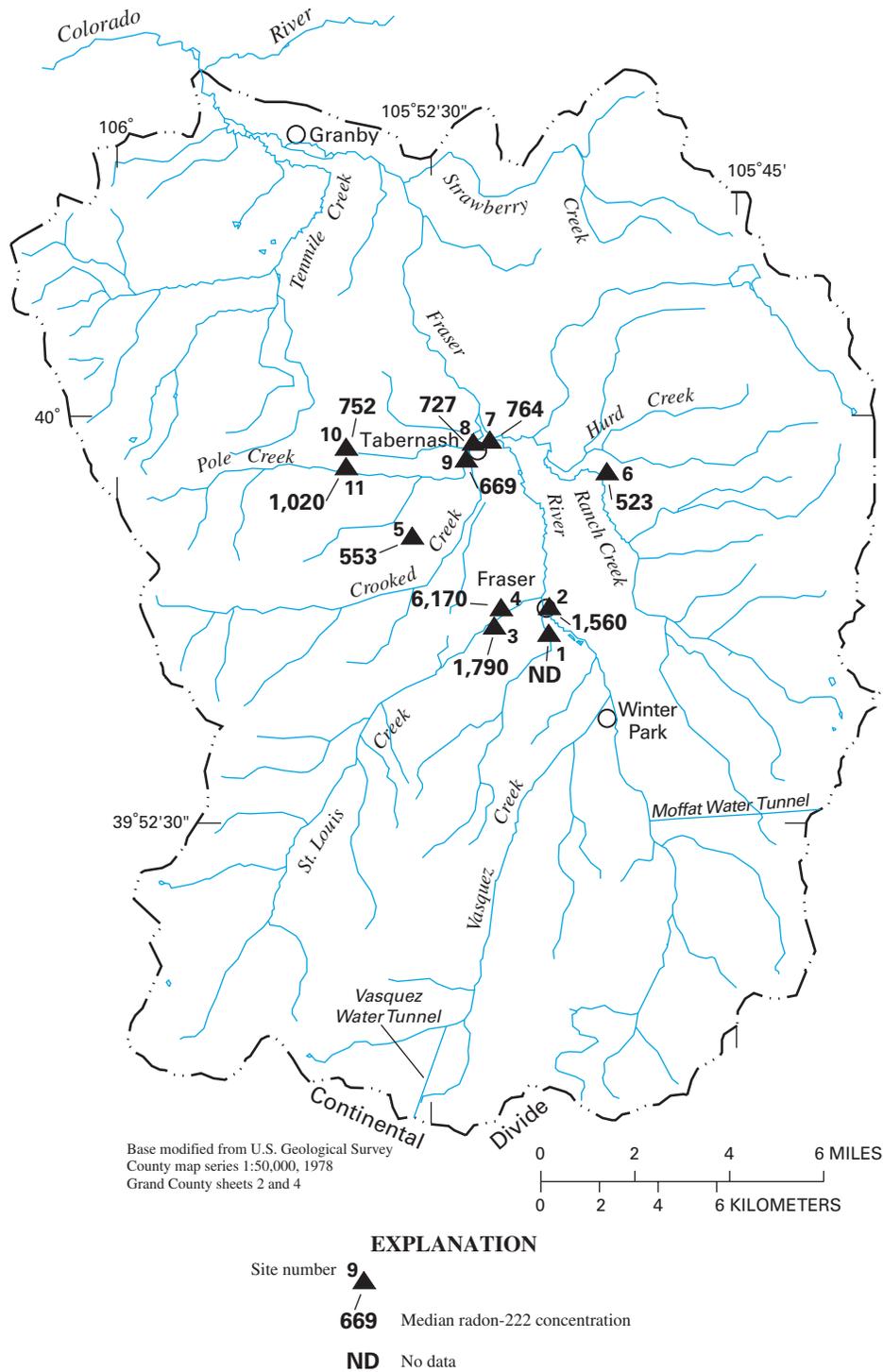


Figure 7. Median radon-222 concentrations for wells in the Fraser River watershed, 1998–99.

2001 are listed in the annual USGS water-data reports for these years (Crowfoot and others, 2000, 2001, and 2002). A statistical summary of selected surface-water data for the site, applicable State of Colorado instream water-quality standards, and NWQL reporting levels are listed in table 4. All water-quality constituents discussed in this section are in the dissolved form except for total phosphorus, particulate organic carbon, and fecal coliform bacteria.

Field Properties and Suspended Sediment

Discharge in the Fraser River at Tabernash ranged from a minimum of 31.0 ft³/s to a maximum of 244 ft³/s for the sampling period, and the median was 66.2 ft³/s (table 4). Discharge is dominated by snowmelt runoff during spring. Smaller discharges at other times of the year reflect the gradual melting of annual snowfields, precipitation events (primarily

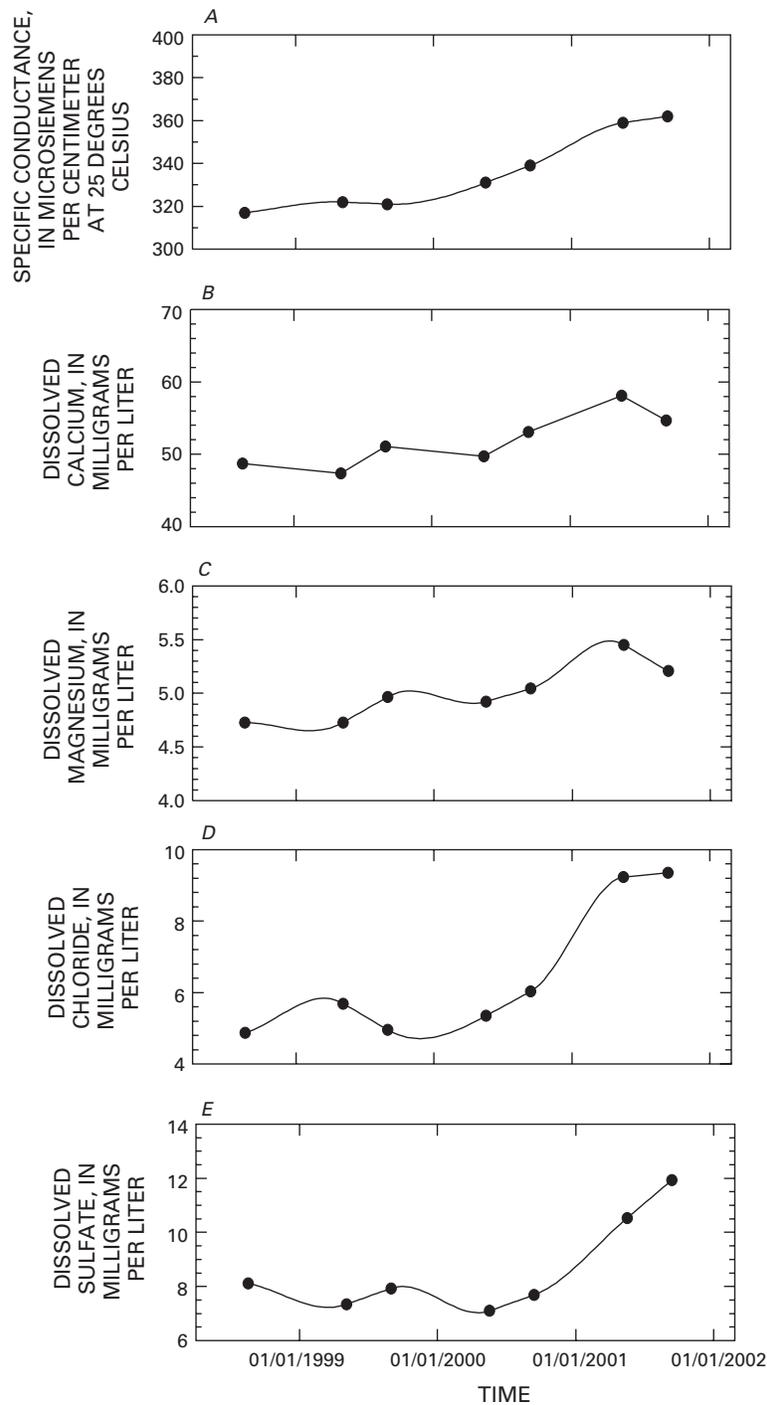


Figure 8. (A) Specific conductance and dissolved (B) calcium, (C) magnesium, (D) chloride, and (E) sulfate concentrations over time for well 7 in the Fraser River watershed, 1998–2001.

thunderstorms in summer), base flow from ground-water discharges, and discharge from wastewater-treatment facilities.

Concentrations of suspended sediment in the Fraser River at Tabernash were low overall, ranging from 3 to 29 mg/L, with a median of 8 mg/L (table 4). Elevated concentrations occurred during early spring or during snowmelt runoff.

Suspended sediment is important in nutrient analysis because a large proportion of phosphorus carried by streams tends to adhere to the sediment.

Measurements of specific conductance ranged from 74 to 146 $\mu\text{S}/\text{cm}$ (table 4) and indicated slightly mineralized water. Minimum specific conductance was detected during times of

Table 4. Statistical summary of selected field properties and water-quality constituents for surface water at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

[All water-quality constituents are in the dissolved form except for total phosphorus, particulate organic carbon, and fecal coliform bacteria. Water-quality standards are from Colorado Department of Public Health and Environment (2002). WY, water year; MRL, minimum reporting level; LT-MDL, long-term method detection level; LRL, laboratory reporting level; ft³/s, cubic feet per second; --, no standard established; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; N, nitrogen; <, less than; nitrate is nitrate plus nitrite; P, phosphorus; C, carbon; col/100 mL, colonies per 100 milliliters; E, estimated]

Field properties, constituents, and reporting units	Number of samples	Minimum	Median	Maximum	State of Colorado water-quality standard	WY 1998		WY 1999		WY 2000		WY 2001		
						MRL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	LT-MDL	LRL (*=MRL)	
Field properties and suspended sediment														
Discharge (ft ³ /s)	24	31.0	66.2	244	--									
Suspended sediment (mg/L)	16	3	8	29	--									
Specific conductance (µS/cm)	23	74	108	146	--	1.0		*1.0		*1.0			*1.0	
Oxygen, dissolved (mg/L)	24	8.0	9.6	11.5	6.0, 7.0	0.1		*0.1		*0.1			*0.1	
pH (standard units)	24	7.8	8.3	8.6	6.5–9.0	0.1		*0.1		*0.1			*0.1	
Dissolved solids, major ions, and trace elements														
Dissolved solids (mg/L)	17	53	70	93	--	Computed concentration ²								
Chloride (mg/L)	24	2.2	3.9	9.0	250	0.1		*0.1		0.14		0.29		0.04
Sulfate (mg/L)	19	1.1	2.7	4.5	250	0.1		*0.1		0.15		0.31		0.05
Iron (µg/L)	19	73	198	354	300 (chronic)	10		5		5		10		5
Manganese (µg/L)	19	14	26	53	50 (chronic)	4		1.5		1.1		2.2		1.6
Nutrients and organic carbon														
Ammonia, ³ as N (mg/L)	24	<0.002	0.015	0.412	--	0.002		*0.002		*0.002		*0.002		*0.002
Un-ionized ammonia, ⁴ as N (mg/L)	24	2.6×10 ⁻⁵	7.4×10 ⁻⁵	0.004	0.02 (chronic)	Computed concentration ⁴								
Nitrite, as N (mg/L)	24	0.001	0.005	0.01	0.05	0.001		*0.001		*0.001		*0.001		*0.001
Nitrate, as N (mg/L)	24	0.012	0.062	0.703	10	0.005		*0.005		*0.005		*0.005		*0.005
Total phosphorus, as P (mg/L)	24	0.032	0.058	0.173	--	0.004		*0.004		0.003		0.006		0.003
Phosphorus, as P (mg/L)	24	0.015	0.030	0.084	--	0.004		*0.004		0.003		0.006		0.003
Orthophosphate, as P (mg/L)	24	0.011	0.024	0.077	--	0.001		*0.001		*0.001		*0.001		0.004
Dissolved organic carbon, as C (mg/L)	19	1.6	3.3	6.3	--	0.1		*0.1		0.16		0.33		0.16
Particulate organic carbon, as C (mg/L)	18	<0.2	0.3	0.7	--									
Fecal coliform bacteria														
Fecal coliform bacteria (col/100 mL)	23	<1	E 7	129	200 (geometric mean)	1		*1		*1		*1		*1

¹Water-quality standard is a minimum of 6.0 mg/L except during periods of fish spawning when it is a minimum of 7.0 mg/L.
²Dissolved solids (sum of constituents) is computed as the sum of calcium, magnesium, sodium, potassium, silica, chloride, sulfate, and carbon (as carbonate equivalent) plus any other constituents, such as dissolved iron, if they are present in the water.
³Un-ionized ammonia [NH₃] plus ammonium [NH₄⁺].
⁴NH₃.

maximum discharge and is an indication of dilution of surface water with snowmelt. Maximum values occurred during late winter and early spring before the onset of snowmelt.

Dissolved-oxygen concentrations in the Fraser River at Tabernash ranged from 8.0 to 11.5 mg/L, with a median of 9.6 mg/L (table 4). Dissolved-oxygen concentrations were inversely related to stream temperature, which is a primary factor controlling the solubility of oxygen in water. The State of Colorado instream water-quality standard for dissolved-oxygen concentration in the Fraser River is 6.0 mg/L except during periods of fish spawning when the standard is raised to 7.0 mg/L (table 4) (Colorado Department of Public Health and Environment, 2002). No dissolved-oxygen concentrations measured during this study were less than the standard.

Values for pH in the Fraser River ranged from 7.8 to 8.6 (table 4). All measurements were within the State instream water-quality standard of 6.5–9.0 (Colorado Department of Public Health and Environment, 2002).

Dissolved Solids, Major Ions, and Trace Elements

The concentrations of dissolved solids in the Fraser River were low, ranging from 53 to 93 mg/L (table 4). These concentrations reflected the high quality of the surface water and indicate the suitability of the water for drinking, residential, industrial, and irrigation purposes.

The surface water was a calcium-bicarbonate type water throughout the study period (fig. 4). Samples from 10 of 11 ground-water wells were the same type water. During most of the year, the surface water primarily is base flow from ground-water discharge. The following discussion will only focus on the major ions chloride and sulfate and the trace ele-

ments iron and manganese, all of which have State of Colorado instream water-quality standards.

Chloride concentrations overall were low (less than or equal to 9.0 mg/L) in the Fraser River at Tabernash (table 4). Maximum concentrations typically occurred during late winter or early spring just prior to peak flow resulting from spring snowmelt. Minimum concentrations occurred during snowmelt runoff (fig. 9). It is likely that chloride in the river comes from nonpoint sources, including salt and gravel applications during winter, and discharges from wastewater-treatment facilities. All chloride concentrations were substantially below the State instream standard of 250 mg/L (Colorado Department of Public Health and Environment, 2002).

Sulfate concentrations also were low (less than or equal to 4.5 mg/L) in the river. Like chloride, maximum concentrations of sulfate typically occurred during late winter or early spring just prior to peak flow resulting from spring snowmelt; minimum concentrations occurred after snowmelt runoff in mid-summer (fig. 9). All sulfate concentrations were substantially below the State instream standard of 250 mg/L (Colorado Department of Public Health and Environment, 2002).

Iron concentrations were relatively high at the site, ranging from 73 to 354 $\mu\text{g/L}$ with a median concentration of 198 $\mu\text{g/L}$ (table 4). The elevated iron concentrations may be related to discharges of iron-rich ground water to the river in the vicinity of Tabernash. A large amount of variability in the iron concentrations was present over the sampling period, but no seasonal patterns were discernible. The State chronic instream iron standard of 300 $\mu\text{g/L}$ for the Fraser River site was exceeded in 1 of 19 samples (Colorado Department of Public Health and Environment, 2002). For trace elements such as iron and manganese, compliance with the State instream standard is met if the concentration of the 85th percentile of all representative data is less

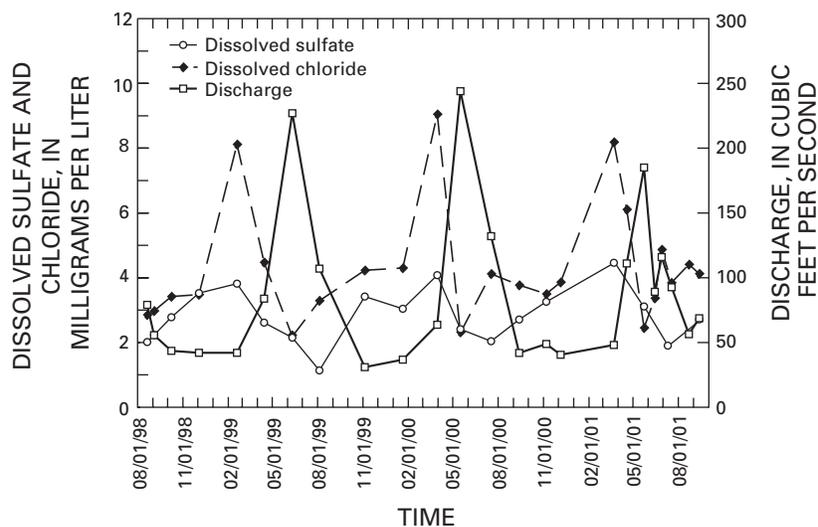


Figure 9. Dissolved sulfate and chloride concentrations and discharge at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

than the standard. For this site, the 85th percentile concentration of iron was 275 $\mu\text{g/L}$. Even though one exceedance did occur, the river was in compliance with the iron standard over the sampling period.

Manganese concentrations ranged from 14 to 53 $\mu\text{g/L}$, and the median concentration was 26 $\mu\text{g/L}$ (table 4). Like iron, manganese concentrations were variable over the sampling period, and no seasonal patterns were discernible. The State chronic instream manganese standard of 50 $\mu\text{g/L}$ was exceeded in 1 of 19 samples (Colorado Department of Public Health and Environment, 2002). Because the 85th percentile concentration was about 37 $\mu\text{g/L}$ for manganese, the Fraser River was in compliance with the stream standard for manganese at this site over the sampling period.

Nutrients and Organic Carbon

Nitrogen and phosphorus constituents that are discussed as nutrients include ammonia (un-ionized ammonia plus ammonium), un-ionized ammonia, nitrite, nitrate, total and dissolved phosphorus, and orthophosphate. In surface water, these nutrients can both come from natural and anthropogenic sources through runoff or the discharge of ground water to surface water. Natural sources include nitrogen fixation as a source of nitrogen and the mineral apatite as a source of phosphorus. Anthropogenic sources of nitrogen are more numerous and include the production and use of synthetic fertilizers, atmospheric deposition from the combustion of fossil fuels, animal

feedlots, and sewage. These latter two sources also are sources of phosphorus in surface water.

There are currently (2003) three wastewater-treatment facilities located upstream from the surface-water-sampling site that discharge into the Fraser River. The largest nutrient input to the Fraser River coincides with a portion of the river near the wastewater-treatment facilities (Bails, 2003). State instream water-quality standards have been established for un-ionized ammonia, nitrite, and nitrate in stream water but not for phosphorus.

Ammonia concentrations at the Fraser River site ranged from less than 0.002 to 0.412 mg/L, and the median concentration was 0.015 mg/L (table 4). Ammonia concentrations showed a seasonal pattern; maximum concentrations occurred during winter and early spring, and minimum concentrations occurred during snowmelt runoff and during the summer and fall months (fig. 10). Stream standards for ammonia are based on un-ionized ammonia (NH_3), the form of ammonia most toxic to aquatic life. For the Fraser River watershed, the State chronic instream standard for un-ionized ammonia is 0.02 mg/L. This is a table value standard (TVS) that is constant whereas the acute TVS is a function of the pH and temperature of the water (Colorado Department of Public Health and Environment, 2002). For each sample, the un-ionized ammonia concentration was estimated from the reported ammonia concentration by using pH, water temperature, and the equilibrium constant for ammonia protonation (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL <http://water.usgs.gov/admin/memo/QW/qw93.12.html>, accessed February 7, 2002). The acute TVS concentration also

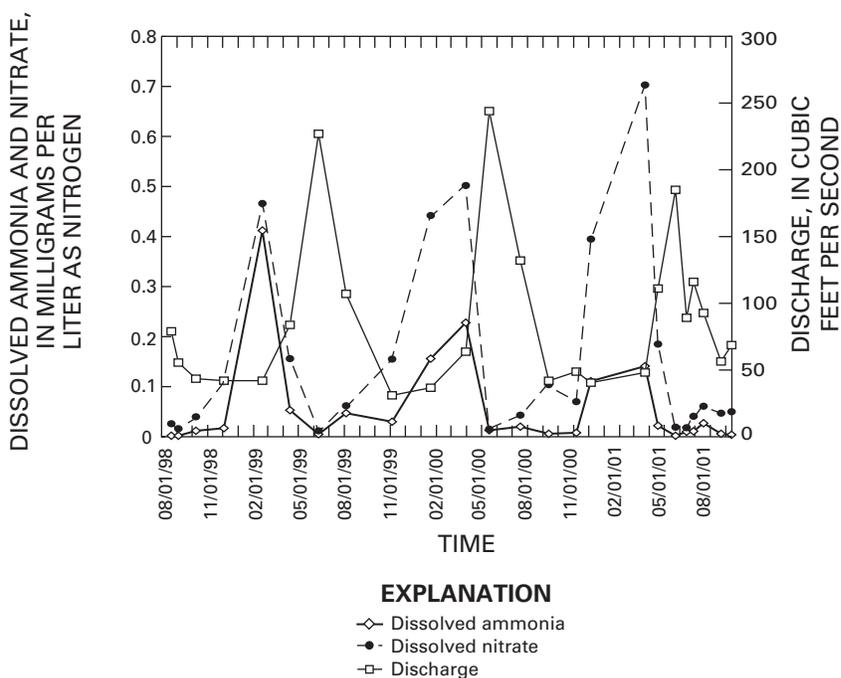


Figure 10. Dissolved ammonia and nitrate concentrations and discharge at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

was calculated for each sample and then compared to the calculated un-ionized ammonia concentration. No surface-water sample had an un-ionized ammonia concentration that exceeded the chronic standard or the calculated acute TVS for un-ionized ammonia.

In noncontaminated waters, nitrite usually is not detected or is detected at low concentrations because it is unstable in the presence of oxygenated water and is rapidly converted to nitrate. All nitrite concentrations in the Fraser River were less than or equal to 0.01 mg/L and met the State instream water-quality standard of 0.05 mg/L (Colorado Department of Public Health and Environment, 2002). Nitrate concentrations in the river were very low, ranging from 0.012 to 0.703 mg/L (table 4). Nitrate concentrations fluctuated with the same seasonality as ammonia concentrations (fig. 10). Low nitrate concentrations at the beginning of summer resulted from dilution of surface water with snowmelt water. During summer, the low concentrations probably reflected the consumption of nitrate by stream biota. All nitrate concentrations were well below the State instream standard of 10 mg/L (table 4) (Colorado Department of Public Health and Environment, 2002).

Total phosphorus concentrations ranged from 0.032 to 0.173 mg/L, and the median concentration was 0.058 mg/L (table 4). Typically, more than one-half of the total phosphorus in the Fraser River was particulate rather than dissolved phosphorus. Most of the dissolved phosphorus that was detected in surface-water samples was orthophosphate (fig. 11), the form of phosphorus that is most readily used in plant and animal metabolism. Maximum concentrations for all phosphorus species occurred in late winter or early spring, and minimum concentrations occurred during snowmelt runoff and, at times, during fall.

All natural waters contain organic carbon (Hem, 1992). Sources of organic carbon in surface water include living and decaying vegetation and biota, wastewater, and ground water. Organic carbon is important in surface water as a nutrient for microbiota that mediate chemical processes (Hem, 1992), and it can increase the solubility or transport of hydrophobic organic chemicals such as pesticides. Most organic carbon in the Fraser River at Tabernash was dissolved organic carbon. Concentrations of dissolved organic carbon ranged from 1.6 to 6.3 mg/L (table 4). The median concentration of 3.3 mg/L was similar to the national average of 3.0 mg/L for semiarid regions (Hem, 1992). Dissolved organic carbon concentrations in the river fluctuated seasonally, with maximum concentrations during snowmelt runoff and minimum concentrations during winter (fig. 12). Particulate organic carbon concentrations ranged from less than 0.2 to 0.7 mg/L (table 4). Two of the three highest concentrations occurred during spring at the onset of snowmelt runoff, and then concentrations decreased during the runoff period (fig. 12). The timing of these peak concentrations of dissolved and particulate organic carbon indicates that the concentrations are likely derived from decaying vegetation and organic detritus transported from the landscape during snowmelt runoff.

Fecal Coliform Bacteria

Fecal coliform bacteria are an indication of the sanitary quality of the surface water and the potential for adverse human-health effects. The Fraser River is classified as a class 1 recreation river, which allows for primary contact with the water in such activities as swimming, kayaking, and rafting

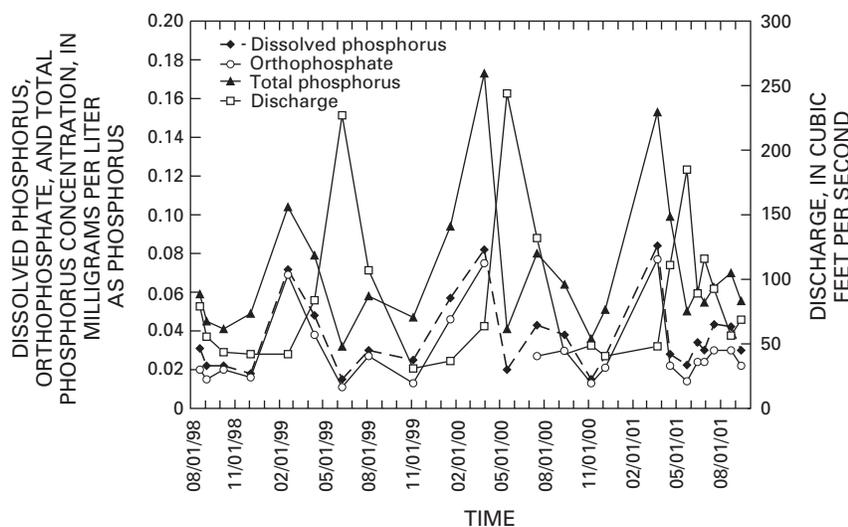


Figure 11. Phosphorus concentrations and discharge at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

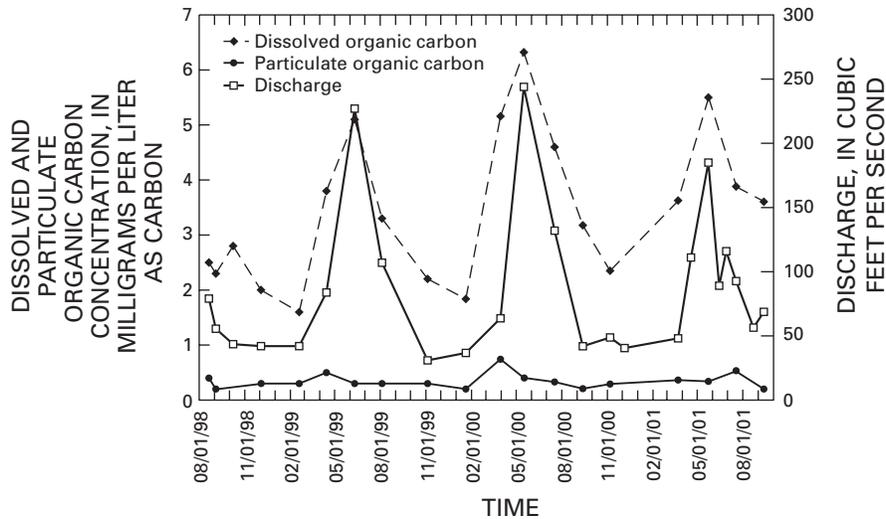


Figure 12. Organic carbon concentrations and discharge at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

where the ingestion of small amounts of water may occur (Colorado Department of Public Health and Environmental, 2002). Under this classification, the geometric mean of all data for fecal coliform bacteria must be less than 200 col/100 mL. The geometric mean of the fecal coliform samples collected for this report was 7.4 col/100 mL, well below the State instream standard. The maximum fecal coliform bacteria concentration was 129 col/100 mL (table 4). Fecal coliform bacteria concentrations showed a seasonal pattern, with maximum concentrations occurring in summer and lower concentrations throughout the rest of the year (fig. 13). Maximum concentrations in summer potentially could be of future concern, as most recreational uses of the river would be expected to take place during that time.

The most likely sources of fecal coliform bacteria in the Fraser River are the wastewater-treatment facilities and domestic and wild animals.

Ground-Water Quantity

The assessment of ground-water quantity for the Fraser River watershed focused on the upper portion of the watershed where the majority of development is occurring. The alluvial aquifer and Troublesome Formation aquifer are the primary sources of ground water for domestic and municipal use in the Fraser River valley. The alluvial aquifer in the upper Fraser

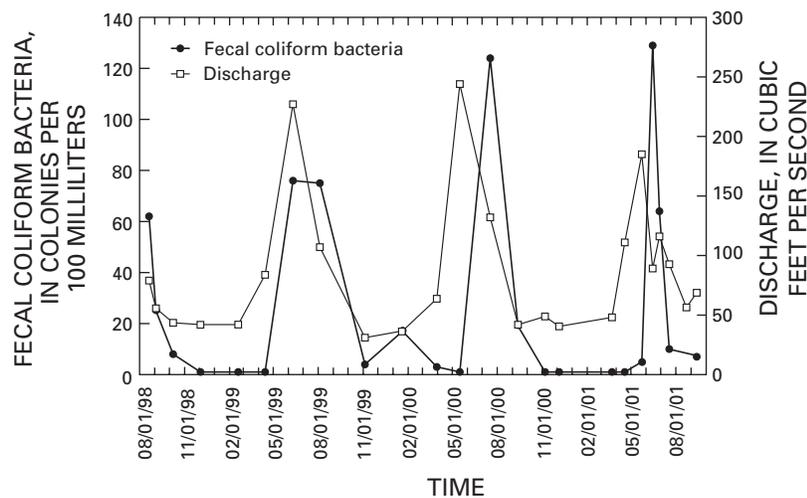


Figure 13. Fecal coliform bacteria concentrations and discharge at the Fraser River below Crooked Creek at Tabernash, Colorado, 1998–2001.

River watershed consists of unconsolidated, poorly sorted, valley-fill deposits that range in thickness from a few feet along the valley walls up to at least 140 ft in the valley center. The Troublesome Formation aquifer consists primarily of siltstone with interbedded sandstone and conglomerate, with a thickness of more than 600 ft. Previous estimates of ground-water storage in the alluvial and Troublesome Formation aquifers were made by Apodaca and Bails (1999).

Ground-water quantity is discussed in terms of aquifer properties, water-level measurements, and where appropriate, qualitative estimates of ground water available to be withdrawn by wells. Aquifer properties were derived from lithologic well-log data, from results of available aquifer tests (Resource Engineering, Incorporated, 1999 and 2000; Wilson, 1965), and from comparison to aquifer properties of similar systems. In addition, two downhole monitors were installed in wells completed in the alluvial and Troublesome Formation aquifers to measure water level and temperature. The monitors were installed in September of 1998 and continuously collected data until mid-September 2001.

The quantity of available water in the alluvial aquifer is a function of the areal extent of the aquifer, the saturated thickness of the aquifer, and the effective porosity (specific yield) of water in the saturated zone. The extent of the alluvial aquifer overlying the Troublesome Formation was determined from a geographic information system (GIS) coverage of the Fraser River valley geology (Green, 1992; Tweto, 1979). Unconsolidated surficial deposits of Quaternary age were aggregated, and a total areal extent of 22 mi² was calculated (fig. 14). Information from well logs obtained from the Colorado Division of Water Resources indicates the maximum alluvial aquifer depth of at least 140 ft in the area of interest upstream from Tabernash. Data collected from the continuous water-level monitor in the alluvial aquifer at site 9 indicated the average depth to water over the period of study was 8.5 ft below land surface with a minimum of 5.9 ft and a maximum of 9.5 ft below land surface (fig. 15). The minimum depth to water occurred during early spring as snowmelt recharged the alluvial aquifer. The maximum depth to water occurred during the fall and winter as discharge of ground water to surface water exceeded recharge, causing the water table to decline.

To determine the volume of the saturated alluvial aquifer, the volume of the alluvial aquifer above the water table was subtracted from the total volume of the alluvial aquifer by using a GIS procedure. The total volume of the alluvial aquifer was estimated by generating a generalized map of aquifer thickness from lithologic logs obtained from the Colorado Division of Water Resources for 291 wells (fig. 14). Locations of wells and the thickness of the alluvium were plotted on a map of the areal extent of the alluvial aquifer. Thickness contour lines of 50 ft were then drawn on the map to determine areas where the alluvial aquifer was either 0 to 50 ft thick or 50 to 100 ft thick. A 100-ft maximum thickness was assumed because of the uncertainties in the limited data. The assumed 100-ft maximum thick-

ness allows for some equalization in the estimate of aquifer volume such that some areas may not reach the full 100-ft depth, while in some areas the full depth is at least 140 ft. An additional assumption was made concerning the geometry of the bottom of the alluvial aquifer. It was assumed that the bottom is not flat but is actually thickest in the center of the valley and tapers off toward the edges of the aquifer boundary in a lenslike morphology. To account for this, the total volume of the area of the 0- to 50-ft thickness was calculated by multiplying the areal extent of the aquifer by one-half the maximum thickness, or 25 ft. For the areas of 50- to 100-ft aquifer thickness, the total volume is a combination of the top 50 ft, which would not have any effect from the bottom of the aquifer morphology, plus the bottom 50 ft, which would be affected by the configuration of the bottom of the aquifer. To calculate the total volume, the areal extent of the 50- to 100-ft-thick areas was multiplied by 50 ft to represent the upper part of the aquifer that was unaffected by the lower boundary. This number was then added to the same areal extent multiplied by one-half the thickness, or 25 ft, to represent the bottom one-half of the aquifer where the boundary condition was present. This equates to 75 ft multiplied by the areal extent in the 50- to 100-ft-thick areas for the alluvial aquifer. Saturated thickness of the alluvial aquifer was calculated for minimum, average, and maximum depths to water to yield estimates for the seasonal variation in aquifer storage. To generate the saturated volume of the alluvial aquifer, the depths to water were subtracted from average aquifer thicknesses and the differences were multiplied by aquifer area. This approach yields a maximum saturated volume of the alluvial aquifer equal to about 3.33×10^{10} ft³, an average saturated volume of 3.17×10^{10} ft³, and a minimum saturated volume of 3.11×10^{10} ft³. These values result in a seasonal change in saturated volume of the alluvial aquifer of about 7 percent during the 2 years of available data.

Alluvial aquifer testing in the Fraser River Basin conducted by the USGS in 1960 (Wilson, 1965) indicated a coefficient of transmissivity of 12,000 gpd/ft (gallons per day per foot) or a hydraulic conductivity of 114 ft/d (feet per day), which is in the range of well-sorted sands or glacial outwash (Fetter, 1994). Common specific yields (effective porosity) for aquifers of this type range from 0.19 to 0.27 (Fetter, 1994). Assuming a specific yield of 0.2, the amount of available water in the alluvial aquifer at average saturated volume is estimated to be about 150,000 acre-ft. Seasonal fluctuations in water level indicate that recharge occurs fairly rapidly and that water discharged from the alluvial aquifer is replenished during spring snowmelt. Determination of sustainable yields from the alluvial aquifer would require more information regarding the amount of recharge, regional flow, amount of discharge, and the locations and pumping rates of proposed water-supply wells.

The Troublesome Formation aquifer in the Fraser River watershed encompasses an area of about 52 mi² upstream from Tabernash (fig. 3). Aquifer testing of the Troublesome Formation (Resource Engineering, Incorporated, 1999 and 2000) indi-

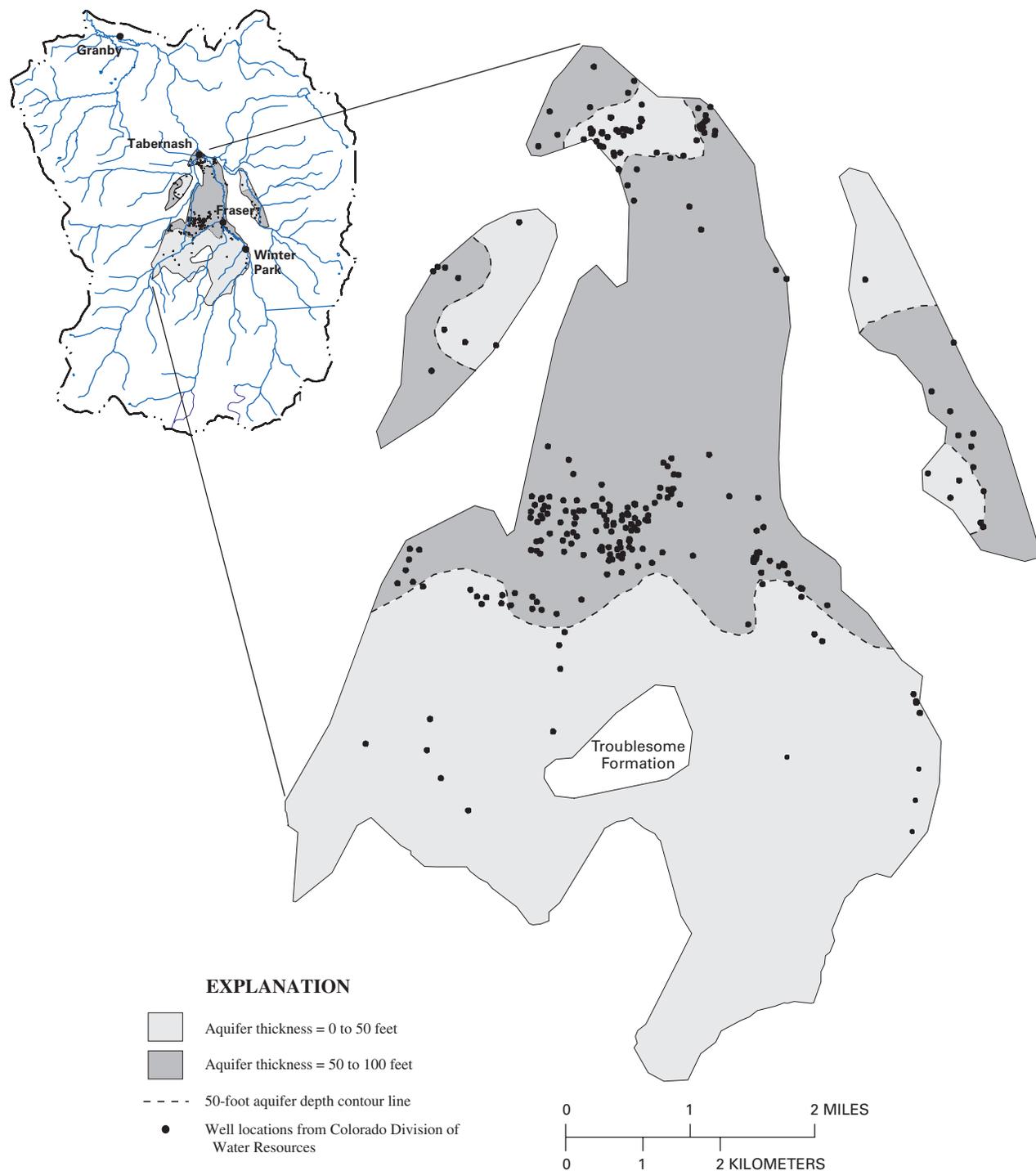


Figure 14. Extent and depth of the alluvial aquifer in the upper Fraser River watershed.

cates that the formation acts as a confined aquifer with little or no hydrologic communication with the alluvial aquifer. Lithologic logs of wells installed in the area were obtained from the Colorado Division of Water Resources and were tabulated to infer physical properties of the Troublesome Formation aquifer. Lithologic logs were examined for 162 wells drilled from 80 to 600 ft below land surface, which were either completed in or drilled through the Troublesome Formation. Well depth, over-

burden thickness, total thickness of water-bearing units, and total thickness of nonwater-bearing units in the Troublesome Formation aquifer were tabulated from the logs. Wells were grouped by township-range-section location, and results were averaged for each section that overlies the Troublesome Formation. A maximum of 16 well logs was used to characterize the Troublesome Formation aquifer in each section. Some sections had no wells completed in the Troublesome Formation. Further

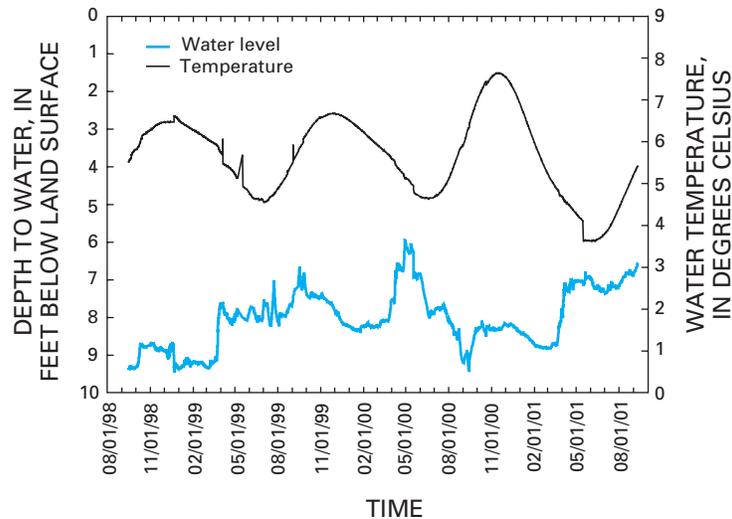


Figure 15. Ground-water level and temperature in the alluvial aquifer (site 9) in the upper Fraser River watershed, 1998–2001.

refinement of the well-log selection in sections with a large number of available well logs included preference to wells of at least 200 ft in depth and wells that were drilled through the Troublesome Formation. Tabulated measurements then were summarized to give average percentages of water-bearing units compared to nonwater-bearing units per section. Total average percentages of water-bearing compared to nonwater-bearing units then were calculated from the section averages. This method was used to give an equally weighted spatial representation of the Troublesome Formation aquifer properties. To estimate the available water in the Troublesome Formation, a total Troublesome Formation aquifer thickness of 500 ft was assumed. Though the aquifer is thicker than 500 ft in some parts of the area, 500 ft was selected as a reasonable maximum depth for a water-production well. Wells drilled in the Troublesome Formation where aquifer testing was done were completed to depths less than 300 ft, except for one well completed to 535 ft, and had sufficient yield for community-supply wells (Resource Engineering, Incorporated, 1999 and 2000).

Results of tabulation of well data indicate that the average percentage of water-bearing units in the upper 500 ft of the Troublesome Formation aquifer is 11 percent, with average values for each section ranging from 2 to 35 percent. For a water-storage calculation of the upper 500 ft of the Troublesome Formation, this equates to an average of 55 ft of saturated thickness. Because the Troublesome Formation is a confined aquifer, water does not drain from the aquifer as in unconfined aquifers but is released due to compression of pore spaces and the elasticity of the aquifer itself. The total volume of water stored in the Troublesome Formation aquifer is the sum of the water released from elastic compression of the aquifer (water under pressure) and the amount that would be released from the pore spaces of the saturated thickness of the aquifer under unconfined conditions as the potentiometric surface drops below the upper limit of the confined aquifer (that is, aquifer

dewatering). Because the Troublesome Formation is a series of siltstone and interbedded sandstone and conglomerate and little reliable information is available on the depth to the water-bearing units as well as the aquifer's response to dewatering, the amount of water released from elastic compression was not calculated. An average specific yield for unconfined sedimentary deposits similar to the water-producing zones of the Troublesome Formation give an approximate value of 0.2 (Fetter, 1994). The volume of the saturated thickness of the Troublesome Formation is calculated as the areal extent of the aquifer times the saturated thickness. This calculation yields a saturated aquifer volume of $7.98 \times 10^{10} \text{ ft}^3$. This volume multiplied by the specific yield of 0.2 results in an amount of stored water equal to approximately 370,000 acre-ft, which would be available if the water table dropped below the top of the aquifer and the aquifer became unconfined. The total amount of available water in the Troublesome Formation might be greater than 370,000 acre-ft because the amount of water under pressure has not been accounted for in the estimate. However, if the specific yield is only 0.1 rather than 0.2, then the amount of available ground water would be one-half of the calculated estimate.

Results from five aquifer tests completed in the Troublesome Formation (Resource Engineering, Incorporated, 1999 and 2000) indicate that the average value for coefficient of transmissivity for the Troublesome Formation is approximately 5,000 gpd/ft. When combined with the information on the average saturated thickness of the Troublesome Formation, hydrologic conductivity of the water-bearing units is estimated to be about of 12 ft/d, which is in the range of aquifers consisting of silty to fine sands (Fetter, 1994). Because the testing of the Troublesome Formation aquifer was completed without collecting drawdown data from nearby reference wells, the storage coefficient could not be determined.

In order to better estimate maximum potential withdrawals of water from the Troublesome Formation (that would not cause

dewatering, or damage to the aquifer), more information would be needed on recharge and discharge rates along with a more precise understanding of aquifer properties. The estimate of the amount of water currently available within the Troublesome Formation discussed in this section is not representative of the true full potential yield of the aquifer. Factors that will affect the yield of the aquifer include recharge rate, regional ground-water flow, discharge rate, specific storage of the aquifer, and location and pumping rates of proposed water-supply wells. The use of ground-water-flow modeling combined with more comprehensive aquifer testing would be necessary to refine estimates of future water availability.

Summary

Increasing urban development, as well as the seasonal influx of tourists, is placing more demands on the water resources in the Fraser River watershed. The U.S. Geological Survey, in cooperation with the Grand County Board of County Commissioners, conducted an assessment of ground- and surface-water quality and ground-water quantity in the Fraser River watershed, Grand County, Colorado. Eleven wells were sampled semiannually from August 1998 through September 2001. The data were related to aquifer type (alluvial, Troublesome Formation), land use (urban, nonurban), and presence or absence of individual septic disposal systems. One surface-water site, Fraser River below Crooked Creek at Tabernash, Colorado, was sampled bimonthly. This site represents the cumulative effects of natural and human factors that affect surface-water quality in the Fraser River watershed upstream from the town of Tabernash. Ground-water-quantity estimates were made for the surficial alluvial aquifer and the Troublesome Formation aquifer.

The ground water primarily was a calcium-bicarbonate type water. Except for elevated radon-222 activities, no widespread ground-water-quality problems in the watershed were indicated. The ground-water data were compared to U.S. Environmental Protection Agency or State of Colorado water-quality standards. In general, ground water in the Fraser River watershed is suitable as a source of drinking water and for domestic, municipal, industrial, and irrigation purposes. Concentrations of dissolved solids, chloride, fluoride, sulfate, nitrite, and nitrate in the ground-water samples were substantially less than their respective drinking-water or water-quality standards. Properties and constituents from samples from at least one well that did not meet the standards were turbidity, iron, manganese, methylene blue active substances, and radon-222. The constituent of most concern is radon-222. All radon-222 concentrations for every well sample exceeded the U.S. Environmental Protection Agency proposed drinking-water standard of 300 pCi/L, which is currently (2003) under review.

Results of the two-tailed Wilcoxon rank-sum tests indicated that there were statistically significant differences

(p -value ≤ 0.05) in values or concentrations of some field properties and water-quality constituents between aquifer type (alluvium, Troublesome Formation), land use (urban, nonurban), and areas with or without individual septic disposal systems. Chloride, magnesium, and sulfate concentrations were significantly higher in the alluvial aquifer, urban areas, and areas with the septic systems. Orthophosphate concentrations were significantly higher in the Troublesome Formation aquifer and in areas without individual septic disposal systems. Dissolved organic carbon concentrations were significantly higher in the alluvial aquifer and areas without individual septic disposal systems than in the Troublesome Formation aquifer and areas with individual septic disposal systems, although these concentration differences likely had no environmental significance.

An examination of changes in ground-water-quality data over time revealed that changes were apparent only for one of nine wells examined. For this well, specific conductance appeared to increase over time, probably due to increasing concentrations of calcium, magnesium, chloride, and sulfate during parts of the sampling period.

Surface water collected at the Fraser River below Crooked Creek at Tabernash from August 1998 through September 2001 also was a calcium-bicarbonate type water and had low concentrations of dissolved solids. Water quality at this site generally was good and indicated the suitability of the water for drinking, residential, industrial, and irrigation purposes. All pH values and concentrations of dissolved oxygen, chloride, sulfate, iron, manganese, un-ionized ammonia, nitrite, nitrate, and fecal coliform bacteria met State of Colorado instream water-quality standards.

Concentrations of most constituents in the Fraser River varied seasonally. Maximum values of specific conductance and maximum concentrations of chloride, sulfate, ammonia, nitrate, and all phosphorus species typically occurred during winter or early spring when discharge was minimal and when local wastewater-treatment facilities were near maximum discharge. Minimum values or concentrations of all constituents except sulfate generally occurred during snowmelt runoff, indicating the dilution of the surface water with snowmelt. Minimum sulfate concentrations were detected during midsummer after snowmelt runoff. Ammonia and nitrate concentrations also were at a minimum during summer and fall, with low nitrate concentrations probably occurring because of consumption by instream biota. Maximum concentrations of suspended sediment occurred during early spring or during snowmelt runoff, and maximum concentrations of dissolved organic carbon occurred during snowmelt runoff. Concentrations of fecal coliform bacteria peaked during summer but remained below the State of Colorado instream standard for the Fraser River.

Estimates of ground-water quantity in the upper Fraser River watershed were made for the surficial alluvial aquifer and the Troublesome Formation aquifer, the primary sources of ground water for domestic and municipal use in the valley. Calculations of the saturated volume of the alluvial aquifer were made for minimum, average, and maximum potentiometric sur-

face conditions and show a seasonal variance in saturated volume of about 7 percent. A ground-water reserve estimate was made for average potentiometric surface conditions and is a function of the volume of saturated aquifer and the specific yield of aquifer material. This calculation yields an average of 150,000 acre-ft of available stored water in the alluvial aquifer. Calculations of water available in the upper 500 ft of the Troublesome Formation were made by assuming an average thickness of water-bearing units equal to 11 percent (55 feet) and a specific yield of 0.2, which is typical of an aquifer similar to the water-bearing units of the Troublesome Formation. These numbers yield an estimate of available ground water (stored water) of about 370,000 acre-ft within the Troublesome Formation aquifer in the upper portion of the Fraser River watershed. This reserve represents the amount of available water if the aquifer became unconfined. Information is not available to estimate the fraction of this water reserve that can be withdrawn without dewatering, or damaging, the aquifer.

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Appendixes

Appendix I
Selected ground-water-quality data for wells in
the Fraser River watershed, 1998–2001

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Water temperature (°C) (00010)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (standard units) (00400)	Turbidity (NTU) (00076)	Alkalinity (mg/L as CaCO ₃) (39086)	Bromide (mg/L) (71870)	Calcium (mg/L) (00915)	Chloride (mg/L) (00940)	Fluoride (mg/L) (00940)	Iron (µg/L) (01046)
Site 1 (395623105481000)												
05/16/00	0900	5.1	88	7.0	6.4	4.0	28	<0.01	7.12	4.5	0.2	<10
09/11/00	1330	9.8	151	1.2	6.1	6.2	31	0.04	12.1	19.3	0.2	E 8
05/14/01	1500	5.2	117	10.1	6.3	6.2	35	<0.01	9.52	7.2	0.2	<10
09/11/01	1030	9.3	106	3.0	6.3	7.7	27	<0.01	8.00	5.2	0.3	E 5
Site 2 (395658105485400)												
08/21/98	0830	6.9	162	0.8	6.5	0.1	79	0.01	21.8	1.7	0.2	<10
05/04/99	1230	6.0	164	0.8	6.8	0.3	70	0.01	20.8	2.0	0.1	<10
09/01/99	1415	7.7	171	2.1	6.8	0.3	78	<0.01	22.7	5.1	0.1	<10
05/18/00	1100	6.5	164	1.1	7.1	0.2	88	0.02	22.4	2.1	0.2	<10
09/14/00	1030	7.5	171	1.0	7.2	0.1	79	<0.01	22.7	3.8	0.1	<10
05/16/01	1230	6.6	171	0.8	7.0	0.1	77	0.02	23.3	4.8	E 0.1	<10
09/12/01	1000	6.9	165	1.0	7.2	0.1	70	<0.01	21.3	5.4	0.2	<10
Site 3 (395642105500700)												
08/25/98	0900	6.5	120	7.6	7.2	0.6	60	<0.01	17.0	0.4	0.2	<10
05/06/99	1000	5.9	120	5.3	7.2	1.1	64	0.02	17.3	0.8	0.2	<10
09/01/99	0830	6.7	117	5.1	7.9	0.1	57	<0.01	16.2	1.0	0.1	<10
Site 4 (395657105495300)												
08/26/98	1230	6.0	137	4.2	6.7	0.2	52	0.02	18.0	5.4	<0.1	<10
05/06/99	1530	5.4	133	3.9	6.9	2.4	53	0.02	18.3	3.9	<0.1	20
09/01/99	1015	6.2	134	5.5	7.0	0.6	57	0.01	18.1	4.4	<0.1	<10
05/16/00	1200	5.3	136	5.1	6.8	0.3	55	0.02	18.8	4.8	<0.1	<10
09/14/00	1400	6.5	137	4.3	6.9	0.1	55	0.01	18.7	3.8	<0.1	E 8
05/17/01	1115	5.5	134	4.3	7.3	0.1	59	0.02	19.0	3.5	<0.2	<10
09/11/01	1600	6.1	134	4.3	6.9	0.1	53	0.01	17.8	3.8	E 0.1	<10
Site 5 (395750105515800)												
08/20/98	1200	14.3	256	6.5	7.8	0.3	140	0.02	43.4	0.5	0.3	<10
05/06/99	1230	11.8	259	4.4	7.9	0.2	127	0.01	43.7	0.9	0.3	<10
09/01/99	1600	12.7	256	5.7	8.0	0.3	126	<0.01	42.7	1.4	0.3	<10
05/16/00	1500	13.9	257	5.4	8.0	0.6	131	0.02	44.3	0.84	0.3	<10
09/12/00	1500	13.6	260	4.8	8.1	0.4	130	<0.01	43.5	0.88	0.3	<10
05/15/01	1530	13.5	258	5.0	8.1	1.0	129	0.03	45.9	0.88	0.3	<10
09/13/01	1500	15.0	260	4.4	8.1	1.3	131	<0.01	42.6	0.92	0.3	<10

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Water temperature (°C) (00010)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (standard units) (00400)	Turbidity (NTU) (00076)	Alkalinity (mg/L as CaCO ₃) (39086)	Bromide (mg/L) (71870)	Calcium (mg/L) (00915)	Chloride (mg/L) (00940)	Fluoride (mg/L) (00940)	Iron (µg/L) (01046)
Site 6 (395921105472300)												
08/27/98	1130	7.7	179	4.4	8.0	0.6	88	<0.01	30.0	0.3	1.4	<10
05/05/99	1330	7.1	225	2.6	8.0	0.3	118	<0.01	35.4	0.8	1.2	20
08/31/99	1300	8.1	227	3.3	7.9	0.3	105	<0.01	38.2	0.6	1.2	30
05/17/00	1430	6.5	237	3.4	8.5	0.2	118	<0.01	40.3	0.9	1.1	<10
09/13/00	1330	8.5	216	3.7	8.1	0.2	106	<0.01	34.7	0.9	1.3	<10
05/16/01	1515	6.6	223	3.3	8.4	0.2	108	<0.01	37.7	0.9	1.2	<10
09/12/01	1400	9.8	199	3.4	8.0	0.6	93	<0.01	29.7	0.6	1.4	<10
Site 7 (395942105502000)												
08/18/98	1530	7.0	317	0.1	7.2	0.5	152	0.02	48.7	4.9	0.2	240
05/05/99	0930	4.0	322	0.2	7.2	0.3	142	0.02	47.4	5.7	0.3	260
08/31/99	0830	8.1	321	0.1	7.3	0.4	142	<0.01	51.1	5.0	0.2	210
05/18/00	0830	5.5	331	0.2	7.6	0.6	164	0.02	49.7	5.3	0.2	310
09/13/00	1600	8.1	339	0.2	7.3	0.2	162	<0.01	53.1	6.0	0.2	190
05/17/01	0845	5.6	359	0.2	7.6	0.3	164	0.03	58.1	9.2	0.4	20
09/12/01	1630	7.7	362	0.3	7.6	0.5	161	0.02	54.6	9.4	0.3	100
Site 8 (395937105500500)												
08/24/98	1130	7.7	389	5.0	7.8	0.2	143	0.05	51.6	16.4	0.3	<10
05/04/99	1530	6.6	417	1.3	7.5	0.2	138	0.07	57.1	24.7	0.2	<10
08/31/99	1030	8.0	392	1.7	7.6	0.4	130	0.06	55.1	18.9	0.2	<10
05/18/00	1500	6.2	403	2.2	7.6	0.6	140	0.07	54.0	23.8	0.2	<10
09/13/00	0930	8.4	430	1.2	7.5	0.3	139	0.06	60.5	21.3	0.3	<10
05/16/01	0900	6.1	353	1.8	7.7	0.3	135	0.05	50.8	11.3	0.2	<10
09/13/01	0945	8.0	341	1.9	8.0	0.2	143	0.03	46.7	8.7	0.3	<10
Site 9 (395929105510300)												
08/19/98	1000	7.3	260	0.5	6.7	1.8	132	0.01	40.1	1.2	0.1	<10
05/03/99	1500	6.3	273	0.5	6.5	1.7	130	0.01	41.0	1.4	0.1	<10
08/30/99	1500	7.4	267	0.6	6.9	2.1	142	<0.01	43.3	1.4	0.1	<10
05/15/00	1500	6.3	256	0.4	6.9	1.0	127	<0.01	38.4	1.6	0.1	<10
09/12/00	0930	7.4	271	0.3	6.8	0.2	133	<0.01	41.7	1.8	0.2	<10
05/15/01	0930	4.8	250	0.7	6.9	0.8	126	<0.01	39.6	3.1	E 0.1	<10
09/10/01	1445	7.2	262	0.6	6.6	--	125	<0.01	39.0	2.8	E 0.1	<10

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Water temperature (°C) (00010)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (standard units) (00400)	Turbidity (NTU) (00076)	Alkalinity (mg/L as CaCO ₃) (39086)	Bromide (mg/L) (71870)	Calcium (mg/L) (00915)	Chloride (mg/L) (00940)	Fluoride (mg/L) (00940)	Iron (µg/L) (01046)
Site 10 (39592810553500)												
08/20/98	0930	8.0	292	4.7	7.5	0.7	220	0.02	50.5	1.1	0.1	<10
05/07/99	0900	7.0	294	5.3	7.6	0.4	146	0.02	49.5	1.6	<0.1	<10
09/02/99	0900	7.3	294	5.6	8.0	0.1	147	0.01	52.8	1.8	<0.1	<10
05/19/00	0830	7.0	294	6.5	8.0	0.1	149	0.03	51.0	1.5	<0.1	<10
09/14/00	0835	7.2	290	5.5	7.9	0.1	147	<0.01	51.0	1.5	0.1	<10
05/17/01	1430	7.3	291	4.9	7.8	0.1	143	0.02	52.1	1.8	E 0.1	<10
09/13/01	1230	7.9	291	4.5	7.9	0.1	146	<0.01	49.0	2.0	E 0.1	<10
Site 11 (395907105540100)												
08/18/98	0900	10.4	310	5.1	7.6	0.1	130	0.03	47.2	1.7	0.2	<10
05/04/99	0900	7.9	317	4.2	6.9	0.2	156	0.03	49.2	1.9	0.2	<10
08/31/99	1445	9.2	317	4.2	7.9	0.2	152	0.02	50.9	3.1	0.2	<10
05/17/00	1000	7.7	322	5.2	7.8	0.1	169	0.03	51.9	2.5	0.2	<10
09/12/00	1230	10.0	324	3.9	7.8	0.1	167	0.03	50.6	2.7	0.2	<10
05/15/01	1300	8.0	324	5.9	7.8	0.1	162	0.03	52.3	3.0	0.2	<10
09/11/01	1345	10.5	322	4.4	7.7	0.4	160	0.02	49.6	2.8	0.2	<10

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base.]

Date	Time	Magnesium (mg/L) (00925)	Manganese (µg/L) (01056)	Potassium (mg/L) (00935)	Silica (mg/L) (000955)	Sodium (mg/L) (000930)	Sulfate (mg/L) (000945)	Dissolved solids (mg/L) (70301)	Ammonia ¹ (mg/L) (00608)	Ammonia plus organic nitrogen (mg/L) (00623)	Nitrite (mg/L) (00613)	Nitrate plus nitrite (mg/L) (00631)
Site 1 (395623105481000)												
05/16/00	0900	1.74	<2.2	0.90	13.0	7.4	3.2	55	0.003	0.23	<0.001	1.09
09/11/00	1330	2.85	<2.2	1.42	14.1	11.3	7.4	89	<0.002	0.12	<0.001	0.288
05/14/01	1500	2.24	<3.0	1.02	12.0	9.3	6.0	76	0.003	0.22	<0.001	1.73
09/11/01	1030	1.83	<3.0	1.14	13.3	9.6	9.0	70	<0.002	0.19	0.001	1.11
Site 2 (395658105485400)												
08/21/98	0830	3.70	<4.0	1.96	31.9	5.2	3.2	119	<0.002	<0.10	<0.001	0.245
05/04/99	1230	3.73	<3.0	1.89	31.9	5.2	3.0	112	0.005	<0.10	<0.001	0.208
09/01/99	1415	3.94	<3.0	2.18	34.7	5.4	3.5	126	<0.002	E 0.09	0.001	0.294
05/18/00	1100	3.93	<2.2	1.72	33.6	5.1	--	--	<0.002	<0.10	<0.001	0.233
09/14/00	1030	3.93	<2.2	1.92	34.5	5.3	3.4	125	0.005	E 0.06	<0.001	0.292
05/16/01	1230	3.88	<3.0	1.92	34.4	5.3	4.0	125	0.006	<0.10	<0.001	0.249
09/12/01	1000	3.70	<3.0	1.80	35.1	5.4	4.2	120	<0.002	E 0.05	0.001	0.195
Site 3 (395642105500700)												
08/25/98	0900	2.05	<4.0	1.75	21.4	4.0	1.7	86	<0.002	<0.10	<0.001	0.210
05/06/99	1000	2.14	<3.0	1.47	22.1	3.9	1.4	89	0.006	<0.10	<0.001	0.177
09/01/99	0830	2.05	<3.0	1.68	23.3	3.8	2.0	86	<0.002	<0.10	<0.001	0.206
Site 4 (395657105495300)												
08/26/98	1230	2.51	<4.0	1.42	22.3	4.1	2.8	92	<0.002	<0.10	<0.001	1.03
05/06/99	1530	2.52	E 2.3	1.43	23.7	3.9	2.3	94	0.011	<0.10	0.001	0.872
09/01/99	1015	2.52	<3.0	1.54	23.6	4.0	2.6	96	<0.002	<0.10	<0.001	1.11
05/16/00	1200	2.64	<2.2	1.30	23.7	4.0	2.6	96	<0.002	<0.10	<0.001	1.20
09/14/00	1400	2.52	<2.2	1.44	23.8	4.0	2.5	95	0.004	<0.10	0.001	1.16
05/17/01	1115	2.47	<3.0	1.45	23.6	3.8	2.9	96	0.008	<0.10	<0.001	1.01
09/11/01	1600	2.44	<3.0	1.39	23.2	3.9	2.8	92	<0.002	<0.10	0.001	1.10
Site 5 (395750105515800)												
08/20/98	1200	3.36	<4.0	1.48	22.8	5.4	3.0	165	<0.002	<0.10	<0.001	0.172
05/06/99	1230	3.50	<3.0	1.52	23.2	5.2	2.7	158	0.009	<0.10	<0.001	0.145
09/01/99	1600	3.40	<3.0	1.56	23.5	5.3	2.8	158	<0.002	0.12	0.001	0.200
05/16/00	1500	3.55	2.8	1.36	23.4	5.2	2.7	161	<0.002	<0.10	<0.001	0.187
09/12/00	1500	3.43	E 2.0	1.43	23.1	5.2	2.7	160	<0.002	<0.10	<0.001	0.186
05/15/01	1530	3.53	E 2.5	1.29	23.1	5.1	3.2	162	<0.002	<0.10	<0.001	0.169
09/13/01	1500	3.45	3.9	1.42	22.7	4.9	3.1	159	<0.002	<0.10	<0.001	0.143

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base.]

Date	Time	Magnesium (mg/L) (00925)	Manganese (µg/L) (01056)	Potassium (mg/L) (00935)	Silica (mg/L) (000955)	Sodium (mg/L) (000930)	Sulfate (mg/L) (000945)	Dissolved solids (mg/L) (70301)	Ammonia ¹ (mg/L) (00608)	Ammonia plus organic nitrogen (mg/L) (00623)	Nitrite (mg/L) (00613)	Nitrate plus nitrite (mg/L) (00631)
Site 6 (395921105472300)												
08/27/98	1130	2.18	<4.0	1.27	21.6	7.0	2.0	119	0.002	<0.10	<0.001	0.019
05/05/99	1330	2.58	<3.0	1.25	20.5	6.3	1.9	141	0.009	<0.10	<0.001	0.034
08/31/99	1300	2.75	<3.0	1.44	21.4	6.4	2.4	138	0.040	<0.10	<0.001	0.063
05/17/00	1430	2.84	<2.2	1.16	20.7	6.5	--	--	<0.002	<0.10	<0.001	0.109
09/13/00	1330	2.44	<2.2	1.19	20.3	6.4	2.5	134	<0.002	E 0.06	<0.001	0.054
05/16/01	1515	2.59	<3.0	1.15	20.2	6.4	2.9	138	0.007	<0.10	<0.001	0.062
09/12/01	1400	2.15	<3.0	1.16	21.6	8.2	2.6	123	<0.002	<0.10	<0.001	0.020
Site 7 (395942105502000)												
08/18/98	1530	4.73	436	3.86	39.3	9.0	8.1	211	0.010	0.13	0.001	<0.005
05/05/99	0930	4.73	456	3.79	39.4	9.1	7.3	204	0.014	E 0.10	<0.001	<0.005
08/31/99	0830	4.97	457	4.10	42.0	9.0	7.9	210	<0.002	E 0.09	<0.001	<0.005
05/18/00	0830	4.92	457	4.07	39.0	8.7	7.1	218	<0.002	0.10	<0.001	<0.005
09/13/00	1600	5.04	461	3.97	41.2	9.5	7.7	225	0.003	E 0.10	<0.001	<0.005
05/17/01	0845	5.45	510	3.88	41.2	9.4	10.5	237	0.024	E 0.08	<0.001	<0.005
09/12/01	1630	5.21	375	3.96	40.7	9.2	11.9	232	0.006	E 0.09	0.001	0.008
Site 8 (395937105500500)												
08/24/98	1130	4.65	9.4	4.37	38.5	16.3	10.9	249	<0.002	<0.10	<0.001	4.68
05/04/99	1530	5.20	8.4	4.66	37.5	16.2	11.4	258	0.024	0.16	0.001	4.02
08/31/99	1030	4.98	16.5	4.81	41.4	16.9	11.9	252	<0.002	E 0.06	<0.001	4.38
05/18/00	1500	5.01	14.9	4.52	37.3	15.5	10.7	253	<0.002	E 0.06	<0.001	3.95
09/13/00	0930	5.34	14.9	4.50	40.1	16.8	16.0	269	<0.002	E 0.10	0.004	4.72
05/16/01	0900	4.41	<3.0	3.54	38.2	14.8	12.1	230	0.005	0.12	<0.001	3.10
09/13/01	0945	4.17	E 2.3	3.50	40.2	15.4	10.2	227	0.002	<0.10	0.001	2.62
Site 9 (395929105510300)												
08/19/98	1000	4.58	167	2.04	32.1	7.3	4.5	173	<0.002	<0.10	<0.001	0.125
05/03/99	1500	4.80	130	2.02	32.3	7.4	3.2	171	0.011	E 0.08	--	0.059
08/30/99	1500	4.96	73.8	2.31	35.2	7.5	4.6	185	<0.002	0.11	<0.001	0.082
05/15/00	1500	4.48	28.4	2.05	32.9	6.7	4.6	167	0.002	0.11	<0.001	0.088
09/12/00	0930	4.73	88.2	2.16	35.0	7.3	3.4	176	<0.002	E 0.08	<0.001	0.084
05/15/01	0930	4.39	18.2	1.79	31.5	6.7	3.3	166	0.004	E 0.10	<0.001	0.008
09/10/01	1445	4.47	39.6	2.02	34.2	7.2	3.2	168	<0.002	0.12	0.001	0.110

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Magnesium (mg/L) (00925)	Manganese (µg/L) (01056)	Potassium (mg/L) (00935)	Silica (mg/L) (000955)	Sodium (mg/L) (000930)	Sulfate (mg/L) (000945)	Dissolved solids (mg/L) (70301)	Ammonia ¹ (mg/L) (00608)	Ammonia plus organic nitrogen (mg/L) (00623)	Nitrite (mg/L) (00613)	Nitrate plus nitrite (mg/L) (00631)
Site 10 (395928105533500)												
08/20/98	0930	1.88	<4.0	5.23	38.0	5.7	2.6	238	<0.002	<0.10	<0.001	0.267
05/07/99	0900	1.92	<3.0	4.87	38.4	5.4	2.3	193	0.012	<0.10	<0.001	0.236
09/02/99	0900	1.99	<3.0	5.61	40.3	5.6	2.3	198	<0.005	E 0.08	<0.001	0.292
05/19/00	0830	1.96	<2.2	4.40	38.7	5.1	--	--	<0.002	<0.10	<0.001	0.252
09/14/00	0835	1.90	<2.2	5.07	39.0	5.5	2.4	196	<0.002	<0.10	<0.001	0.277
05/17/01	1430	1.91	<3.0	5.11	39.0	5.3	2.6	195	0.018	<0.10	<0.001	0.221
09/13/01	1230	1.86	<3.0	4.81	38.8	5.6	2.5	192	0.009	<0.10	<0.001	0.227
Site 11 (395907105540100)												
08/18/98	0900	1.91	<4.0	6.30	43.5	13.6	1.7	125	0.003	<0.10	<0.001	0.214
05/04/99	0900	1.97	<3.0	6.03	44.1	13.4	1.3	205	0.009	<0.10	0.001	0.206
08/31/99	1445	2.02	<3.0	6.65	45.5	13.2	1.7	215	0.004	<0.10	0.001	0.225
05/17/00	1000	2.04	<2.2	6.00	43.9	12.3	1.6	223	0.003	<0.10	<0.001	0.233
09/12/00	1230	1.97	<2.2	6.15	43.4	12.2	1.7	220	<0.002	<0.10	<0.001	0.235
05/15/01	1300	1.99	<3.0	5.77	43.4	12.1	2.0	219	0.011	E 0.06	<0.001	0.202
09/11/01	1345	1.97	<3.0	5.89	43.7	12.5	1.9	215	0.008	<0.10	<0.001	0.183

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Phosphorus (mg/L) (00666)	Ortho- phosphate mg/L (00671)	Dissolved organic carbon (mg/L) (00681)	Coliform, bacteria, total (col/100 mL) (30501)	<i>E. coli</i> (col/100 mL) (50278)	Methylene blue active substances (mg/L) (38260)	Radon-222, total (pCi/L) (82303)
Site 1 (395623105481000)								
05/16/00	0900	0.007	0.007	4.0	40	<1	<0.02	--
09/11/00	1330	0.007	0.007	3.0	<1	--	0.02	--
05/14/01	1500	0.007	E 0.005	3.3	E 140	<1	0.02	--
09/11/01	1030	0.009	0.007	3.6	<1	--	<0.02	--
Site 2 (395658105485400)								
08/21/98	0830	0.123	0.130	0.6	<1	--	<0.02	1,560
05/04/99	1230	0.124	0.131	0.5	<1	--	<0.02	1,590
09/01/99	1415	0.131	0.136	0.8	<1	--	<0.02	1,390
05/18/00	1100	0.128	0.121	0.67	<1	--	<0.02	--
09/14/00	1030	0.135	0.125	0.78	<1	--	<0.02	--
05/16/01	1230	0.131	0.126	0.68	<1	--	<0.02	--
09/12/01	1000	0.136	0.129	0.69	<1	--	<0.02	--
Site 3 (395642105500700)								
08/25/98	0900	0.025	0.025	0.3	1	<1	<0.02	1,670
05/06/99	1000	0.026	0.026	0.2	<1	--	<0.02	1,790
09/01/99	0830	0.026	0.030	0.3	<1	--	<0.02	1,980
Site 4 (395657105495300)								
08/26/98	1230	0.015	0.015	0.5	<1	--	<0.02	6,380
05/06/99	1530	0.017	0.015	0.3	<1	--	<0.02	6,050
09/01/99	1015	0.014	0.016	0.4	<1	--	<0.02	6,170
05/16/00	1200	0.017	0.016	0.46	<1	--	<0.02	--
09/14/00	1400	0.017	0.016	0.49	<1	--	<0.02	--
05/17/01	1115	0.017	0.017	0.35	<1	--	<0.02	--
09/11/01	1600	0.016	0.013	0.46	2	<1	<0.02	--
Site 5 (395750105515800)								
08/20/98	1200	0.046	0.047	0.5	<1	--	<0.02	553
05/06/99	1230	0.055	0.051	0.5	<1	--	<0.02	511
09/01/99	1600	0.048	0.049	0.7	<1	--	<0.02	570
05/16/00	1500	0.045	0.047	0.60	<1	--	<0.02	--
09/12/00	1500	0.048	0.046	0.61	<1	--	<0.02	--
05/15/01	1530	0.045	0.041	0.53	<1	--	<0.02	--
09/13/01	1500	0.046	0.042	0.72	<1	--	<0.02	--

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Phosphorus (mg/L) (00666)	Ortho-phosphate mg/L (00671)	Dissolved organic carbon (mg/L) (00681)	Coliform, total bacteria, total (col/100 mL) (30501)	<i>E. coli</i> (col/100 mL) (50278)	Methylene blue active substances (mg/L) (38260)	Radon-222, total (pCi/L) (82303)
08/27/98	1130	0.060	0.061	1.9	<1	--	<0.02	365
05/05/99	1330	0.066	0.066	1.3	4	<1	0.05	556
08/31/99	1300	0.067	0.070	1.4	<1	--	<0.02	523
05/17/00	1430	0.066	0.064	1.4	<1	--	0.10	--
09/13/00	1330	0.069	0.066	1.9	1	<1	<0.02	--
05/16/01	1515	0.066	0.061	1.3	<1	--	0.02	--
09/12/01	1400	0.056	0.056	1.7	<1	--	<0.02	--
Site 6 (395921105472300)								
08/18/98	1530	0.022	0.018	1.8	<1	--	0.03	710
05/05/99	0930	0.016	0.017	1.9	<1	--	<0.02	764
08/31/99	0830	0.022	0.017	1.9	<1	--	<0.02	784
05/18/00	0830	0.014	0.024	1.9	<1	--	<0.02	--
09/13/00	1600	0.029	0.028	2.0	1	<1	0.02	--
05/17/01	0845	0.023	0.014	1.9	2	<1	0.04	--
09/12/01	1630	0.028	0.021	1.8	<1	--	<0.02	--
Site 8 (395937105500500)								
08/24/98	1130	0.044	0.048	1.1	<1	--	0.02	727
05/04/99	1530	0.059	0.061	1.1	<1	--	<0.02	801
08/31/99	1030	0.048	0.052	1.1	1	<1	<0.02	710
05/18/00	1500	0.058	0.056	1.4	<1	--	3.82	--
09/13/00	0930	0.052	0.049	1.3	<1	--	<0.02	--
05/16/01	0900	0.050	0.047	1.2	<1	--	<0.02	--
09/13/01	0945	0.051	0.046	0.98	<1	--	<0.02	--
Site 9 (395929105510300)								
08/19/98	1000	0.063	0.060	2.0	<1	--	<0.02	636
05/03/99	1500	0.064	0.060	2.0	<1	--	<0.02	669
08/30/99	1500	0.059	0.062	2.3	<1	--	<0.02	687
05/15/00	1500	0.052	0.052	2.3	<1	--	<0.02	--
09/12/00	0930	0.060	0.055	2.1	<1	--	<0.02	--
05/15/01	0930	0.054	0.050	1.9	<1	--	0.02	--
09/10/01	1445	0.056	0.050	2.2	<1	--	<0.02	--

Table 5. Selected ground-water-quality data for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, *E. coli* (*Escherichia coli*), methylene blue active substances, and radon-222. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; site number refers to table 1 and figure 1; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data. Number in parentheses below the water-quality property or constituent is the data parameter from the U.S. Geological Survey National Water Information System (NWIS) data base]

Date	Time	Phosphorus (mg/L) (00666)	Ortho- phosphate mg/L (00671)	Dissolved organic carbon (mg/L) (00681)	Coliform, bacteria, total (col/100 mL) (30501)	<i>E. coli</i> (col/100 mL) (50278)	Methylene blue active substances (mg/L) (38260)	Radon-222, total (pCi/L) (82303)
				Site 10 (395928105533500)				
08/20/98	0930	0.126	0.131	0.8	<1	--	<0.02	757
05/07/99	0900	0.131	0.130	0.8	<1	--	<0.02	752
09/02/99	0900	0.134	0.137	1.0	<1	--	<0.02	752
05/19/00	0830	0.132	0.126	0.91	<1	--	<0.02	--
09/14/00	0835	0.129	0.120	0.90	<1	--	<0.02	--
05/17/01	1430	0.124	0.121	0.76	<1	--	<0.02	--
09/13/01	1230	0.124	0.122	0.86	<1	--	--	--
				Site 11 (395907105540100)				
08/18/98	0900	0.032	0.033	0.4	<1	--	<0.02	1,020
05/04/99	0900	0.032	0.036	0.5	<1	--	<0.02	998
08/31/99	1445	0.033	0.037	0.7	<1	--	<0.02	1,090
05/17/00	1000	0.035	0.036	0.74	<1	--	<0.02	--
09/12/00	1230	0.038	0.034	1.2	<1	--	<0.02	--
05/15/01	1300	0.033	0.032	0.62	<1	--	0.03	--
09/11/01	1345	0.036	0.033	0.80	<1	--	<0.02	--

¹Un-ionized ammonia [NH₃] plus ammonium [NH₄⁺].

Appendix II
Quality-Control Methods and Analysis

Quality-Control Methods and Analysis

Quality-assurance and quality-control (hereinafter referred to as QC) samples were used to assess the variability and bias of water-quality data that may be introduced by sample collection, processing, storage, and laboratory analysis. Replicate and field-blank samples were collected and processed as QC samples by using the same equipment and procedures as environmental samples. Replicate samples for ground water were analyzed for major ions and trace elements, nutrients (nitrogen and phosphorus), dissolved organic carbon, total coliform bacteria, MBAS, and radon-222. Blank samples were analyzed for major ions, trace elements, nutrients, and dissolved organic carbon (ground-water samples only). Additional information on QC is given in Shelton (1994) and Koterba and others (1995). Ground water QC data will be discussed first, followed by surface water QC data.

Replicate samples were used to test for data variability, which is the degree of random error in independent measurements of the same quantity. Replicate samples were collected and processed in sequence with environmental samples at a site to yield samples of presumably identical composition. By comparing the analytical results of the replicate pair (environmental sample and QC sample), information is obtained on the precision of the measured concentration values and consistency in identifying the constituents of interest.

Replicate samples were first assessed with a unit called the lowest rounding unit, which is the magnitude of the least significant figure reported by the USGS NWQL. A nitrate concentration of 0.923 mg/L, for example, would be rounded to the nearest 0.001 mg/L, whereas a concentration of 4.73 mg/L would be rounded to the nearest 0.01 mg/L; a lowest rounding unit of 1 would represent 0.001 mg/L for the 0.923-mg/L sample and 0.01 for the 4.73-mg/L sample. For either sample of a replicate pair, concentrations below the laboratory reporting level (less than, or <, concentrations) were given a value of zero for replicate analysis. A replicate pair with estimated (E) concentrations was included in the replicate analysis when both the environmental and QC samples had an estimated value but were excluded when only one sample of the replicate pair had an estimated value.

When analysis of lowest rounding unit data identified a constituent with 50 percent or more rounding units above 2, the mean relative standard deviation was used to estimate variability and uncertainty in concentration for that constituent. For a given constituent, the relative standard deviation was determined for each replicate pair, and then the mean relative standard deviation was computed for the constituent to determine variability and uncertainty in concentration.

For major ions and trace elements, 204 replicate pairs for ground water were evaluated. Values of the lowest rounding unit difference ranged between 0 and 197 (tables 6–7, Appendix II). Most replicate pairs for bromide, chloride, fluoride, sodium, sulfate, and iron had a lowest rounding unit of 2 or less. These differences probably are well within instrument variation and do not seem to be related to a particular constituent concentration. Variability associated with sample collection, processing, storage, and laboratory analysis did not appreciably affect the results of environmental data for these constituents.

Most ground-water replicate pairs for calcium, magnesium, potassium, silica, and manganese had a lowest rounding unit difference of 2 or greater (tables 6–7, Appendix II). Variability and uncertainty in concentration values were not determined for calcium, magnesium, potassium, and silica because of the small environmental significance of the concentration differences for the respective replicate pairs. The maximum dissolved-solids concentration of 269 mg/L in the ground-water samples was below the USEPA SDWR of 500 mg/L (table 2). The maximum concentration difference between environmental and QC samples for calcium, magnesium, potassium, and silica (constituents of dissolved solids) was 3.0 mg/L for calcium and was insufficient to significantly affect calculated dissolved-solids concentrations. Variability in manganese concentrations, however, may affect the interpretation of environmental data because manganese concentrations in some samples exceeded the USEPA SDWR for manganese. Most differences in manganese concentrations in replicate pairs for sites 7, 8, and 9 were greater than 10 rounding units, whereas concentrations in replicate pairs for other sites varied insignificantly (tables 6–7, Appendix II). Variability in manganese concentrations for site 9 was 15.3 percent (± 31.8 percent) of the concentration value at the 95-percent confidence level (table 8, Appendix II). Variability in manganese concentrations for sites 7 and 8 was not determined because of few data (only one replicate pair per well).

For nutrients and dissolved organic carbon, 122 ground-water replicate pairs were evaluated. Lowest rounding unit differences ranged from 0 to 137 (tables 6–7, Appendix II). The latter value was an outlier, however, as the next highest difference was 19. Most replicate pairs for ammonia plus organic nitrogen, nitrite, orthophosphate, and dissolved organic carbon had lowest rounding unit differences of 2 or less. Interpretation of environmental data for these constituents was not affected by variability in reported concentrations. Lowest rounding unit differences greater than 2 were most common for ammonia, phosphorus, and nitrate. For ammonia and phosphorus, all differences in lowest rounding unit were 6 or less. Interpretation of environmental data for ammonia was affected by the variability in reported concentrations, as the variability was within the concentration range of the environmental data (table 8, Appendix II). Variability in phosphorus data did not affect the interpretation of environmental data for phosphorus. For nitrate, some differences in concentrations between the environmental and quality-control samples were large, ranging between 12 and 137 lowest rounding unit (tables 6–7, Appendix II). Excluding the replicate pair with the latter value, variability in nitrate concentrations was 1.79 percent (± 3.72 percent) of the concentration value at the 95-percent confidence level (table 8, Appendix II). However, because the maximum nitrate concentration of 4.72 mg/L in the ground-water samples was well below the USEPA MCL of 10 mg/L (table 2), variability in nitrate concentrations did not affect the interpretation of environmental data for nitrate.

All environmental and QC samples for the six ground-water replicate pairs of total coliform bacteria had concentrations less than the reporting level of 1 col/100 mL (tables 6–7, Appendix II); therefore, variability in the concentration of total coliform bacteria could not be determined. Variability in the concentration of MBAS also could not be determined because most (15 of 18) of the replicate pairs had all concentrations below the reporting level (tables 6–7, Appendix II). Differences in radon-222 concentrations in the environmental and QC samples ranged between 7 and 78 lowest rounding unit (tables 6–7, Appendix II), which did affect the interpretation of environmental data

for one sample. Variability in radon-222 concentrations was 8.3 percent (± 17.3 percent) of the concentration value at the 95-percent confidence level (table 8, Appendix II).

Eleven constituents had one or both samples of a replicate pair reported as “less than” concentrations, concentrations undetected at the reporting level (table 7, Appendix II). Of these 11, only bromide, ammonia, nitrite, and MBAS had at least one replicate pair with a “less than” concentration for one sample and a concentration greater than the reporting level for the other sample, indicating some inconsistency in detecting bromide, ammonia, nitrite, and MBAS in the ground-water samples. The most significant of these was for ammonia. One-half (four of eight) of the ammonia replicate pairs with a “less than” concentration also had a detected concentration (table 7, Appendix II). Most concentrations of bromide, ammonia, nitrite, and MBAS in the ground-water samples were low, near the respective reporting levels.

Field-blank samples were used to test for bias, defined as the systematic error inherent in sampling and analytical methods. Blank samples were collected using inorganic- and organic-free water that contained no detectable concentrations of the constituents of interest. The blank water was processed through the sampling equipment, handled, and analyzed in the same manner as the environmental samples. The ground- and surface-water field blanks were analyzed for major ions, nutrients, trace elements, and dissolved organic carbon, with the last two only for ground water. Because constituents in this report were analyzed at low concentrations in the laboratory, field blanks were useful in determining possible contamination of a sample from collection, processing, cleaning, storage, and laboratory analysis procedures.

Seventeen field-blank samples for ground water were collected for major-ion and trace-element analysis (table 9, Appendix II). Reporting levels for some constituents changed during the 4-year sampling period. In the field blanks, concentrations of chloride, fluoride, potassium, silica, sodium, sulfate, and manganese were below the laboratory reporting levels. Bromide and iron were detected at the laboratory reporting levels in one blank sample each. Calcium was detected in three blank samples and magnesium was detected in one blank sample above the laboratory reporting levels. Estimated concentrations were reported for three calcium, two magnesium, and five sodium blank samples and one blank sample each of sulfate and manganese. The one magnesium detection with a concentration greater than two times the lowest rounding unit of the reporting level had no appreciable effect on the reliability of environmental data because of substantially higher magnesium concentrations in environmental samples. Therefore, interpretation of major-ion and trace-element environmental data was not affected by detections of major ions and trace elements in the blank samples.

Nineteen field-blank samples for ground water were collected for nutrient and dissolved organic carbon analysis (table 9, Appendix II). All constituents except phosphorus were detected in some field-blank samples. Estimated concentrations of ammonia plus organic nitrogen and dissolved organic carbon were detected in two and seven blank samples, respectively. Nitrite and nitrate were detected at or within one lowest rounding unit of the respective reporting levels. Interpretation of the environmental data for ammonia plus organic nitrogen, nitrite, and nitrate in ground water was not affected by detections of these nutrients in blank samples.

Ammonia was detected in seven blank samples, primarily at or within three times the lowest rounding unit (table 9, Appendix II). Blank samples commonly are contaminated with ammonia when exposed to the atmosphere, especially when analyzed at low concentrations—as was done in this study. As discussed above, an inconsistency in the detection of ammonia in ground-water samples was indicated by four of eight replicate pairs with a “less than” concentration for one sample and a detected concentration for the other sample. These two factors, combined with blank samples having a similar concentration range of ammonia as that of the environmental samples, indicate that the exact concentration of ammonia in the ground-water samples collected during this study is not known with certainty. It is known, however, that only small amounts of ammonia were present in the samples, and all concentrations were less than or equal to about 0.04 mg/L. The blank sample with an ammonia detection of 21 times the lowest rounding unit did not affect the interpretation of environmental data because the sample collected prior to the blank did not indicate the presence of ammonia, and subsequent samples were not collected during that sampling phase.

Almost all detections of orthophosphate and dissolved organic carbon in blank samples were equal to or within two times the lowest rounding unit of the laboratory reporting levels (table 9, Appendix II). Interpretation of orthophosphate and dissolved organic carbon data were not affected by detections in blank samples because concentrations in the blank samples were at least one order magnitude smaller than concentrations in environmental samples.

Surface-water sample collection at Fraser River below Crooked Creek at Tabernash was done as part of a larger USGS surface-water sampling network in the Fraser River watershed. During the August 1998–September 2001 time period, no replicate samples were collected on the Fraser River, and no replicate-pair analysis could be performed. Field-blank samples for analysis of major ions and nutrients were collected on the Fraser River at four of the network sites, not including the Fraser River site discussed in this report.

For major ions, the blank results indicate that the environmental data for major ions were free of bias during sampling and laboratory analysis. Analysis of the three blank samples for dissolved magnesium and sodium indicate no detections. The two dissolved-silica blank samples also had no detections. Dissolved calcium was detected in one blank sample at a value five times the laboratory minimum reporting level. Interpretation of dissolved-calcium data for surface water was not affected by this blank detection because all values for calcium in the environmental surface-water samples were many orders of magnitude higher than the concentration detected in the field blank.

Analysis of the surface-water blank samples for nutrients indicate two detections of ammonia at the reporting level and one detection of orthophosphate at one rounding unit above the laboratory reporting level. These detected concentrations are within the expected instrument or method variance, and the interpretation of ammonia and orthophosphate concentrations in surface water was not affected by the detections in the blank samples.

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998–2001.

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. no., number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite; -, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero]

Site no. (fig. 1; table 1)	Date	Time	Bromide			Calcium			Chloride			Fluoride		
			Env. QC	Conc. (mg/L)	RU diff.									
1	09/11/00	1330	0.04	-0.01	1	12.1	-0.1	1	19.3	0.5	5	0.2	-0.1	1
	1400		0.05			12.2			18.8			0.3		
1	05/14/01	1500	<0.01	0.00	0	9.52	-0.03	3	7.2	-0.1	1	0.2	0.0	0
	1515		<0.01			9.55			7.3			0.2		
4	09/14/00	1400	0.01	0.00	0	18.7	-0.1	1	3.8	-0.1	1	<0.1	0.0	0
	1415		0.01			18.8			3.9			<0.1		
5	09/13/01	1500	<0.01	0.00	0	42.6	-0.8	8	0.9	0.0	0	0.3	0.0	0
	1530		<0.01			43.4			0.9			0.3		
6	08/27/98	1130	<0.01	0.00	0	30.0	-0.1	1	0.3	-0.1	1	1.4	0.0	0
	1200		<0.01			30.1			0.4			1.4		
7	05/05/99	0930	0.02	0.00	0	47.4	-3.0	30	5.7	-0.1	1	0.3	0.1	1
	1000		0.02			50.4			5.8			0.2		
8	09/13/00	0930	0.06	0.00	0	60.5	-0.2	2	21.3	0.1	1	0.3	0.1	1
	1000		0.06			60.7			21.2			0.2		
8	05/16/01	0900	0.05	0.00	0	50.8	-0.7	7	11.3	-0.3	3	0.2	0.0	0
	0930		0.05			51.5			11.6			0.2		
8	09/13/01	0945	0.03	0.00	0	46.7	1.4	14	8.7	0.2	2	0.3	0.0	0
	1000		0.03			45.3			8.5			0.3		
9	05/03/99	1500	0.01	-0.01	1	41.0	-1.7	17	1.4	-0.1	1	0.1	0.0	0
	1530		0.02			42.7			1.5			0.1		
9	08/30/99	1500	<0.01	0.00	0	43.3	0.3	3	1.4	0.0	0	0.1	0.0	0
	1530		<0.01			43.0			1.4			0.1		
9	05/15/00	1500	<0.01	-0.01	1	38.4	-1.7	17	1.6	0.0	0	0.1	0.0	0
	1530		0.01			40.1			1.6			0.1		
9	09/10/01	1445	<0.01	0.00	0	39.0	0.8	8	2.8	-0.1	1	0.1	0.0	0
	1515		<0.01			38.2			2.9			0.1		
10	05/07/99	0900	0.02	0.00	0	49.5	-2.4	24	1.6	0.0	0	<0.1	0.0	0
	0915		0.02			51.9			1.6			<0.1		
10	09/02/99	0900	0.01	-0.01	1	52.8	0.1	1	1.8	0.0	0	<0.1	0.0	0
	0915		0.02			52.7			1.8			<0.1		
10	05/19/00	0830	0.03	0.01	1	51.0	-0.9	9	1.5	0.0	0	<0.1	0.0	0
	0845		0.02			50.1			1.5			<0.1		
10	05/17/01	1430	0.02	-0.01	1	52.1	-0.1	1	1.8	0.0	0	0.1	0.0	0
	1500		0.03			52.2			1.8			0.1		
11	08/31/99	1445	0.02	0.00	0	50.9	-0.4	4	3.1	1.0	10	0.2	0.0	0
	1500		0.02			51.3			2.1			0.2		
11	05/17/00	1000	0.03	0.00	0	51.9	-0.1	1	2.5	0.0	0	0.2	0.0	0
	1015		0.03			52.0			2.5			0.2		

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. no., number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite, --, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero]

Site no. (fig. 1; table 1)	Date	Time	Magnesium			Potassium			Silica			Sodium		
			Env. QC	Conc. diff.	RU diff.									
			(mg/L)			(mg/L)			(mg/L)			(mg/L)		
1	09/11/00	1330	2.85	-0.01	1	1.42	-0.01	1	14.1	0.0	0	11.3	0.0	0
		1400	2.86			1.43			14.1			11.3		
1	05/14/01	1500	2.24	0.01	1	1.02	0.02	2	12.0	0.1	1	9.3	-0.1	1
		1515	2.23			1.00			11.9			9.4		
4	09/14/00	1400	2.52	0.01	1	1.44	0.02	2	23.8	-0.3	3	4.0	0.0	0
		1415	2.51			1.42			24.1			4.0		
5	09/13/01	1500	3.45	-0.06	6	1.42	0.10	10	22.7	-0.3	3	4.9	-0.2	2
		1530	3.51			1.32			23.0			5.1		
6	08/27/98	1130	2.18	-0.01	1	1.27	-0.02	2	21.6	0.0	0	7.0	-0.1	1
		1200	2.19			1.29			21.6			7.1		
7	05/05/99	0930	4.73	-0.21	21	3.79	0.05	5	39.4	-1.0	10	9.1	0.1	1
		1000	4.94			3.72			40.4			9.0		
8	09/13/00	0930	5.34	-0.08	8	4.50	-0.01	1	40.1	-0.5	5	16.8	0.3	3
		1000	5.42			4.51			40.6			16.5		
8	05/16/01	0900	4.41	-0.04	4	3.54	-0.34	34	38.2	0.1	1	14.8	0.0	0
		0930	4.45			3.88			38.1			14.8		
8	09/13/01	0945	4.17	0.11	11	3.50	-0.16	16	40.2	0.4	4	15.4	0.6	6
		1000	4.06			3.66			39.8			14.8		
9	05/03/99	1500	4.80	-0.13	13	2.02	-0.10	10	32.3	-0.3	3	7.4	0.1	1
		1530	4.93			2.12			32.6			7.3		
9	08/30/99	1500	4.96	0.02	2	2.31	-0.01	1	35.2	0.3	3	7.5	0.0	0
		1530	4.94			2.32			34.9			7.5		
9	05/15/00	1500	4.48	-0.15	15	2.05	0.15	15	32.9	-0.7	7	6.7	-0.4	4
		1530	4.63			1.90			33.6			7.1		
9	09/10/01	1445	4.47	0.08	8	2.02	0.13	13	34.2	0.4	4	7.2	0.1	1
		1515	4.39			1.89			33.8			7.1		
10	05/07/99	0900	1.92	-0.05	5	4.87	-0.14	14	38.4	-0.9	9	5.4	0.0	0
		0915	1.97			5.01			39.3			5.4		
10	09/02/99	0900	1.99	0.00	0	5.61	0.13	13	40.3	0.0	0	5.6	0.0	0
		0915	1.99			5.48			40.3			5.6		
10	05/19/00	0830	1.96	0.03	3	4.40	0.00	0	38.7	0.6	6	5.1	-0.9	9
		0845	1.93			4.40			38.1			6.0		
10	05/17/01	1430	1.91	0.01	1	5.11	0.08	8	39.0	0.1	1	5.3	0.0	0
		1500	1.90			5.03			38.9			5.3		
11	08/31/99	1445	2.02	0.00	0	6.65	1.01	101	45.5	-0.3	3	13.2	-0.1	1
		1500	2.02			5.64			45.8			13.3		
11	05/17/00	1000	2.04	-0.02	2	6.00	0.32	32	43.9	-0.3	3	12.3	-0.1	1
		1015	2.06			5.68			44.2			12.4		

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998-2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. no. number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃]; plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite; --, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero]

Site no. (fig. 1; table 1)	Date	Time	Sulfate			Iron			Manganese		
			Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.
			(mg/L)			(mg/L)			(mg/L)		
1	09/11/00	1330	7.4	0.1	1	E 8	nc	nc	<2.2	0.0	0
		1400	7.3			<10			<2.2		
1	05/14/01	1500	6.0	0.0	0	<10	0	0	<3.2	0.0	0
		1515	6.0			<10			<3.2		
4	09/14/00	1400	2.5	-0.1	1	E 8	nc	nc	<2.2	nc	nc
		1415	2.6			E 10			E 1.2		
5	09/13/01	1500	3.1	-0.2	2	<10	0	0	3.9	-0.3	3
		1530	3.3			<10			4.2		
6	08/27/98	1130	2.0	-0.1	1	<10	0	0	<4	0	0
		1200	2.1			<10			<4		
7	05/05/99	0930	7.3	0.0	0	260	0	0	456	-14	14
		1000	7.3			260			470		
8	09/13/00	0930	16.0	0.1	1	<10	0	0	14.9	1.5	15
		1000	15.9			<10			13.4		
8	05/16/01	0900	12.1	-0.3	3	<10	0	0	<3.2	0.0	0
		0930	12.4			<10			<3.2		
8	09/13/01	0945	10.2	0.1	1	<10	0	0	E 2.3	nc	nc
		1000	10.1			<10			E 1.9		
9	05/03/99	1500	3.2	-0.1	1	<10	0	0	130	-13	13
		1530	3.3			<10			143		
9	08/30/99	1500	4.6	0.0	0	<10	0	0	73.8	-3.3	33
		1530	4.6			<10			77.1		
9	05/15/00	1500	4.6	0.0	0	<10	0	0	28.4	-11.2	112
		1530	4.6			<10			39.6		
9	09/10/01	1445	3.2	-0.1	1	<10	nc	nc	39.6	-19.7	197
		1515	3.3			E 8			59.3		
10	05/07/99	0900	2.3	0.0	0	<10	0	0	<3	0	0
		0915	2.3			<10			<3		
10	09/02/99	0900	2.3	-0.1	1	<10	0	0	<3	0	0
		0915	2.4			<10			<3		
10	05/19/00	0830	<0.3	0.0	0	<10	0	0	<2.2	0.0	0
		0845	<0.3			<10			<2.2		
10	05/17/01	1430	2.6	0.1	1	<10	0	0	<3.2	0.0	0
		1500	2.5			<10			<3.2		
11	08/31/99	1445	1.7	-0.2	2	<10	0	0	<3	0	0
		1500	1.9			<10			<3		
11	05/17/00	1000	1.6	0.0	0	<10	0	0	<2.2	0.0	0
		1015	1.6			<10			<2.2		

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998–2001.—Continued

All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222, no., number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite; --, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero)

Site no. (fig. 1; table 1)	Date	Time	Ammonia			Ammonia plus organic nitrogen			Nitrite			Nitrate		
			Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.
			(mg/L)			(mg/L)			(mg/L)			(mg/L)		
1	09/11/00	1330	<0.002	0.000	0	0.1	-0.1	1	<0.001	0.000	0	0.288	-0.002	2
		1400	<0.002			0.2			<0.001			0.290		
1	05/14/01	1500	0.003	-0.003	3	0.2	0.0	0	<0.001	0.000	0	1.73	0.04	4
		1515	0.006			0.2			<0.001			1.69		
4	09/14/00	1400	0.004	-0.003	3	<0.1	0.0	0	0.001	0.000	0	1.16	0.01	1
		1415	0.007			<0.1			0.001			1.15		
5	09/13/01	1500	<0.002	-0.002	2	<0.1	0.0	0	<0.001	0.000	0	0.143	0.002	2
		1530	0.002			<0.1			<0.001			0.141		
6	08/27/98	1130	0.002	-0.006	6	<0.1	0.0	0	<0.001	0.000	0	0.019	0.001	1
		1200	0.008			<0.1			<0.001			0.018		
7	05/05/99	0930	0.014	0.003	3	E 0.1	nc	nc	<0.001	0.000	0	<0.005	0.000	0
		1000	0.011			E 0.09			<0.001			<0.005		
8	09/13/00	0930	<0.002	0.000	0	E 0.1	0.0	0	0.004	0.001	1	4.72	-0.01	1
		1000	<0.002			E 0.1			0.003			4.73		
8	05/16/01	0900	0.005	-0.006	6	0.1	0.0	0	<0.001	0.000	0	3.10	1.37	137
		0930	0.011			0.1			<0.001			1.73		
8	09/13/01	0945	0.002	-0.002	2	<0.1	0.0	0	0.001	0.001	1	2.62	0.06	6
		1000	0.004			<0.1			<0.001			2.56		
9	05/03/99	1500	0.011	0.003	3	E 0.08	nc	nc	--	--	--	0.059	0.006	6
		1530	0.008			0.1			<0.001			0.053		
9	08/30/99	1500	<0.002	0.000	0	0.1	nc	nc	<0.001	-0.001	1	0.082	0.001	1
		1530	<0.002			E 0.09			0.001			0.081		
9	05/15/00	1500	0.002	-0.003	3	0.1	0.0	0	<0.001	0.000	0	0.088	0.003	3
		1530	0.005			0.1			<0.001			0.085		
9	09/10/01	1445	<0.002	0.000	0	0.1	0.0	0	0.001	0.000	0	0.110	0.000	0
		1515	<0.002			0.1			0.001			0.110		
10	05/07/99	0900	0.012	0.002	2	<0.1	0.0	0	<0.001	0.000	0	0.236	-0.006	6
		0915	0.010			<0.1			<0.001			0.242		
10	09/02/99	0900	0.005	0.005	5	E 0.08	0.00	0	0.001	-0.001	1	0.292	0.012	12
		0915	<0.002			E 0.08			0.002			0.280		
10	05/19/00	0830	<0.002	-0.002	2	<0.1	0.0	0	<0.001	0.000	0	0.252	-0.019	19
		0845	0.002			<0.1			<0.001			0.271		
11	08/31/99	1445	0.004	0.004	4	<0.1	0.0	0	0.001	0.001	1	0.225	0.000	0
		1500	<0.002			<0.1			<0.001			0.225		
11	05/17/00	1000	0.003	0.001	1	<0.1	0.0	0	<0.001	0.000	0	0.233	0.000	0
		1015	0.002			<0.1			<0.001			0.233		

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. no., number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite; -, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero]

Site no. (fig. 1 table 1)	Date	Time	Phosphorus			Orthophosphate			Dissolved organic carbon		
			Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.
			(mg/L)			(mg/L)			(mg/L)		
1	09/11/00	1330	0.007	-0.003	3	0.007	0.000	0	3.0	0.0	0
		1400	0.010			0.007			3.0		
1	05/14/01	1500	0.007	0.000	0	E 0.005	0.000	0	3.3	0.1	1
		1515	0.007			E 0.005			3.2		
4	09/14/00	1400	0.017	-0.001	1	0.016	-0.001	1	0.49	-0.07	7
		1415	0.018			0.017			0.56		
5	09/13/01	1500	0.046	0.000	0	0.042	-0.002	2	0.72	0.02	2
		1530	0.046			0.044			0.70		
6	08/27/98	1130	0.060	-0.002	2	0.061	0.001	1	1.9	0.1	1
		1200	0.062			0.060			1.8		
7	05/05/99	0930	0.016	-0.005	5	0.017	-0.006	6	1.9	0.0	0
		1000	0.021			0.023			1.9		
8	09/13/00	0930	0.052	-0.001	1	0.049	0.000	0	1.3	0.0	0
		1000	0.053			0.049			1.3		
8	05/16/01	0900	0.050	-0.002	2	0.047	-0.002	2	1.2	0.2	2
		0930	0.052			0.049			1.0		
8	09/13/01	0945	0.051	0.003	3	0.046	-0.001	1	0.98	-0.02	2
		1000	0.048			0.047			1.0		
9	05/03/99	1500	0.064	0.006	6	0.060	0.001	1	2.0	-0.2	2
		1530	0.058			0.059			2.2		
9	08/30/99	1500	0.059	0.001	1	0.062	0.002	2	2.3	0.0	0
		1530	0.058			0.060			2.3		
9	05/15/00	1500	0.052	-0.002	2	0.052	-0.002	2	2.3	0.1	1
		1530	0.054			0.054			2.2		
9	09/10/01	1445	0.056	0.000	0	0.050	0.000	0	2.2	0.0	0
		1515	0.056			0.050			2.2		
10	05/07/99	0900	0.131	0.001	1	0.130	-0.001	1	0.8	0.0	0
		0915	0.130			0.131			0.8		
10	09/02/99	0900	0.134	0.002	2	0.137	0.003	3	1.0	0.0	0
		0915	0.132			0.134			1.0		
10	05/19/00	0830	0.132	-0.001	1	0.126	0.000	0	0.91	0.00	0
		0845	0.133			0.126			0.91		
11	08/31/99	1445	0.033	0.000	0	0.037	0.001	1	0.7	0.0	0
		1500	0.033			0.036			0.7		
11	05/17/00	1000	0.035	0.000	0	0.036	0.001	1	0.74	0.07	7
		1015	0.035			0.035			0.67		

Table 6. Comparison of laboratory results for environmental and quality-control samples for 9 wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. no., number; Env., environmental sample; QC, quality-control sample; Conc. diff., difference in concentration between environmental sample and quality-control sample; RU diff., absolute difference in lowest rounding unit; mg/L, milligrams per liter; shaded cells represent differences greater than 1 rounding unit; <, concentration less than the laboratory reporting level; E, estimated; nc, not calculated; ammonia, un-ionized ammonia [NH₃]; plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite; --, no data; col/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter. For calculations, "less than" (<) concentrations are presumed to be zero]

Site no. (fig. 1 table 1)	Date	Time	Total coliform bacteria			MBAS			Radon-222, total		
			Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.	Env. QC	Conc. diff.	RU diff.
			(col/100 mL)	(mg/L)	(pCi/L)						
1	09/11/00	1330	<1	0.02	2	<0.02	0.02	--	--	--	--
	1400		--	<0.02							
1	05/14/01	1500	E 140	0.02	0	0.02	0.00	--	--	--	--
	1515		--	0.02							
4	09/14/00	1400	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1415		--	<0.02							
5	09/13/01	1500	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1530		--	<0.02							
6	08/27/98	1130	<1	<0.02	0	<0.02	0.00	365	--	--	--
	1200		--	<0.02							
7	05/05/99	0930	<1	<0.02	0	<0.02	0.00	764	31	31	31
	1000		--	<0.02				733	--	--	--
8	09/13/00	0930	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1000		--	<0.02							
8	05/16/01	0900	<1	<0.02	3	<0.02	-0.03	--	--	--	--
	0930		--	0.03							
8	09/13/01	0945	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1000		--	<0.02							
9	05/03/99	1500	--	<0.02	0	<0.02	0.00	669	-78	78	78
	1530		--	<0.02				747	--	--	--
9	08/30/99	1500	<1	<0.02	0	<0.02	0.00	687	10	10	10
	1530		<1	<0.02				677	--	--	--
9	05/15/00	1500	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1530		<1	<0.02							
9	09/10/01	1445	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1515		--	<0.02							
10	05/07/99	0900	<1	<0.02	3	<0.02	-0.03	752	14	14	14
	0915		--	0.03				738	--	--	--
10	09/02/99	0900	<1	<0.02	0	<0.02	0.00	752	47	47	47
	0915		<1	<0.02				705	--	--	--
10	05/19/00	0830	<1	<0.02	0	<0.02	0.00	--	--	--	--
	0845		<1	<0.02							
11	08/31/99	1445	<1	<0.02	0	<0.02	0.00	1093	-7	7	7
	1500		<1	<0.02				1100	--	--	--
11	05/17/00	1000	<1	<0.02	0	<0.02	0.00	--	--	--	--
	1015		<1	<0.02							

Table 7. Summary of differences between environmental and quality-control samples for wells in the Fraser River watershed, 1998–2001.

[All water-quality constituents are in the dissolved form except for total coliform bacteria, MBAS (methylene blue active substances), and radon-222. Lowest rounding unit is equal to the magnitude of the least significant figure reported by the U.S. Geological Survey National Water Quality Laboratory; NA, not applicable; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite]

Constituent	Number of replicate pairs evaluated	Percentage of replicate pairs with no difference	Percentage of replicate pairs within 1 lowest rounding unit	Percentage of replicate pairs within 2 lowest rounding units	Number of replicate pairs with concentration(s) less than the laboratory reporting level	Number of replicate pairs with inconsistency in reporting concentrations less than the laboratory reporting level
Bromide	19	68	100	100	6	1
Calcium	19	0	32	37	NA	NA
Chloride	19	42	79	84	NA	NA
Fluoride	19	84	100	100	4	0
Magnesium	19	11	37	47	NA	NA
Potassium	19	5.3	21	37	NA	NA
Silica	19	16	32	32	NA	NA
Sodium	19	37	74	79	NA	NA
Sulfate	19	37	84	95	1	0
Iron	16	100	100	100	15	0
Manganese	17	59	59	59	10	0
Ammonia	18	22	28	50	8	4
Ammonia plus organic nitrogen	15	93	100	100	8	0
Nitrite	17	71	100	100	13	3
Nitrate	18	22	44	56	1	0
Phosphorus	18	28	56	78	NA	NA
Orthophosphate	18	28	67	89	NA	NA
Dissolved organic carbon	18	50	67	89	NA	NA
Total coliform bacteria	6	100	100	100	6	0
MBAS	18	83	83	89	17	3
Radon-222, total	6	0	0	0	NA	NA

Table 9. Concentrations of major ions, trace elements, nutrients, and dissolved organic carbon in blank samples for wells in the Fraser River watershed, 1998–2001.—Continued

[All water-quality constituents are in the dissolved form. no., number; mg/L., milligrams per liter; <, concentration less than the laboratory reporting level; E, estimated; shaded cells represent concentrations greater than twice the laboratory reporting levels; ammonia, un-ionized ammonia [NH₃] plus ammonium [NH₄⁺]; nitrate is nitrate plus nitrite]

Site no. (fig. 1; table 1)	Date	Time	Concentration (mg/L)							Dissolved organic carbon	
			Ammonia plus organic nitrogen	Nitrite	Nitrate	Phosphorus	Orthophosphate	Ammonia plus organic nitrogen			
6	08/27/98	1530	<0.002	<0.1	0.001	<0.005	<0.001	<0.001	<0.001	<0.1	<0.1
9	05/03/99	1400	0.004	E 0.05	<0.001	0.005	<0.004	<0.001	<0.001	0.4	0.4
7	05/05/99	0800	0.004	<0.1	<0.001	0.005	<0.004	<0.001	<0.001	<0.1	<0.1
10	05/07/99	1000	0.005	<0.1	<0.001	0.005	<0.004	0.001	0.001	<0.1	<0.1
9	08/30/99	1400	<0.002	<0.1	<0.001	<0.005	<0.004	0.001	0.001	0.2	0.2
11	08/31/99	1545	0.003	<0.1	<0.001	0.005	<0.004	<0.001	<0.001	<0.1	<0.1
10	09/02/99	1000	<0.002	E 0.06	<0.001	<0.005	<0.004	<0.001	<0.001	<0.1	<0.1
9	05/15/00	1400	<0.002	<0.1	<0.001	<0.005	<0.006	<0.001	<0.001	E 0.28	E 0.28
11	05/17/00	0900	0.002	<0.1	<0.001	<0.005	<0.006	<0.001	<0.001	E 0.18	E 0.18
10	05/19/00	0930	0.021	<0.1	<0.001	<0.005	<0.006	0.003	0.003	<0.33	<0.33
1	09/11/00	1200	<0.002	<0.1	<0.001	<0.005	<0.006	<0.001	<0.001	<0.33	<0.33
8	09/13/00	0800	<0.002	<0.1	<0.001	<0.005	<0.006	<0.001	<0.001	<0.33	<0.33
4	09/14/00	1530	<0.002	<0.1	<0.001	<0.005	<0.006	0.002	0.002	E 0.26	E 0.26
1	05/14/01	1330	<0.002	<0.1	<0.001	<0.005	<0.006	<0.007	<0.007	<0.33	<0.33
8	05/16/01	0800	<0.002	<0.1	<0.001	<0.005	<0.006	<0.007	<0.007	E 0.23	E 0.23
10	05/17/01	1600	0.004	<0.1	<0.001	<0.005	<0.006	<0.007	<0.007	<0.33	<0.33
9	09/10/01	1345	<0.002	<0.1	<0.001	0.006	<0.006	<0.007	<0.007	E 0.25	E 0.25
8	09/13/01	0830	<0.002	<0.1	<0.001	0.006	<0.006	<0.007	<0.007	E 0.20	E 0.20
5	09/13/01	1620	<0.002	<0.1	<0.001	0.006	<0.006	<0.007	<0.007	E 0.20	E 0.20