Fraser River Watershed, Colorado—Assessment of Available Water-Quantity and Water-Quality Data Through Water Year 1997

By Lori E. Apodaca and Jeffrey B. Bails

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98–4255

Prepared in cooperation with
GRAND COUNTY and the
COLORADO DEPARTMENT OF PUBLIC HEALTH
AND ENVIRONMENT

Denver, Colorado
1999

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

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Denver, CO 80225-0046

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.028	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
inch	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
picocuries per liter (pCi/L)	0.3125	tritium units
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.59	square kilometer

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:
°C = 5/9 (°F–32).

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:
°F = 9/5 (°C) + 32.

ADDITIONAL ABBREVIATIONS OR TERMS

cols/100 mL, colonies per 100 milliliters

DOC, dissolved organic carbon

DWA, drinking water advisory

gpd/ft, gallons per day per foot

HA, health advisory

µg/L, microgram per liter

µS/cm, microsiemens per centimeter at 25 degrees Celsius

mg/L, milligram per liter

mL, milliliter

Ma, Mega-annum

MBAS, methylene blue active substances

MCL, maximum contaminant level

MCLG, maximum contaminant level goal

NTU, nephelometric turbidity units

pfu, plaque-forming unit

PMCL, proposed maximum contaminant level

SMCL, secondary maximum contaminant level

units/yr, units per year

as N, as quantified, as measured nitrogen

as P, as quantified, as measured phosphorus

VOC, volatile organic compound

Water year is the continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with surface-water supply. The water year is designated by the year in which it ends. Thus, the year ending September 30, 1980, is referred to as water year 1980.

Fraser River Watershed, Colorado—Assessment of Available Water-Quantity and Water-Quality Data Through Water Year 1997

By Lori E. Apodaca *and* Jeffrey B. Bails

Abstract

The water-quantity and water-quality data for the Fraser River watershed through water year 1997 were compiled for ground-water and surface-water sites. In order to assess the water-quality data, the data were related to land use/land cover in the watershed. Data from 81 water-quantity and water-quality sites, which consisted of 9 ground-water sites and 72 surface-water sites, were available for analysis. However, the data were limited and frequently contained only one or two water-quality analyses per site.

The Fraser River flows about 28 miles from its headwaters at the Continental Divide to the confluence with the Colorado River. Ground-water resources in the watershed are used for residential and municipal drinking-water supplies. Surface water is available for use, but water diversions in the upper parts of the watershed reduce the flow in the river. Land use/land cover in the watershed is predominantly forested land, but increasing urban development has the potential to affect the quantity and quality of the water resources.

Analysis of the limited ground-water data in the watershed indicates that changes in the land use/land cover affect the shallow ground-water quality. Water-quality data from eight shallow monitoring wells in the alluvial aquifer show that iron and manganese concentrations exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level. Radon concentrations from these monitoring wells exceeded the U.S. Environmental Protection Agency proposed maximum contaminant level. The proposed radon contaminant level is currently being revised. The presence of volatile organic compounds at two monitoring wells in the watershed indicates that land use affects the shallow ground water. In addition, bacteria detected in three samples are at concentrations that would be a concern for public health if the water was to be used as a drinking supply. Methylene blue active substances were detected in the ground water at some sites and are a possible indication of contamination from wastewater. Age of the alluvial ground water ranged from 10 to 30 years; therefore, results of land-management practices to improve water quality may not be apparent for many years.

Surface-water-quality data for the Fraser River watershed are sparse. The surface-water-quality data show that elevated concentrations of selected constituents generally are related to specific land uses in the watershed. For one sample (about 2 percent; 1 of 53), dissolved manganese concentration exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level. Two samples from two surface-water sites in the watershed exceeded the un-ionized ammonia chronic criterion. Spatial distribution of nutrient species (ammonia, nitrite, nitrate, and total phosphorus) shows that elevated concentrations occur primarily downstream from urban areas. Sites with five or more years of record were analyzed for temporal trends in concentration of nutrient species. Downward

trends were identified for ammonia and nitrite for three surface-water sites. For nitrate, no trends were observed at two sites and a downward trend was observed at one site. Total phosphorus showed no trend for the site near the mouth of the Fraser River. Downward trends in the nutrient species may reflect changes in the wastewater-treatment facilities in the watershed. Bacteria sampling completed in the watershed indicates that more bacteria are present in the water near urban settings.

The limited ground-water and surface-water data for the Fraser River watershed provide a general assessment of the quantity and quality of these resources. Concentrations of most water-quality constituents generally are less than ground- and surface-water-quality standards, but the presence of bacteria, some volatile organic compounds, methylene blue active substances, and increased nutrients in the water may indicate that land use is affecting the water quality.

INTRODUCTION

The Fraser River, which has a drainage area of about 287 mi^2 (fig. 1), flows about 28 mi from an area along the Continental Divide in the Arapaho National Forest through the towns of Winter Park, Fraser, Tabernash, and Granby and empties into the Colorado River near Granby, Colorado. The Fraser River watershed is located in the southeastern part of Grand County.

Because of changes in land-use practices in the Fraser River watershed, there is the potential to see effects in the overall water quantity and quality in the watershed. For this reason, the U.S. Geological Survey (USGS), in cooperation with Grand County and the Colorado Department of Public Health and Environment, compiled and analyzed information on water quantity and quality in the Fraser River watershed through water year 1997. This information was compiled in order to identify potential concerns that relate to the effects of changes in land use/land cover on the quantity and quality of the ground-water and surface-water resources.

Purpose and Scope

This report presents the available water-quantity and water-quality data through water year 1997 for the Fraser River watershed in order to assess the ground-water and surface-water resources. Ground-water data are available primarily in the Winter Park, Fraser, and Tabernash areas, whereas surface-water data are available throughout the watershed. The study provides an assessment of the quantity and quality of the water resources in relation to land use/land cover. Specific objectives of this study are to: (1) Characterize existing water-resources data for the Fraser River watershed; (2) analyze historical data and assess the broad-scale geographic and seasonal variability in the quantity and quality of water in the Fraser River watershed; and (3) summarize, where possible, the changes in land use/land cover that affect observed water-quantity and water-quality conditions in the Fraser River watershed.

From 1904 through 1997, the Fraser River watershed had 81 water-quantity and water-quality sampling sites (9 ground-water sites and 72 surface-water sites), which were sampled or measured for discharge at various times throughout this period of record. A large percentage of these sites had only one or two water-quality analyses. The ground-water analyses typically include a more comprehensive suite of constituents than the surface-water analyses. Eight of the nine ground-water-sampling sites are located in the area of Winter Park, Fraser, and Tabernash (fig. 1). For most ground-water sites, data were available for field parameters (such as water temperature, specific conductance, dissolved oxygen, pH, alkalinity, and turbidity), major ions, nutrients, trace elements, radon, dissolved organic carbon, pesticides, volatile organic compounds, bacteria, methylene blue active substances, and chlorofluorocarbons. For the surface-water sites, information was available on field parameters (such as water temperature, specific conductance, dissolved oxygen, pH, and alkalinity), major ions, nutrients, trace elements, and bacteria. In addition, some information was available for suspended-sediment concentrations and discharge.

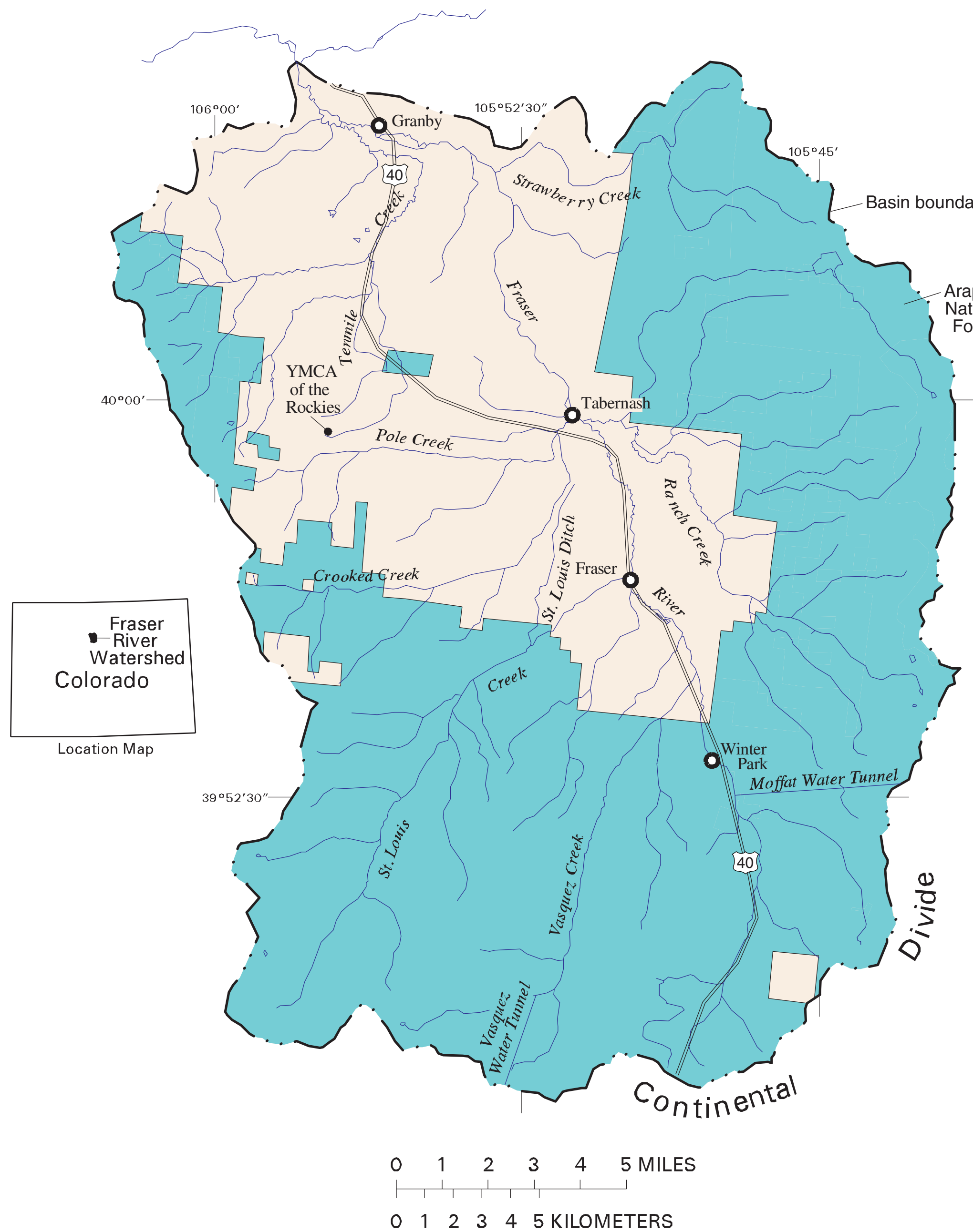

Figure 1. Location of the Fraser River watershed, Grand County, Colorado.

Acknowledgments

The authors of this report thank the many individuals and agencies that provided water-quantity and water-quality data for the Fraser River watershed. Special thanks are extended to Gary Cooper, Silvercreek and Winter Park West Water and Sanitation District; Bruce Hutchins, Grand County Water and Sanitation District; Doreen Schmidt, U.S. Forest Service; and Mike Wajeck, YMCA of the Rockies, Snow Mountain Ranch. We also thank Stephen Char, USGS, for his assistance in compiling the water-quality data for the Fraser River watershed.

DESCRIPTION OF STUDY AREA

The Fraser River watershed is located in the northwestern part of the Southern Rocky Mountains physiographic province of Colorado (Apodaca and others, 1996). Land-surface altitude in the watershed ranges from about 8,000 ft in the valley to about 12,800 ft along the Continental Divide. Daily average temperatures in the Fraser River watershed range from a low of 13°F to a high of 55°F. Precipitation in the watershed on average is less than 20 in/yr in the valleys north and west of Fraser to more than 40 in/yr in the higher peaks of the watershed (fig. 2).

The geology of the Fraser River watershed varies from Precambrian-age basement rocks to Quaternary alluvial deposits (fig. 3). The oldest rocks are of Precambrian age and are exposed in the eastern and southern mountains of the watershed. Fractured Precambrian rocks generally yield small quantities of water that are adequate only for domestic supplies. Where the Precambrian rocks are fractured, water may discharge from springs. Sedimentary rocks of Triassic, Jurassic, and Cretaceous age are in the western part of the watershed and generally are low yielding; however, water from these sedimentary rocks probably is suitable for most domestic uses. The geologic units in the watershed that will yield water more readily are Tertiary or younger in age (Voegeli, 1965). These units include the Troublesome Formation and alluvial deposits in the lower altitudes in the watershed. These aquifers provide water for residential and municipal use. The Troublesome Formation is predominantly siltstone with some interbedded sandstones and conglomerates and is as much as 1,000 ft thick. The alluvial deposits consist of alluvial sands and gravels and older glacial drift and are as much as 200 ft thick.

Land use/land cover in the Fraser River watershed is 71 percent forested (deciduous, evergreen, and mixed) land; 14 percent cropland, pasture, agricultural, and rangeland; 11 percent tundra, bare ground, and exposed rock; 2 percent urban; and 2 percent other land-use classifications (fig. 4). The urban classification includes the categories of other urban, commercial, residential, and mixed urban areas. The major urban centers in the watershed are Winter Park, Fraser, and Granby. All land-use/land-cover classifications were determined during the late 1970's (Fegeas and others, 1983), and refined with 1990 population data (Hitt, 1995).

The Fraser River watershed, which is located in the southeastern part of Grand County, comprises about 15 percent of the total area of Grand County (1,869 mi^2). Population of Grand County has increased about 94 percent between 1970 (4,107) and 1990 (7,966) (U.S. Bureau of the Census, 1970 and 1990). An increase from 1990 population of about 105 percent is projected for Grand County by the year 2020 (16,358) (U.S. Bureau of the Census, 1990). Populations for the major towns in 1994 for the Fraser River watershed were Winter Park (660), Fraser (671), and Granby (1,026) (U.S. Bureau of the Census, 1994). However, these population numbers do not represent an exact population for the Fraser River watershed because unincorporated towns are not included in the 1994 census. In addition, the population census does not reflect the full demand on the water resources in the area. Primarily during the winter and summer months, many tourists and vacationers significantly add to the population of the watershed.

DATA SOURCES AND COMPILATION

Many individuals and agencies were contacted within the Fraser River watershed to obtain water-quantity and water-quality data. These data, summarized in table 1, include information on surface water, ground water, and springs. Some of these data are discussed in the report but were not used in the statistical summaries because sampling methods were unknown and the data could not be quality assured. Most of the data used in assessing the water-quality

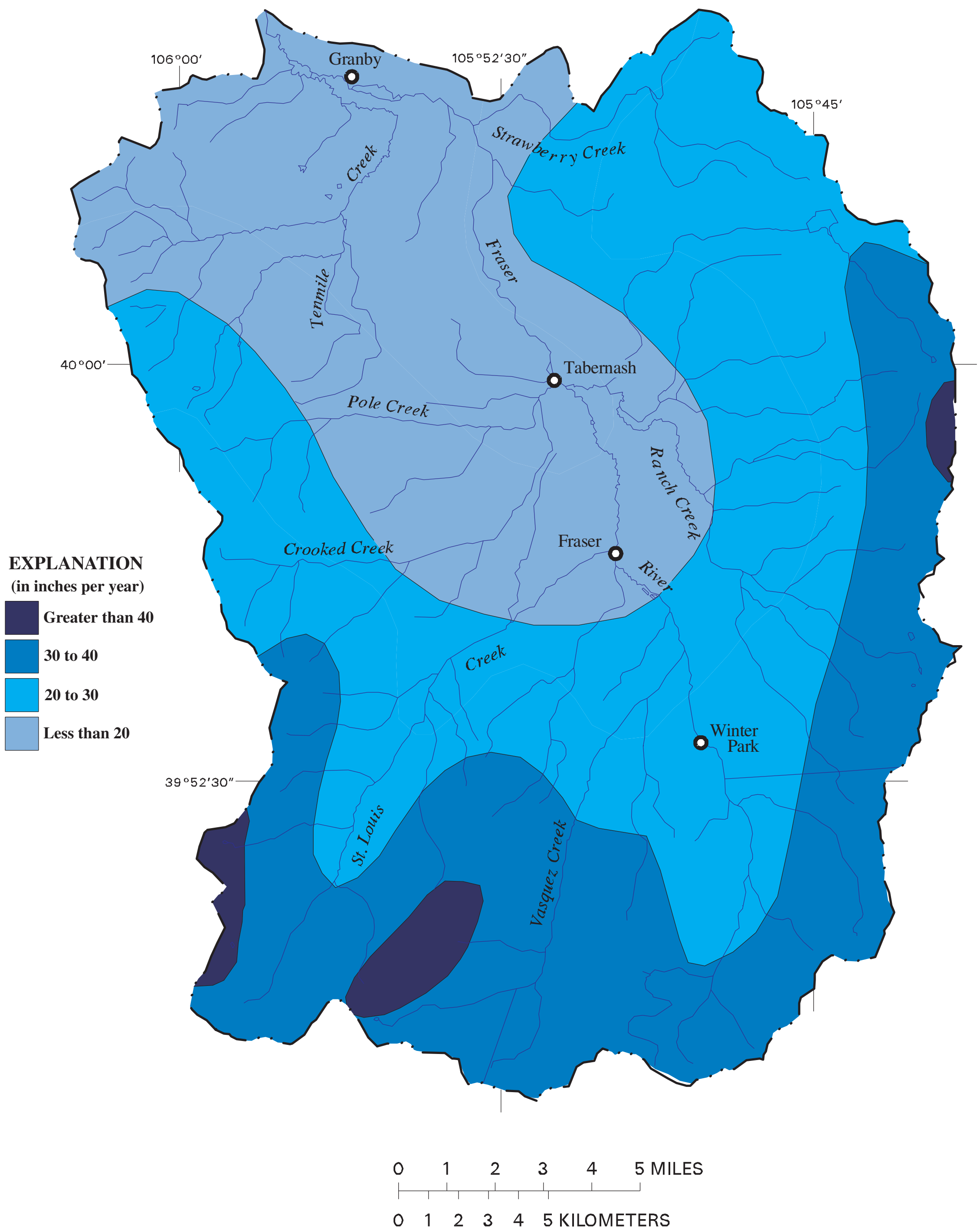

Figure 2. Average annual precipitation (1951–80) in the Fraser River watershed (Colorado Climate Center, 1984).

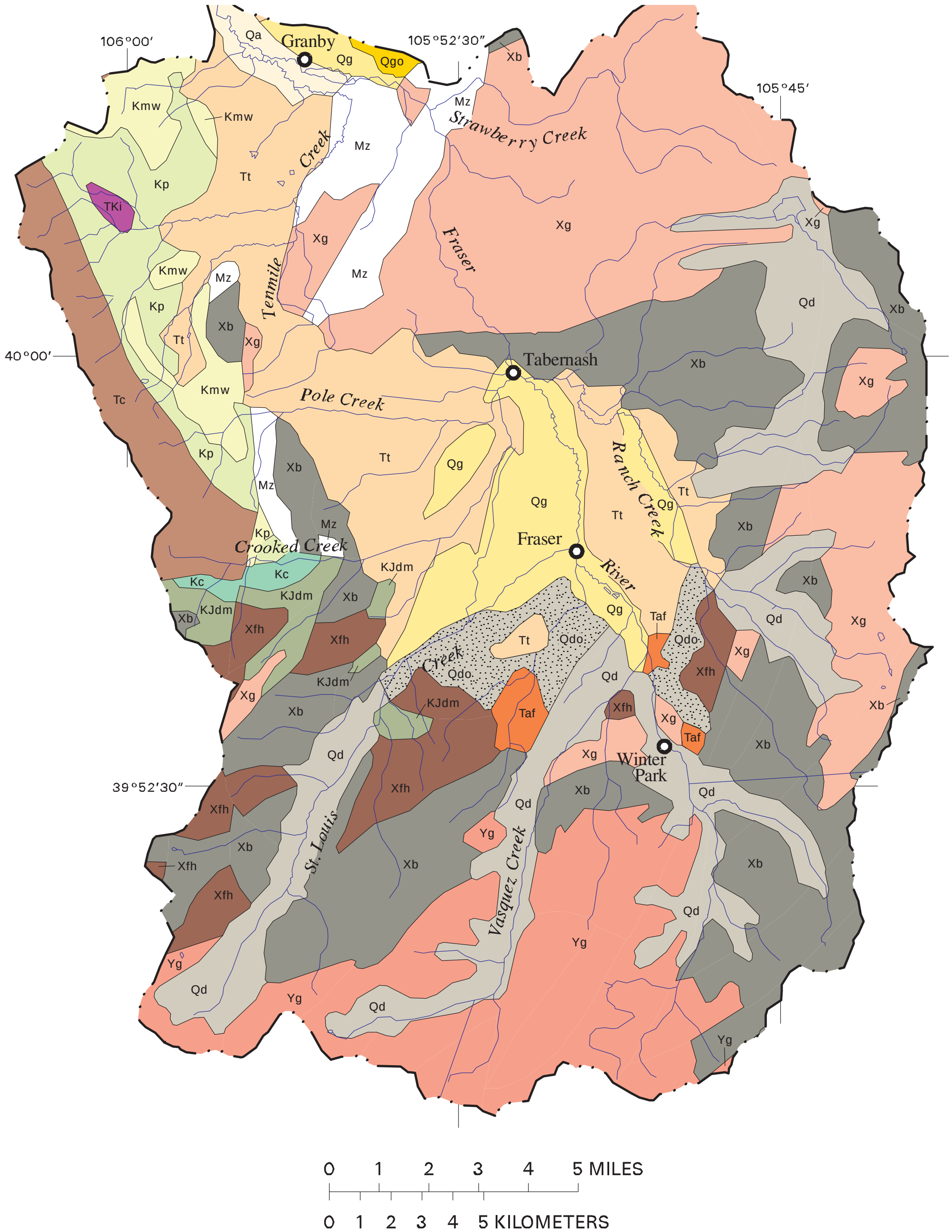

Figure 3. Geology of the Fraser River watershed (Green, 1992; Tweto, 1979).

EXPLANATION

	Unconsolidated surficial deposits of Quaternary age
Qa	**Modern alluvium**
Qg	**Gravels and alluviums**
Qgo	**Older gravels and alluviums**
Qd	**Glacial drift of Pinedale and Bull Lake Glaciations**
Qdo	**Older glacial drift (pre-Bull Lake age)**
	Igneous rocks of Tertiary and/or Cretaceous age
TKi	**Laramide intrusive rocks**
Taf	**Ash-flow tuff of main volcanic sequence**
	Sedimentary rocks of Tertiary age
Tt	**Troublesome Formation**—Siltstone, sandstone, and conglomerate
Tc	**Coalmont Formation**—Sandstone, shale, coal beds, and conglomerate
	Sedimentary rocks of Cretaceous age
Kmw	**Windy Gap Member of Middle Park Formation**
Kp	**Pierre Shale, undivided**
Kc	**Colorado Group**
	Sedimentary rocks of Cretaceous and Jurassic age
KJdm	**Dakota and Morrison Formations**
	Sedimentary rocks broadly classified
Mz	**Mesozoic rocks**—Mainly early Cretaceous, Jurassic, and Triassic age
	Igneous and metamorphic rocks of Precambrian age
Yg	**Granitic rock of 1,400 Ma**
Xg	**Granitic rock of 1,700 Ma**
Xb	**Biotite gneiss, schist, and migmatite**
Xfh	**Felsic and hornblende gneisses, either separate or interlayered**

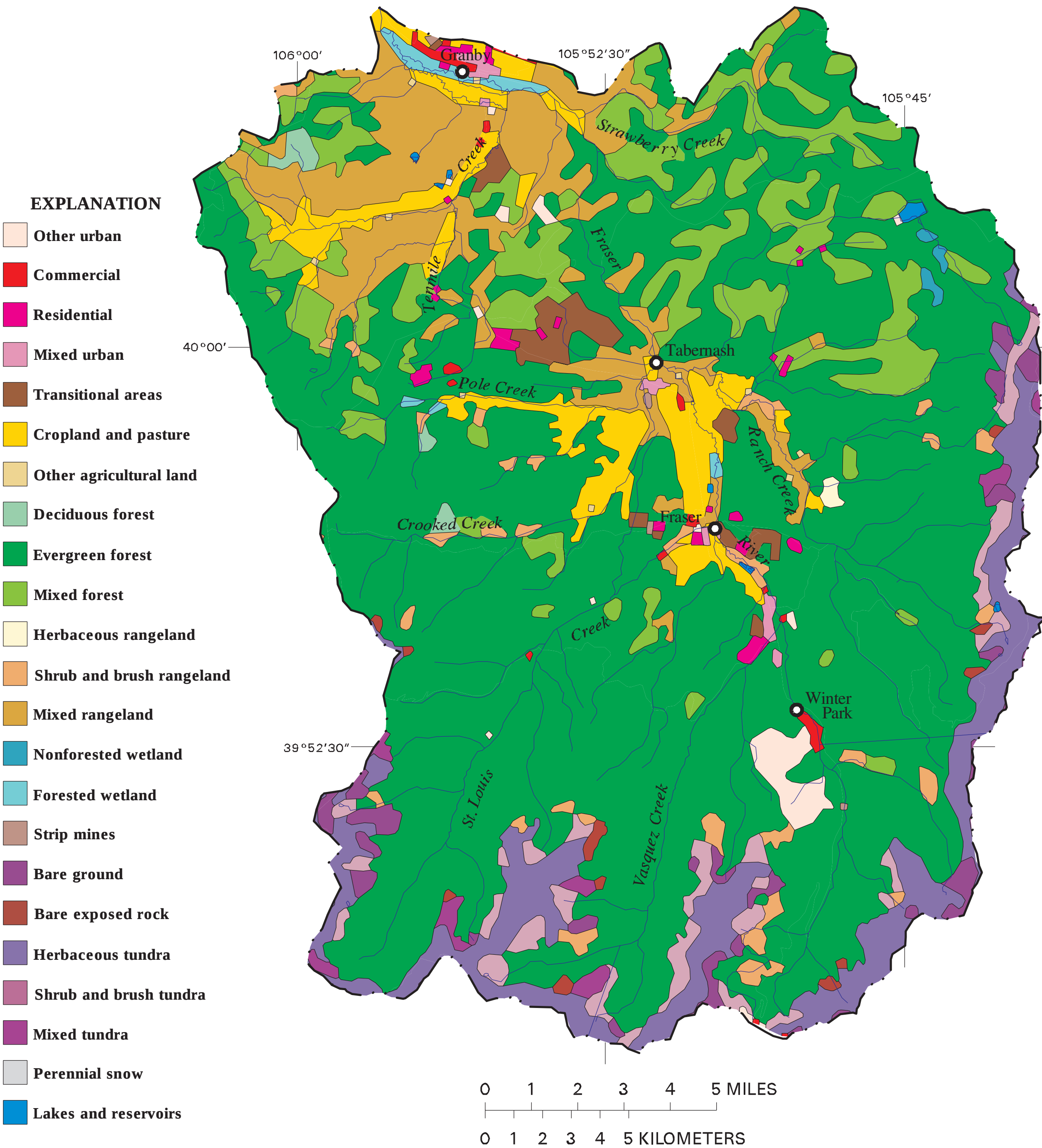

Figure 4. Land use/land cover for the Fraser River watershed, 1990. [Based on GIRAS (Geographic Information Retrieval and Analysis System) land-use data from the 1970's (Fegeas and others, 1983), and refined with 1990 population data (Hitt, 1995)].

Table 1. Sources of water-related data for the Fraser River watershed

[USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; ---, no data]

Source	General purpose for collecting information	Number of sites	Number of samples per site	Data collected	Period of record	Results
Colorado Department of Public Health and Environment	Fraser River field investigation	14	4	Field parameters, discharge, and nutrients[1]	1982–83	Nutrients were detected in the effluent.
	Sampling of Fraser River upstream and downstream from effluent discharges to evaluate wastewater-treatment facilities	7	1	Field parameters, discharge, and nutrients	1984	Nutrients were detected in the effluent.
	Local Fraser River study	24	4	Field parameters, nutrients, and bacteria	1983	Nutrients and fecal coliforms were detected in the effluent.
	Water-quality investigations of the Fraser River	6	1	Field parameters, major ions, and nutrients, and benthic and fish communities	1977–78	Results are summarized in report by Mars, 1979.
Denver Water Board	Surface-water-quality data	4	6 or 8	Field parameters, major ions, nutrients, trace elements, radionuclides, and bacteria data	1992–94	Constituents did not exceed USEPA stream standards (USEPA, 1986).
Silvercreek Water and Sanitation District	Develop potential ground-water supplies in the alluvial deposits for use by the planned Val Moritz development (south of Granby)	6	1	Nutrients, major ions, trace elements, and aquifer tests	1973–74	Manganese concentrations may be high.
U.S. Forest Service	Estimation of bedload sediment yield	---	---	---	1996	Annual sediment introduced into the Fraser River from activity along U.S. Highway 40 is estimated at 1,300 cubic yards.
	Determination of fish population in the Fraser River	---	---	---	1995	Fish populations in the Fraser River are impacted by sediment loads.
Winter Park West Water and Sanitation District	Inorganic analyses of ground-water samples	24	1	Copper and lead	1994	Lead levels exceeded the USEPA MCL drinking-water standards at four sites sampled (USEPA, 1996).
	Analyses completed for volatile organic compounds of ground-water samples	4	1	Volatile organic compounds	1993	Volatile organic compounds detected were all less than USEPA MCL drinking-water standards (USEPA, 1996).
	Well construction and aquifer test reports for eight wells in the Fraser River valley in the Troublesome Formation	8	---	---	1992	Wells are located in the Troublesome Formation and are recharged by precipitation.
YMCA of the Rockies—Snow Mountain Ranch	Water-quality analyses for the Ruesch and Just springs	2	5	Inorganics, nutrients, organics, radiological, and waterborne particulates	1991–94	Constituents did not exceed USEPA MCL drinking-water standards (USEPA, 1996).

[1] Field parameters may include dissolved oxygen, pH, specific conductance, and water temperature.

conditions of the Fraser River watershed were obtained from two sources: (1) the USGS National Water Information System (NWIS) and (2) the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval (STORET) system. Data from 81 water-quantity and water-quality sampling sites were available for the Fraser River watershed from these sources, which included 9 ground-water sites and 72 surface-water sites (figs. 5 and 6). Eight of the nine ground-water wells were completed in the unconsolidated alluvium and were sampled as part of the USGS Upper Colorado River Basin (UCOL) National Water-Quality Assessment (NAWQA) Program. Twenty-nine of the surface-water sites were from the USGS NWIS data base.

Water-quality data for the ground-water sites (fig. 5, table 2) consist of a more comprehensive suite of constituents analyzed than the surface-water data. Information was available on field parameters (water temperature, specific conductance, dissolved oxygen, pH, alkalinity, and turbidity), major ions, nutrients, trace elements, radon-222, dissolved organic carbon (DOC), pesticides, volatile organic compounds (VOC's), bacteria (total coliform and *Escherichia coli* [*E. coli*] and viruses [somatic coliphage]), methylene blue active substances (MBAS), and chlorofluorocarbons (CFC's) at most sites.

The surface-water-quality data for the watershed (table 3) consist of field parameters (water temperature, specific conductance, dissolved oxygen, pH, and alkalinity), major ions (primarily chloride), nutrients, trace elements, and other constituents, which include bacteria and suspended-sediment data. The data for most of these sites are limited and may include only one sample per site. The most abundant surface-water-quality data are field parameters, nutrients, and chloride. In figure 7, the distribution of nutrient species samples for the surface-water sites is shown by date and period of sampling. In the watershed, surface-water sites with long-term water-quality data are limited; only four sites had at least 5 years of record.

METHODS OF DATA REVIEW AND ANALYSIS

In this report water-quality properties and constituents are represented graphically and statistically. The ground-water and surface-water data were quality assured by examining the differences between the total-cation and total-anion concentrations. Differences between total-cation and total-anion concentrations for all nine wells from the NWIS data base were less than 10 percent. For the surface-water-quality sites from the NWIS and STORET data bases, less than 1 percent of the samples (total of 3,759 water-quality samples) contained cation and anion data. For these sites the differences between the total-cation and total-anion charge balance were less than 10 percent. A difference between the total-cation and the total-anion charge balance of less than 10 percent is assumed acceptable for this report. Because of the limited cation and anion data, not all of the data used in this report were able to be quality assured. However, laboratory analyses performed by the USGS or by the other agencies as indicated in table 3 were assumed to be reliable for the general assessment of the water quality in the watershed.

Water-quality data were analyzed using nonparametric statistical methods. Nonparametric methods were used because they are not strongly influenced by outliers, require few assumptions about the statistical properties of a data set, and are suitable for use with small data sets. Water-quality data for surface-water sites in the basin had many values that were less than the detection or reporting limits. Because different laboratory analytical methods were used for the surface-water sites, the laboratory analytical detection or reporting limits for a given constituent were not consistent. Data that are less than the detection or reporting limits are censored data. In order to statistically compare the water-quality data for a given constituent and not exclude all of the censored data, these data needed to have a common detection or reporting limit. For the data used in this report, the most common detection or reporting limit was kept. However, values that were censored above the most common detection or reporting limit were deleted and censored values below the common detection or reporting limit were converted to the most common detection or reporting limit before statistically analyzing the data.

Boxplots are used to display variability in a data set. Boxplots (for example, fig. 12) graphically represent the median, or 50th percentile (the centerline of the box), the interquartile range (the part of the box representing the range between the 25th and 75th percentile), and the 10th and 90th percentiles (the

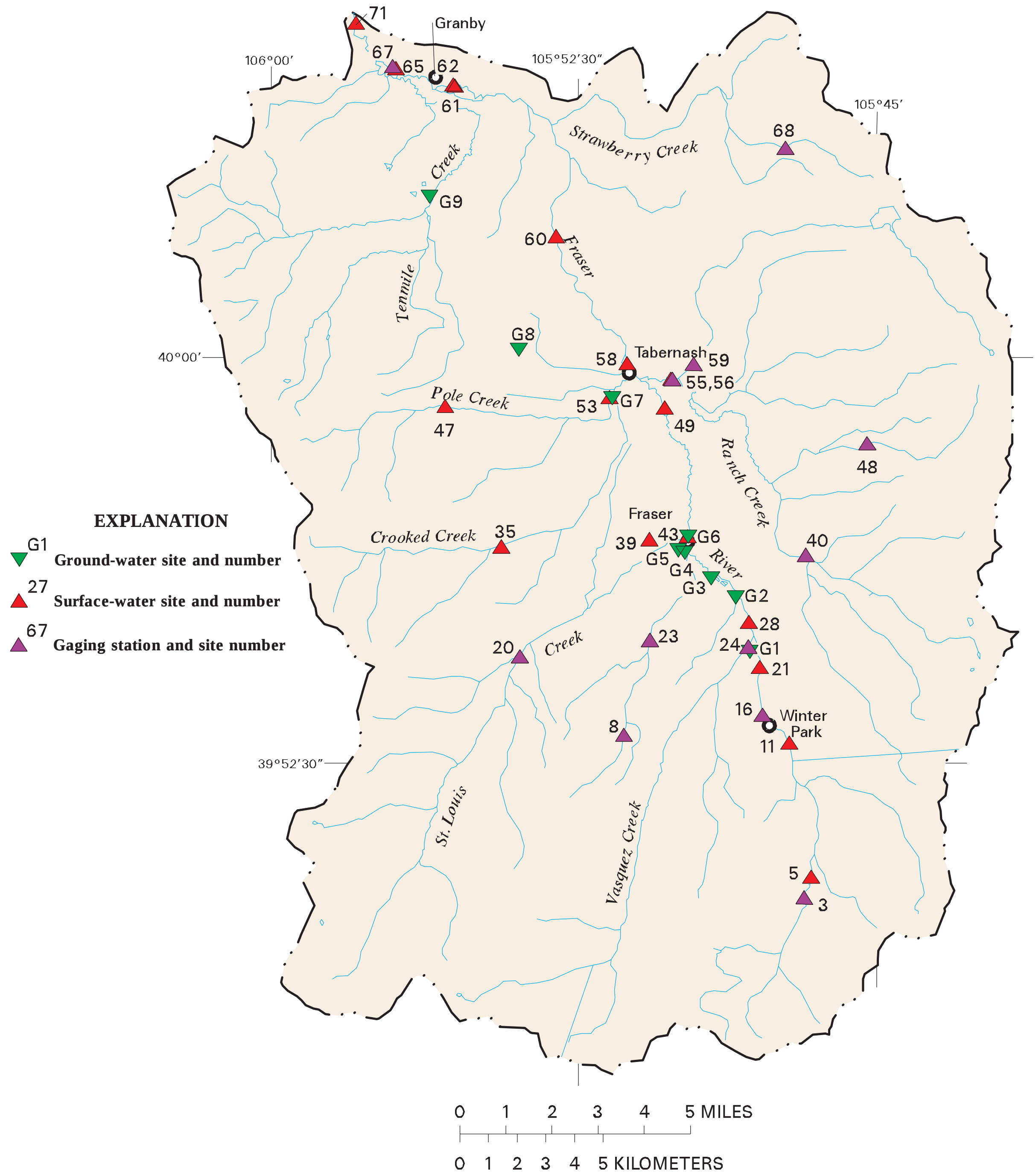

Figure 5. Location of the U.S. Geological Survey (USGS) National Water Information System (NWIS) ground-water-quality and surface-water-quantity and water-quality sites in the Fraser River watershed.

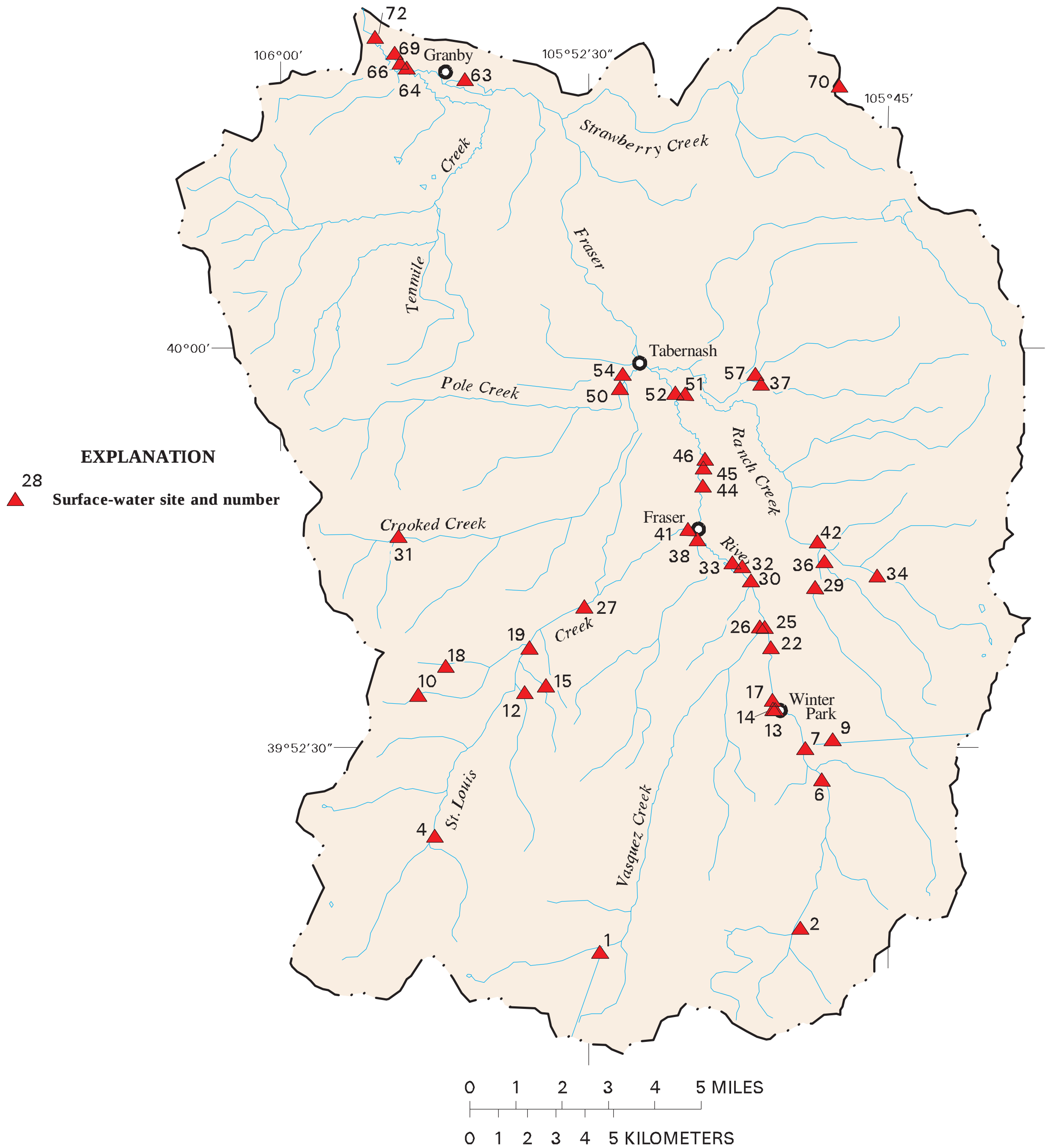

Figure 6. Location of the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval (STORET) surface-water-quality sites in the Fraser River watershed.

Table 2. Characteristics of ground-water-quality sites from the U.S. Geological Survey (USGS) National Water Information System (NWIS) data base in the Fraser River watershed

[---, no data; ft, feet; PVC, polyvinyl chloride; USGS, U.S. Geological Survey; FP, field parameters, MI, major ions; N, nutrients; O, other constituents (bacteria, chlorofluorocarbons, and/or methylene blue active substances); P, pesticides; TE, trace elements; VOC's, volatile organic compounds; land-use/land-cover classifications for the ground-water sites are based on the predominant land use/land cover within a 500-meter radius of the well location]

Site no. (fig. 5)	Site identification number (latitude-longitude)	Water use[1]	Well-depth (ft)	Static water level below land surface (ft)[2]	Casing	Year constructed	Data source	Type of data	Aquifer	Land use/land cover
G1	395507105470200	U	26	3.8 (5.95)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Urban
G2	395605106473100	U	22	6.36 (7.85)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Rangeland
G3	395623105481000	U	17	0.90 (9.60)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Rangeland
G4	395648105485300	U	16	1.94 (2.8)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Urban
G5	395658105485400	PS	110	---	Steel	1983	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Urban
G6	395706105485000	U	18	2.84 (3.55)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Urban
G7	395929105510300	U	28	6.97 (9.3)	PVC	1996	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Rangeland
G8	395935105535800	H	115	70	PVC	1968	USGS	FP, MI, N, O, P, TE, VOC's	Alluvium	Forest
G9	400248105560300	---	603	---	---	---	USGS	FP, MI, N, TE	Middle Park Formation	Rangeland

[1]Water use: H, domestic; PS, public supply, U, unused.
[2]Static water level for May 1997; number in parentheses is static water level measured in October 1997.

Table 3. Characteristics of surface-water-quality sites in the Fraser River watershed

[no., number; latitude and longitude = degrees, minutes, and seconds; mi^2, square miles; ---, no data; ft, feet; n.d., not determined; CDPHE, Colorado Department of Public Health and Environment; DWB, Denver Water Board; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; USGS, U.S. Geological Survey; FP, field parameters; MI, major ions; N, nutrients; O, other constituents (bacteria and/or suspended sediment); Q, discharge; TE, trace elements; surface-water land-use/land-cover classifications are determined by the land use/land cover upstream from the surface-water site; if the site was within an urban area, the site was classified as urban]

Site no. (figs. 5 and 6)	Site name	Station identification number	Latitude	Longitude	Drainage area (mi^2)	Data source	Period of record, in water years	Type of data	Land use/land cover
1	Upper Colorado River, Upper Vasquez #45	394900105501001	39°49'00"	105°50'10"	---	USFS	1977–78	FP, O, Q	Forest
2	Upper Colorado River, Fraser River at Berthoud Pass #47	394950105452001	39°49'50"	105°45'20"	---	USFS	1977	FP, O, Q	Forest
3	Fraser River at Upper Station near Winter Park, CO	09022000	39°50'45"	105°45'05"	10.5	USGS	1969–97	FP, MI, N, Q, TE	Forest
4	Upper Colorado River, East St. Louis Creek #42	395050105543001	39°50'50"	105°54'30"	---	USFS	1977	FP, O, Q	Forest
5	Fraser River above Mary Jane	395104105460000	39°51'04"	105°46'00"	---	USGS	1976–77	FP, MI, N, O, Q TE	Forest
6	Jim Creek at intake near Taber-nash	395212105452501	39°52'12"	105°45'25"	---	DWB	1982	FP, MI, N, O, TE	Forest
7	Upper Colorado River, Fraser River at USGS station #48	395310105484001	39°53'10"	105°48'40"	---	USFS	1977–78	FP, O, Q	Forest
8	Elk Creek at Upper Station near Fraser, CO	09025300	39°53'22"	105°49'55"	1.67	USGS	1996–97	FP, Q	Forest
9	Ranch Creek at intake near Tabernash	395323105450501	39°53'23"	105°45'05"	---	DWB	1982	FP, MI, N, O, TE	Forest
10	Upper Colorado River, Lexen Creek #55	395330105552001	39°53'30"	105°55'20"	---	USFS	1977–79	FP, O, Q	Forest
11	Fraser River below Buck Creek at Winter Park, CO	09023750	39°53'33"	105°45'49"	25.6	USGS	1990–97	FP, MI, N, Q	Forest
12	Upper Colorado River, Upper St. Louis Creek #44	395340105524001	39°53'40"	105°52'40"	---	USFS	1977	FP, O, Q	Forest
13	Upper Colorado River Basin, Fraser River	395350105463001	39°53'50"	105°46'30"	---	CDPHE	1983–84	FP, MI, N	Urban
14	Upper Colorado River, Winter Park WWTP	395350105463301	39°53'50"	105°46'33"	---	CDPHE	1982–84	FP, MI, N	Urban
15	Upper Colorado River, Fool Creek #40	395350105521001	39°53'50"	105°52'10"	---	USFS	1977	FP, O, Q	Forest
16	Fraser River at Winter Park, CO	09024000	39°54'00"	105°46'34"	27.6	USGS	1910–97	FP, MI, N, O, Q, TE	Urban
17	Upper Colorado Basin, Fraser River at USGS gage	395400105463501	39°54'00"	105°46'35"	---	CDPHE	1982–84	FP, MI, N	Urban
18	Upper Colorado River, Dead Horse Creek #43	395400105544001	39°54'00"	105°54'40"	---	USFS	1977–79	FP, O, Q	Forest

Table 3. Characteristics of surface-water-quality sites in the Fraser River watershed—Continued

[no., number; latitude and longitude = degrees, minutes, and seconds; mi^2, square miles; ---, no data; ft, feet; n.d., not determined; CDPHE, Colorado Department of Public Health and Environment; DWB, Denver Water Board; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; USGS, U.S. Geological Survey; FP, field parameters; MI, major ions; N, nutrients; O, other constituents (bacteria and/or suspended sediment); Q, discharge; TE, trace elements; surface-water land-use/land-cover classifications are determined by the land use/land cover upstream from the surface-water site; if the site was within an urban area, the site was classified as urban]

Site no. (figs. 5 and 6)	Site name	Station identification number	Latitude	Longitude	Drainage area (mi^2)	Data source	Period of record, in water years	Type of data	Land use/land cover
19	Upper Colorado River, Main St. Louis Creek #41	395430105524001	39°54'30"	105°52'40"	---	USFS	1977	FP, O, Q	Forest
20	St. Louis Creek near Fraser, CO	09026500	39°54'36"	105°52'40"	32.9	USGS	1934–97	FP, Q	Forest
21	Fraser River near Fraser	395452105464500	39°54'52"	105°46'45"	---	USGS	1976–77	FP. MI, N, O, Q, TE	Urban
22	Fraser River at Winter Park Ski Resort	12163	39°54'59"	105°46'34"	---	CDPHE	1996–97	FP, MI, N, O, TE	Urban
23	Elk Creek near Fraser, CO	09025400	39°55'09"	105°49'31"	7.15	USGS	1971–96	FP, Q	Forest
24	Vasquez Creek at Winter Park, CO	09025000	39°55'13"	105°47'05"	27.8	USGS	1934–97	FP, Q	Urban
25	Upper Colorado River Basin, Fraser River	395520105465801	39°55'20"	105°46'58"	---	CDPHE	1984	FP, MI, N	Urban
26	Upper Colorado River Basin, Vasquez	395520105470501	39°55'20"	105°47'05"	---	CDPHE	1982–84	FP, MI, N	Urban
27	St. Louis Creek above Fraser	12165	39°55'22"	105°51'26"	---	CDPHE	1996–97	FP, MI, N, O, TE	Forest
28	Fraser River below Vasquez Creek at Winter Park, CO	09025010	39°55'40"	105°47'08"	59.1	USGS	1990–97	FP, MI, N, O, Q, TE	Urban
29	Upper Colorado River, South Fork Ranch #30	395610105455001	39°56'10"	105°45'50"	---	USFS	1976–78	Q	Forest
30	Upper Colorado River Basin, Fraser River above Grand WWT	395610105472501	39°56'10"	105°47'25"	---	CDPHE	1982–84	FP, MI, N	Urban
31	Upper Colorado River, Crooked Creek #54	395620105561001	39°56'20"	105°56'10"	---	USFS	1977	FP, O, Q	Forest
32	Upper Colorado River, Grand County WWTF no. 1	395625105474001	39°56'25"	105°47'40"	---	CDPHE	1982–84	FP, MI, N	Urban
33	Upper Colorado River Basin, Fraser River below Grand WWT	395628105475501	39°56'28"	105°47'55"	---	CDPHE	1982–84	FP, MI, N	Urban
34	Upper Colorado River, Main Ranch Creek #29	395630105442001	39°56'30"	105°44'20"	---	USFS	1978	Q	Forest
35	Crooked Creek below Tipperary Creak near Tabernash, CO	395634105532401	39°56'34"	105°53'24"	---	USGS	1997	FP, MI, N, O, Q	Forest
36	Upper Colorado River, Middle Fork Ranch Creek #31	395640105454001	39°56'40"	105°45'40"	---	USFS	1976	Q	Forest

Table 3. Characteristics of surface-water-quality sites in the Fraser River watershed—Continued

[no., number; latitude and longitude = degrees, minutes, and seconds; mi^2, square miles; ---, no data; ft, feet; n.d., not determined; CDPHE, Colorado Department of Public Health and Environment; DWB, Denver Water Board; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; USGS, U.S. Geological Survey; FP, field parameters; MI, major ions; N, nutrients; O, other constituents (bacteria and/or suspended sediment); Q, discharge; TE, trace elements; surface-water land-use/land-cover classifications are determined by the land use/land cover upstream from the surface-water site; if the site was within an urban area, the site was classified as urban]

Site no. (figs. 5 and 6)	Site name	Station identification number	Latitude	Longitude	Drainage area (mi^2)	Data source	Period of record, in water years	Type of data	Land use/land cover
37	Upper Colorado River, Hamilton Creek at Mouth #28	395950105474001	39°59'50"	105°47'40"	---	USFS	1978	Q	Forest
38	Upper Colorado River Basin, Fraser River	395650105485001	39°56'50"	105°48'50"	---	CDPHE	1984	FP, MI, N	Urban
39	St. Louis Creek above Fraser, CO	395659105494700	39°56'59"	105°49'47"	---	USGS	1976	FP, N, O, Q	Range-land
40	Ranch Creek near Fraser, CO	09032000	39°57'00"	105°45'54"	19.9	USGS	1957–97	FP, MI, N, O, Q	Forest
41	Upper Colorado River Basin, St. Louis Creek	395700105490501	39°57'00"	105°49'05"	---	CDPHE	1984	FP, MI, N	Urban
42	Ranch Creek 3 mi east of US 40 near Fraser	395701105455301	39°57'01"	105°45'53"	---	DWB	1981	FP, MI, N, O, TE	Forest
43	Fraser River below St. Louis Creek at Fraser, CO	09027010	39°57'07"	105°48'51"	111	USGS	1956–97	FP, N, Q	Urban
44	Upper Colorado River Basin, Fraser River above Fraser WWTP	395750105485001	39°57'50"	105°48'50"	---	CDPHE	1982–84	FP, MI, N	Urban
45	Upper Colorado River, Fraser WWTP	395810105485201	39°58'10"	105°48'52"	---	CDPHE	1982–84	FP, MI, N	Urban
46	Upper Colorado, Fraser River 300 ft below Fraser WWTP	395820105485101	39°58'20"	105°48'51"	---	CDPHE	1982–83	FP, MI, N	Urban
47	Pole Creek at Upper Station near Tabernash, CO	395901105550800	39°59'01"	105°55'08"	---	USGS	1997	FP, MI, N, O, Q	Range-land
48	Cabin Creek near Fraser, CO	09032100	39°59'09"	105°44'40"	4.87	USGS	1984–97	FP, Q	Forest
49	Fraser River at Tabernash, CO	09027100	39°59'25"	105°49'44"	116	USGS	1990–97	FP, MI, N, Q, TE	Urban
50	Pole Creek near Tabernash	12164	39°59'29"	105°51'07"	---	CDPHE	1996–97	FP, MI, N, O, TE	Range-land
51	Upper Colorado River, Ranch Creek	395930105493001	39°59'30"	105°49'30"	---	CDPHE	1982–83	FP, MI, N	Range-land
52	Upper Colorado River, Fraser near Tabernash	395930105494501	39°59'30"	105°49'45"	---	CDPHE	1982–84	FP, MI, N	Urban
53	Pole Creek at Mouth near Taber-nash, CO	395930105510700	39°59'30"	105°51'07"	---	USGS	1997	FP, MI, Q	Range-land
54	Upper Colorado River, Pole Creek	395945105510501	39°59'45"	105°51'05"	---	CDPHE	1982–83	FP, MI, N	Range-land

Table 3. Characteristics of surface-water-quality sites in the Fraser River watershed—Continued

[no., number; latitude and longitude = degrees, minutes, and seconds; mi^2, square miles; ---, no data; ft, feet; n.d., not determined; CDPHE, Colorado Department of Public Health and Environment; DWB, Denver Water Board; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; USGS, U.S. Geological Survey; FP, field parameters; MI, major ions; N, nutrients; O, other constituents (bacteria and/or suspended sediment); Q, discharge; TE, trace elements; surface-water land-use/land-cover classifications are determined by the land use/land cover upstream from the surface-water site; if the site was within an urban area, the site was classified as urban]

Site no. (figs. 5 and 6)	Site name	Station identification number	Latitude	Longitude	Drainage area (mi^2)	Data source	Period of record, in water years	Type of data	Land use/land cover
55	Ranch Creek below Meadow Creek near Tabernash, CO	09033100	39°59'57"	105°49'37"	n.d.	USGS	1997	FP, MI, N, O, Q	Range-land
56	Ranch Creek near Tabernash, CO	395957105493900	39°59'57"	105°49'39"	---	USGS	1976	FP, N, O, Q	Range-land
57	Upper Colorado River, Hurd Creek at Mouth #27	400000105475001	40°00'00"	105°47'50"	---	USFS	1976	Q	Forest
58	Fraser River below Crooked Creek at Tabernash, CO	400009105504600	40°00'09"	105°50'46"	4.87	USGS	1991–94	FP, N, Q	Urban
59	Meadow Creek at mouth near Tabernash, CO	400016105490800	40°00'16"	105°49'08"	n.d.	USGS	1997	FP, Q	Forest
60	Fraser River below Tabernash, CO	400220105525000	40°02'20"	105°52'50"	---	USGS	1976–77	FP, N, O, Q	Urban
61	Fraser River at Hwy. 40 at Granby, CO	400453105554200	40°04'53"	105°55'42"	---	USGS	1995	FP, MI, N, Q, TE	Urban
62	Fraser River above Granby near Granby, CO	400454105554500	40°04'54"	105°55'45"	---	USGS	1976	FP, N, O, Q	Urban
63	Upper Colorado River, Fraser River near Granby, CO	400454105554201	40°04'54"	105°55'42"	---	CDPHE	1979–92	FP, MI, N, O, TE	Urban
64	Upper Colorado River Basin, Fraser River	400500105571001	40°05'00"	105°57'10"	---	CDPHE	1984	FP, MI, N	Urban
65	Fraser River below Granby, CO	400505105571201	40°05'05"	105°57'12"	---	USGS	1977–79	FP, MI, N, Q, TE	Urban
66	Upper Colorado River, Fraser River	400505105572001	40°05'05"	105°57'20"	---	CDPHE	1982–84	FP, MI, N	Urban
67	Fraser River at Granby, CO	09034000	40°05'07"	105°57'17"	297	USGS	1904–09 1938–55	FP, Q	Urban
68	Strawberry Creek near Granby, CO	09033500	40°05'12"	105°47'39"	11.6	USGS	1936–45 1983	Q	Forest
69	Upper Colorado River Basin, Fraser River	400515105573001	40°05'15"	105°57'30"	---	CDPHE	1984	FP, MI, N, TE	Urban
70	Meadow Creek at Divide near Tabernash, CO	400530105463001	40°05'30"	105°46'30"	---	DWB	1981	FP, MI, N, O	Forest
71	Fraser River near Mouth near Granby, CO	400550105581800	40°05'50"	105°58'18"	---	USGS	1995	FP, MI, N, Q, TE	Urban
72	Fraser River, Granby Sanitation	401000105580001	40°10'00"	105°58'00"	---	USEPA	1974–83	FP, MI, N, O	Urban

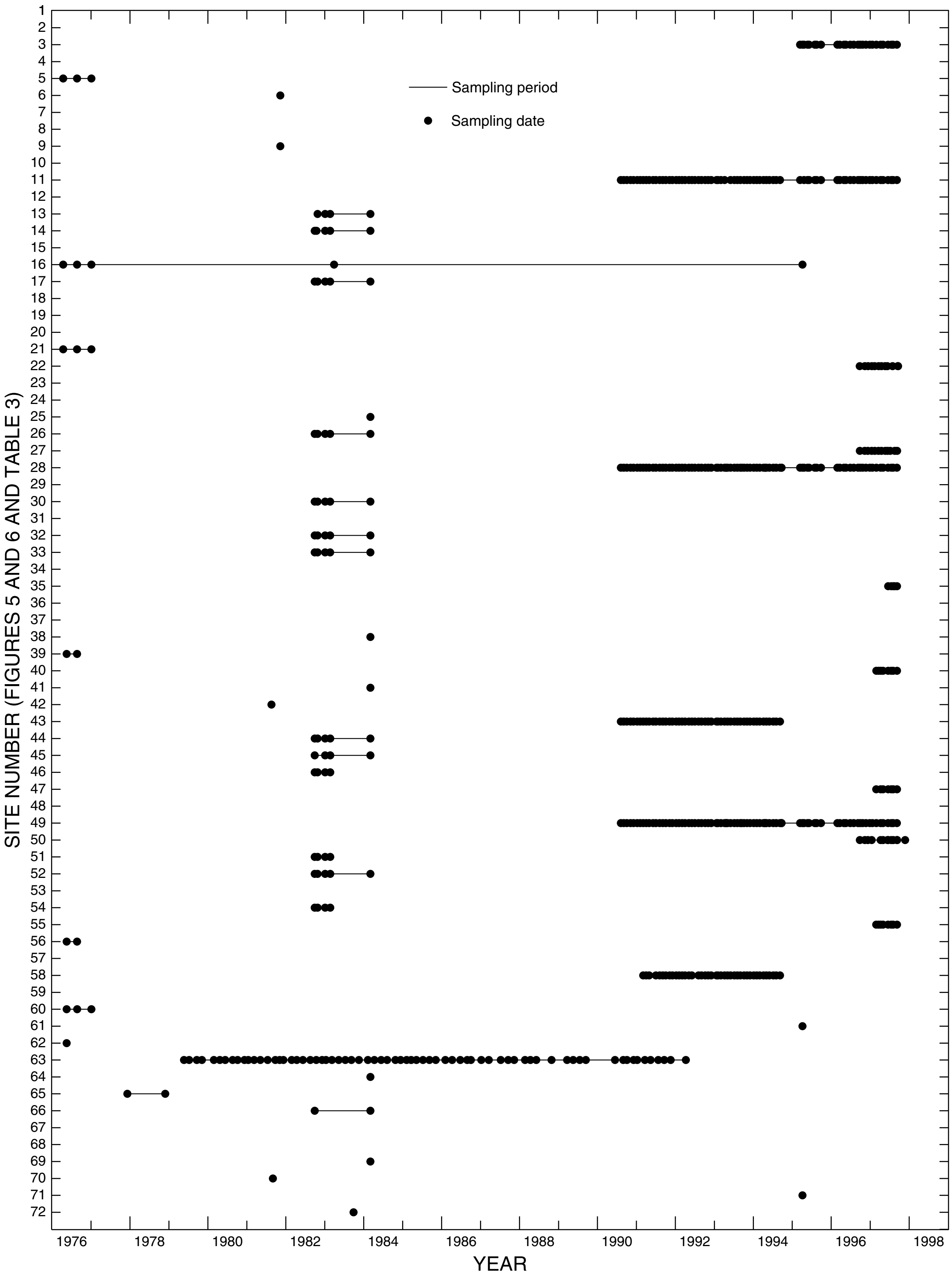

Figure 7. Distribution of sampling dates and period of record for the National Water Information System (NWIS) and the Storage and Retrieval (STORET) surface-water sites for nutrient data collected in the Fraser River watershed.

lines to the boundary points of the boxplot). If analytical values fall outside the 10^{th} and 90^{th} percentile (outliers), they are represented on the boxplots as circles above and below these percentile values on the boxplots.

Nutrient data in this report have been grouped into equivalent nitrogen and phosphorus species using methods described in Mueller and others (1995). The reason for grouping the nutrient species is that nutrient species have been collected for various reasons and are reported in different ways in the data bases. In examining the spatial distribution of nutrients in the watershed, the following nutrient species are discussed: ammonia as N (hereinafter referred to as ammonia); nitrite as N (hereinafter referred to as nitrite); nitrate as N (hereinafter referred to as nitrate); orthophosphate as P (hereinafter referred to as orthophosphate); and total phosphorus. To evaluate the spatial distributions of nutrient species in the watershed, the site location and the median nutrient concentrations were entered into a geographic information system (GIS) file and are represented graphically. Trends were evaluated using the surface-water nutrient data, as they are useful in showing the temporal variability at individual water-quality sites and among sites.

Four sites in the watershed had sufficient data for statistical trend tests. The seasonal Kendall test (Hirsch and others, 1991), a nonparametric test, was used to determine if the trend analysis shows whether or not nutrient concentrations have changed over time. This test accounts for seasonal effects on concentration by only comparing data within the same season. Flow-adjusted concentrations were not used in the trend analysis because no correlations were observed between discharge and concentration by plotting the data on normal, log-normal, and log-log plots. In addition, constituents having greater than 10 percent of the data censored were not flow adjusted because flow adjustment is not possible with nonparametric procedures when a high percentage of the data are censored (Hirsch and others, 1991). Sites used for calculating trends have at least 5 years of record with a minimum of quarterly sampling. In addition, at least one-half of the possible number of seasonal, pairwise data comparisons must have been present in the first and last thirds of the record (Lanfear and Alexander, 1990). For the sites used in determining trends, not more than 50 percent of the data were censored.

The water-quality data have been compared to drinking-water standards and stream-segment standards, where applicable. Drinking-water standards include the primary (MCL), secondary (SMCL), and proposed (PMCL) USEPA maximum contaminant levels established for drinking water, maximum contaminant level goals (MCLG), drinking-water advisory (DWA), and health advisory (HA) standards (U.S. Environmental Protection Agency, 1996). USEPA drinking-water standards are defined as the permissible level of a contaminant in water as delivered to users of a public water system. MCL’s are health related and legally enforceable, whereas SMCL’s apply to the esthetic qualities of water and are recommended levels. PMCL’s are proposed levels that are not currently enforceable. MCLG's are nonenforceable concentrations of a drinking-water contaminant that are intended for protection against adverse human health effects. DWA is intended to protect against taste and odor problems. The USEPA HA's used in this report are defined as the concentration of a contaminant in drinking water that is expected to cause adverse, but noncarcinogenic, effects over a lifetime of typical exposure. The typical exposure assumes that a 70-kilogram adult drinks 2 liters of such water per day for 70 years (U.S. Environmental Protection Agency, 1996). Stream-segment standards include aquatic-life chronic and acute values, and table-value standards for selected elements, which are calculated on the basis of hardness of the water (Colorado Water Quality Control Commission, 1996). Field temperature and pH are used in determining the cold-water chronic and acute values for ammonia in surface water (Colorado Water Quality Control Commission, 1996).

Land-use/land-cover classifications for the ground-water sites are based on the predominant land use/land cover within a 500-meter radius of the well location. Surface-water land-use/land-cover classifications are determined by the land use/land cover upstream from the surface-water site; if the site was within an urban area, the site was classified as urban. For example, the area from Winter Park to Fraser would have a predominant land-use/land-cover classification of urban even though urban development is not continuous between these towns. Land-use/land-cover classifications used in the analysis of the data were grouped into forest (includes deciduous, evergreen, and mixed forest), rangeland (includes all rangeland classifications as well as cropland, pasture, and agriculture), and urban (other urban, commercial, residential, and mixed urban) land use (fig. 4). These land-use classifications include the predominant land use/land cover for the ground-water and surface-water sites in the watershed.

GROUND WATER

Water Quantity

Water-level measurements obtained from the Colorado Division of Water Resources well permit data base were used to generate a generalized water-table map (fig. 8) for part of the watershed upstream from Tabernash. The wells in this area (fig. 3) were completed in the alluvial and Troublesome Formation aquifers. To limit the seasonal variability of the water table, only fall (August, September, and October) water-level measurements were used to compile this map from 129 wells. Water-level information is available for wells installed between 1960 and 1996. Ground-water flow directions are from higher altitudes to lower altitudes in the watershed and generally follow topography. The depth to water in the area ranged from 3 to 240 ft. The water-table map was constructed using 100-ft contour intervals because of limited data and uncertainties with the data. The uncertainties are related to the accuracy of the well locations and to the possibility that the water-level measurements, which are taken upon completion of drilling, may not reflect the static water level.

Common yields for wells in alluvial aquifers in the Upper Colorado River Basin range from 5 to 100 gal/min but can exceed 500 gal/min (U.S. Geological Survey, 1985). Results from aquifer tests of the alluvial aquifer near Granby indicate that at a depth of about 15 ft the alluvial aquifer yields 100 gal/min with only a few feet of drawdown (Voegeli, 1965). Transmissivity for the alluvial aquifer near Granby was 12,000 gpd/ft. Near the town of Fraser, aquifer tests conducted in 1994 from wells installed in the Troublesome Formation indicated yields that ranged from 110 to 220 gal/min and transmissivities that ranged from 5,000 to 11,000 gpd/ft (Winter Park West Water and Sanitation District, written commun., 1997).

The available ground-water resources for the watershed can be estimated on the basis of the saturated thickness of the aquifers and their specific yield. The areal extent of the exposed Troublesome Formation and the alluvial deposits in the Fraser River watershed upstream from Tabernash is about 52 mi^2 (Green, 1992; Tweto, 1979). This area was selected for estimating the ground-water reserves because of the likelihood that these aquifers will provide water for a part of the watershed that is being affected by increasing urban development. In order to calculate ground-water reserves, a few assumptions were made. Saturated thickness for the aquifers was assumed to be 400 ft with a specific yield ranging from 0.12 to 0.2 (Fetter, 1994; Bishop-Brogden Associates, Inc., written commun., 1997). Total estimated volume of ground water available from the Troublesome Formation and the overlying alluvium ranges from about 1.6 to 2.7 million acre-ft. The specific yield for the aquifers is believed to be variable as a result of changes in the lithology of the Troublesome Formation. The lower specific yield used to calculate ground-water reserves is representative of a fine sand and shale aquifer (Fetter, 1994) and the higher specific yield value is more representative of a sand and gravel alluvial aquifer (Wilson, 1965). Additional information is needed to obtain a more accurate calculation of the ground-water reserves in the alluvial and Troublesome Formation aquifers upstream from Tabernash.

Water Quality

Historical ground-water-quality data for the Fraser River watershed consist of one site sampled in 1974 from the Middle Park Formation along the Tenmile Creek drainage (G9, fig. 5). Ground-water-quality data collected by the UCOL NAWQA Program provides information from 1997 on water-quality conditions in the alluvial aquifer in the area from Winter Park to Tabernash (fig. 5). Six monitoring wells were installed in the alluvium as part of the UCOL NAWQA Program in 1996 and were sampled for water-quality constituents in May and October of 1997 (G1–G4, G6, and G7, table 2). The wells were installed following the NAWQA Program protocols in order to limit possible contamination of the water-quality constituents and properties (Lapham and others, 1995). The purpose of this sampling was to provide information on water-quality conditions in an

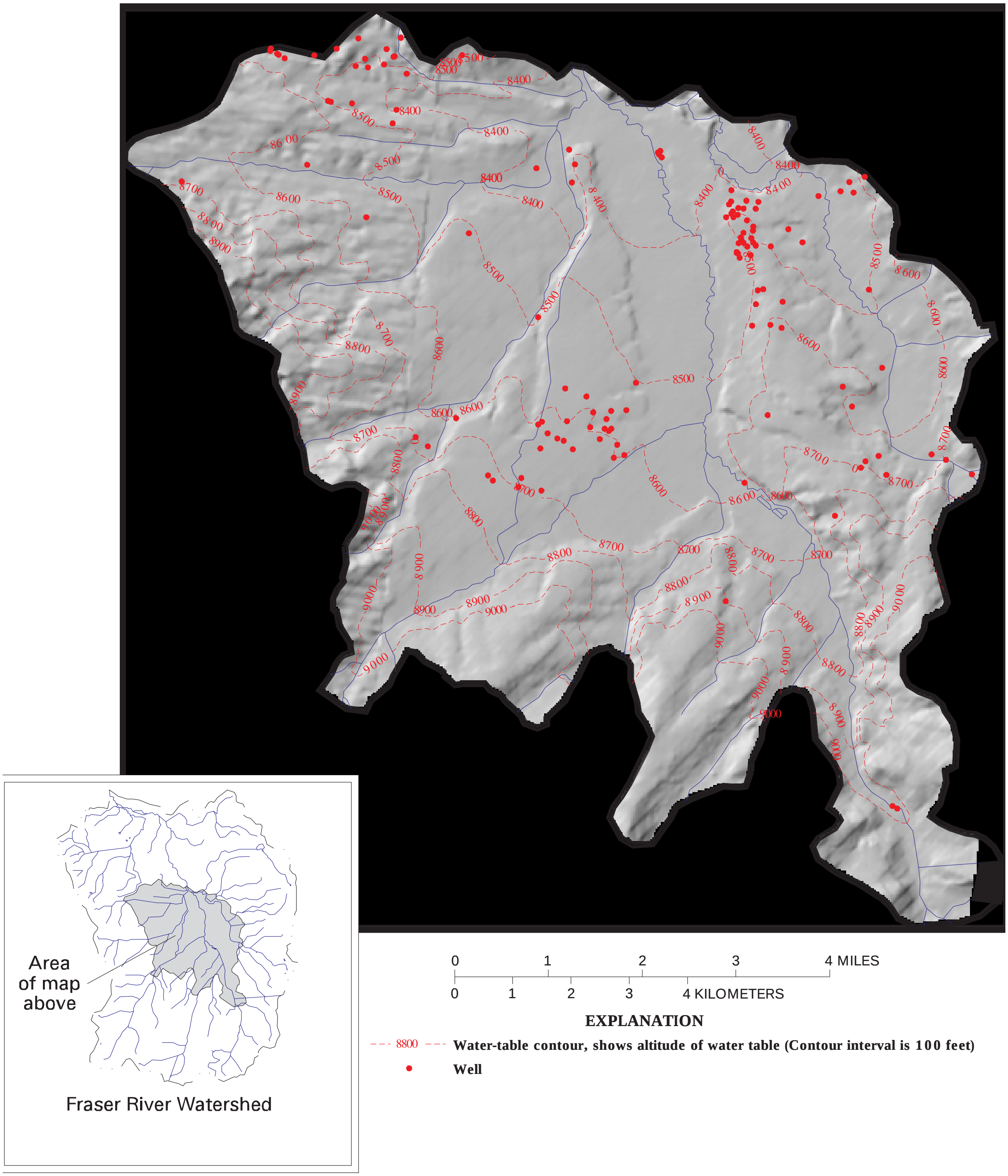

Figure 8. Generalized water-table map for the alluvial and Troublesome Formation aquifers upstream from Tabernash in the Fraser River watershed (1960–96).

area that is undergoing increasing urban development. These wells were installed to assess the effects of land use on the ground-water quality. In addition, two pre-existing wells in the alluvium were sampled in the watershed in September 1997 (G5 and G8, table 2). These wells were sampled as part of another UCOL NAWQA study, which was designed to describe water-quality conditions in alluvial aquifers in the Southern Rocky Mountains physiographic province.

All ground-water sites were sampled in accordance with the procedures and protocols of the NAWQA Program as described in Koterba and others (1995). Field parameters, which included specific conductance, pH, temperature, dissolved oxygen, alkalinity, and turbidity, were measured at all sites. Samples collected from the sites were analyzed for major ions, nutrients, trace elements, radon-222, DOC, 87 pesticides (pre-existing wells were sampled for only 47 pesticides), and 87 VOC's. The following analytical methods were used: Inorganics, various methods (Fishman and Friedman, 1989); Radon-222, liquid scintillation counting (American Society for Testing and Materials, 1992); DOC, ultraviolet (UV) promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993); Pesticides, solid-phase extraction (SPE) technology on a C-18 cartridge and gas chromatography/mass spectrometry (Zaugg and others, 1995); and VOC's, purge and trap capillary gas chromatography/mass spectrometry (Rose and Schroeder, 1995).

Ground-water samples collected for the study also were analyzed for total coliform and *E. coli* by using the mENDO and NA-MUG method (American Public Health Association and others, 1992; Britton and Greeson, 1989; U.S. Environmental Protection Agency, 1991). This method allows all positive total coliform membranes to be transferred to a NA-MUG plate in order to determine if total coliform colonies are positive for *E. coli*. Four sites were analyzed for total coliform using an MI agar (Brenner and others, 1993), and these same sites were analyzed for somatic coliphage (Sobsey and others, 1995). Ground-water samples analyzed for bacteria were collected in a sterilized (autoclaved) bottle using a peristaltic pump with autoclaved tubing. In May 1997, samples were analyzed for CFC's (Plummer and others, 1993).

Quality-control and quality-assurance samples were collected during these sampling efforts and represented about 10 percent of the total samples collected. Water-quality samples were analyzed at the USGS National Water Quality Laboratory in Arvada, Colo., and CFC's were analyzed at the USGS CFC Laboratory in Reston, Va.

OCCURRENCE OF INORGANIC COMPOUNDS

Table 4 provides a summary of the water-quality properties and constituents for the eight shallow alluvial wells sampled (total of 14 samples) in the Fraser River watershed by the UCOL NAWQA Program and also indicates the USEPA drinking-water and HA standards. Appendix I lists all properties and constituents measured and analyzed for the ground-water samples collected as part of the UCOL NAWQA Program. The pH values ranged from 5.8 to about 7.6 with a median value of about 6.6. USEPA SMCL's for pH, which are recommended values, range from 6.5 to 8.5 (table 4). For the Fraser River watershed 28 percent of the samples (4 of 14) were below the 6.5 pH value. Dissolved oxygen ranged from 0.10 to 5.87 mg/L, with values less than 0.3 mg/L at half the sites. Dissolved-oxygen values of less than 1.0 mg/L can be considered low values for the Fraser River watershed. The odor of hydrogen sulfide was apparent at some of the sites with the very low dissolved-oxygen concentrations, indicating anaerobic conditions.

Major ion chemistry of the ground-water samples showed that the dominant ions were calcium, chloride, and bicarbonate. For some of the wells, sulfate also was a major anion. Ground-water composition is dependent upon the interactions between the water and soil and minerals present in the aquifer material through which the water had moved. In the waters sampled, most inorganic constituents were less than drinking-water standards; however, a few inorganic constituents exceeded drinking-water standards. The USEPA SMCL for dissolved iron (300 μg/L) was exceeded in 50 percent of the samples (7 of 14). High iron concentrations in drinking water form red precipitates that stain laundry and plumbing fixtures (Hem, 1992). For dissolved manganese, the USEPA SMCL (50 μg/L) was exceeded in 71 percent of the samples (10 of 14). High manganese concentrations in drinking water can cause a brown discoloration of the water and affect the taste of the water. In addition, high concentrations of manganese in drinking water are undesirable because of the tendency to deposit black-oxide stains (Hem, 1992). The presence of high concentrations of iron and manganese in the ground water is probably a function of the surrounding geology (sedi-

Table 4. Summary of the minimum, median, and maximum values for the ground-water-quality properties and constituents for wells sampled for the Upper Colorado River Basin (UCOL) NAWQA study

[---, no data; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming units; pCi/L, picocuries per liter; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; PMCL, proposed maximum contaminant level; MCLG, maximum contaminant level goal; DWA, drinking-water advisory; HA, health advisory level]

Properties, constituents, and reporting unit	Number of analyses/ number of detections	Minimum	Median	Maximum	USEPA drinking-water standards or health advisories
Water temperature (degrees Celsius)	14/14	5.20	8.45	16.5	---
Specific conductance, field (µS/cm)	14/14	94.0	185	717	---
Dissolved solids (mg/L)	14/14	61.0	117	376	500 (SMCL)
Hardness, total (mg/L as $CaCO_3$)	14/14	24.0	66.5	200	---
Oxygen, dissolved (mg/L)	14/14	0.10	0.32	5.87	---
pH, field (standard units)	14/14	5.8	6.6	7.6	6.5-8.5 (SMCL)
Alkalinity, lab (mg/L as $CaCO_3$)	14/14	37.2	68.3	179	---
Turbidity (NTU)	14/14	0.2	3.2	46	---
Major ions					
Bicarbonate, dissolved (mg/L)	14/14	45.4	83.4	219	---
Calcium, dissolved (mg/L)	14/14	7.0	19.8	68.4	---
Chloride, dissolved (mg/L)	14/14	0.69	5.89	85.6	250 (SMCL)
Fluoride, dissolved (mg/L)	14/14	0.16	0.23	0.40	2.0 (SMCL)
Magnesium, dissolved (mg/L)	14/14	1.58	3.85	12.9	---
Potassium, dissolved (mg/L)	14/14	1.06	1.91	4.31	---
Silica, dissolved (mg/L as SiO_2)	14/14	10.0	22.8	34.9	---
Sodium, dissolved (mg/L)	14/14	5.08	7.38	37.8	---
Sulfate, dissolved (mg/L)	14/14	0.24	1.92	7.20	250 (SMCL)
Nutrients					
Ammonia, dissolved (mg/L as N)	14/5	0.02	0.15	0.55	30 (HA)
Nitrite, dissolved (mg/L as N)	14/3	<0.01	<0.01	0.06	1.0 (MCL)
Nitrate, dissolved (mg/L as N)	14/7	<0.05	0.07	1.44	10 (MCL)
Orthophosphate, dissolved (mg/L as P)	14/10	<0.01	0.03	0.65	---
Trace elements					
Aluminum, dissolved (µg/L)	14/14	3.75	8.55	55.9	50-200 (SMCL)
Antimony, dissolved (µg/L)	14/0	<1.0	<1.0	<1.0	6.0 (MCL)
Arsenic, dissolved (µg/L)	14/7	<1.0	<1.0	4.7	50 (MCL)
Barium, dissolved (µg/L)	14/14	12.5	36.7	317	2,000 (MCL)
Beryllium, dissolved (µg/L)	14/0	<1.0	<1.0	<1.0	4.0 (MCL)
Boron, dissolved (µg/L)	14/14	7.38	20.7	43.3	---
Cadmium, dissolved (µg/L)	14/0	<1.0	<1.0	<1.0	5.0 (MCL)
Chromium, dissolved (µg/L)	14/13	<1.0	2.39	6.53	100 (MCL)
Cobalt, dissolved (µg/L)	14/4	<1.0	<1.0	4.58	---
Copper, dissolved (µg/L)	14/8	<1.0	1.31	48.0	1,300 (action level)
Iron, dissolved (µg/L)	14/14	3.0	319	49,890	300 (SMCL)
Lead, dissolved (µg/L)	14/1	<1.0	<1.0	1.03	15 (action level)
Manganese, dissolved (µg/L)	14/12	<1.0	242	2,801	50 (SMCL)
Molybdenum, dissolved (µg/L)	14/8	<1.0	1.40	4.07	---
Nickel, dissolved (µg/L)	14/7	<1.0	1.20	4.19	100 (MCL)
Selenium, dissolved (µg/L)	14/0	<1.0	<1.0	<1.0	50 (MCL)

Table 4. Summary of the minimum, median, and maximum values for the ground-water-quality properties and constituents for wells sampled for the Upper Colorado River Basin (UCOL) NAWQA study—Continued

[---, no data; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming units; pCi/L, picocuries per liter; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; PMCL, proposed maximum contaminant level; MCLG, maximum contaminant level goal; DWA, drinking-water advisory; HA, health advisory level]

Properties, constituents, and reporting unit	Number of analyses/ number of detections	Minimum	Median	Maximum	USEPA drinking-water standards or health advisories
Trace elements—Continued					
Silver, dissolved (µg/L)	14/0	<1.0	<1.0	<1.0	100 (SMCL)
Uranium, dissolved (µg/L)	14/2	<1.0	1.06	2.55	20 (PMCL)
Zinc, dissolved (µg/L)	14/4	<1.0	<1.0	257	5,000 (SCML)
Volatile organic compounds					
1,1-Dichloroethane (µg/L)	14/1	---	0.19	---	---
123-Trimethylbenzene (µg/L)	14/1	---	2.13	---	---
124-Trimethylbenzene (µg/L)	14/2	8.65	10.2	11.8	---
135-Trimethylbenzene (µg/L)	14/1	---	1.13	---	---
Acetone (µg/L)	14/1	---	7.54	---	---
Benzene (µg/L)	14/1	---	0.66	---	5.0 (MCL)
Ethylenebenzene (µg/L)	14/1	---	3.52	---	700 (MCL)
Isodurane (µg/L)	14/1	---	6.86	---	---
Isopropyl-benzene (µg/L)	14/1	---	9.37	---	---
M/p xylene unfiltered (µg/L)	14/1	---	11.2	---	---
Methyl ethyl ketone (µg/L)	14/1	---	6.11	---	---
Methyl *tert*-butyl ether (MTBE) (µg/L)	14/1	---	0.29	---	20-40 (DWA)
Napthalene (µg/L)	14/1	---	5.57	---	---
N-butyl-benzene (µg/L)	14/1	---	3.58	---	---
N-propyl-benzene (µg/L)	14/2	1.29	4.72	8.14	---
P-isopropyltoluene (µg/L)	14/1	---	0.27	---	---
Sec-butyl-benzene (µg/L)	14/2	2.81	3.22	3.62	---
Toluene (µg/L)	14/1	---	1.2	---	1,000 (MCL)
Toluene O-ethyl (µg/L)	14/2	16.8	18.7	20.6	---
Total O-xylene (µg/L)	14/1	---	1.27	---	---
Other constituents					
Carbon, organic, dissolved (mg/L as C)	14/14	0.60	3.40	7.30	---
Coliforms, total, m-ENDO agar (cols/100 mL)	14/1	<1	<1	80	0 (MCLG)
Coliforms, total, MI agar (cols/100 mL)	4/2	<1	7	55	0 (MCLG)
Coliphage, *E. coli* (pfu)	4/3	<1	5	37	0 (MCLG)
Methylene blue active substances (MBAS) (mg/L)	8/4	<0.02	0.03	0.12	---
Radon-222, total (pCi/L)	14/14	305	3,159	5,943	300 (PMCL)

mentary rocks) and the low dissolved oxygen. The USEPA SMCL for dissolved aluminum (ranges from 50 to 200 µg/L) was exceeded in 7 percent of the samples (1 of 14). The drinking-water standard for aluminum is for control of odor and taste effects.

Nutrient concentrations at all sites were less than drinking-water standards. The most frequently detected nutrient species were orthophosphate and nitrate. Median nutrient concentrations were less than 0.2 mg/L. The maximum nitrate concentration of 1.44 mg/L occurred at site G3 in May 1997.

Radon-222 is a natural decay product of uranium and occurs in soils and rocks. Radon-222 was detected in all wells sampled and ranged in concentration from 305 to 5,943 pCi/L. All of the wells sampled exceeded the USEPA PMCL of 300 pCi/L, which has currently been withdrawn pending further review (U.S. Environmental Protection Agency, 1996). Once a new standard for radon is finalized, ground water in the Fraser River watershed may require treatment before it is used for human consumption. Radon gas, which causes lung cancer, can enter the home through water use, such as showering or by infiltration into the house from the surrounding ground (U.S. Environmental Protection Agency and others, 1992).

The highest radon-222 concentrations were in the wells located near the towns of Winter Park and Fraser (sites G1–G5, and G7 [fig. 5]). Radon-222 concentrations that exceed the PMCL of 300 pCi/L are not uncommon (Paulsen, 1991). Uranium-bearing minerals are found in association with Precambrian rocks, which are present in the Fraser River watershed.

Seasonal variations in the ground-water quality for the six monitoring wells (G1–G4, G6, and G7 [fig. 5]) are indicated by comparison between the May data and the October data. Spring to fall water-table-level measurements dropped from about 1 to 9 ft at these six sites (table 2). Figure 9 shows the distribution of selected water-quality data for the six monitoring wells and the median concentrations. Generally, the median concentration for a given constituent was about the same or slightly higher in the spring than in the fall sampling. For example, median specific-conductance values decreased from 204 µS/cm in the spring to 173 µS/cm in the fall, and median sulfate concentrations also decreased from 3.38 to 1.92 mg/L. Higher concentrations in the spring may be a result of the increased exposure of the ground water to the surrounding geology. However, median concentrations for iron and manganese were similar for both seasons. For land-use/land-cover classifications, the urban sites typically had higher median concentrations for selected water-quality constituents than for rangeland. More ground-water-quality data are needed to more accurately determine the changes in the water quality related to seasonal variations and different land use/land cover.

In addition to the water-quality samples collected by the UCOL NAWQA Program, a ground-water site (site G9 [fig. 5]) in the Tenmile Creek drainage was sampled in 1974 for major ions, nutrients, and trace elements. This well has a depth of 603 ft and is completed in the Middle Park Formation; therefore, the water quality in this well might be expected to be different than the water quality for the shallower aquifers listed in table 2. Nutrient concentrations at this site met all drinking-water standards, and the concentrations for iron (2,900 µg/L) and manganese (80 µg/L) exceeded the SMCL for these elements. Also, water-quality constituents that were sampled in the ground water as described in table 1 were generally less than USEPA MCL drinking-water standards. However, manganese concentrations may exceed drinking-water standards in an alluvial aquifer south of Granby and lead concentrations also may exceed drinking-water standards as described in table 1 (Silvercreek Water and Sanitation District and Winter Park West Water and Sanitation District).

OCCURRENCE OF ORGANIC COMPOUNDS

Information on the organic compound concentrations is summarized in table 4. Dissolved organic carbon concentrations ranged from 0.60 to 7.30 mg/L, with a median concentration of 3.40 mg/L. Elevated concentrations of DOC in ground water are typically accompanied by low concentrations of dissolved oxygen and elevated concentrations of reduced species, such as dissolved iron and manganese, indicating anaerobic conditions. Microbial activity probably is an important factor contributing to these reduced conditions.

No pesticides were detected in the eight UCOL NAWQA wells sampled in the watershed (appendix I). Volatile organic compounds were detected at site G1 (urban site) and site G2 (rangeland site). Eighteen VOC's were detected at site G1 in May, but only

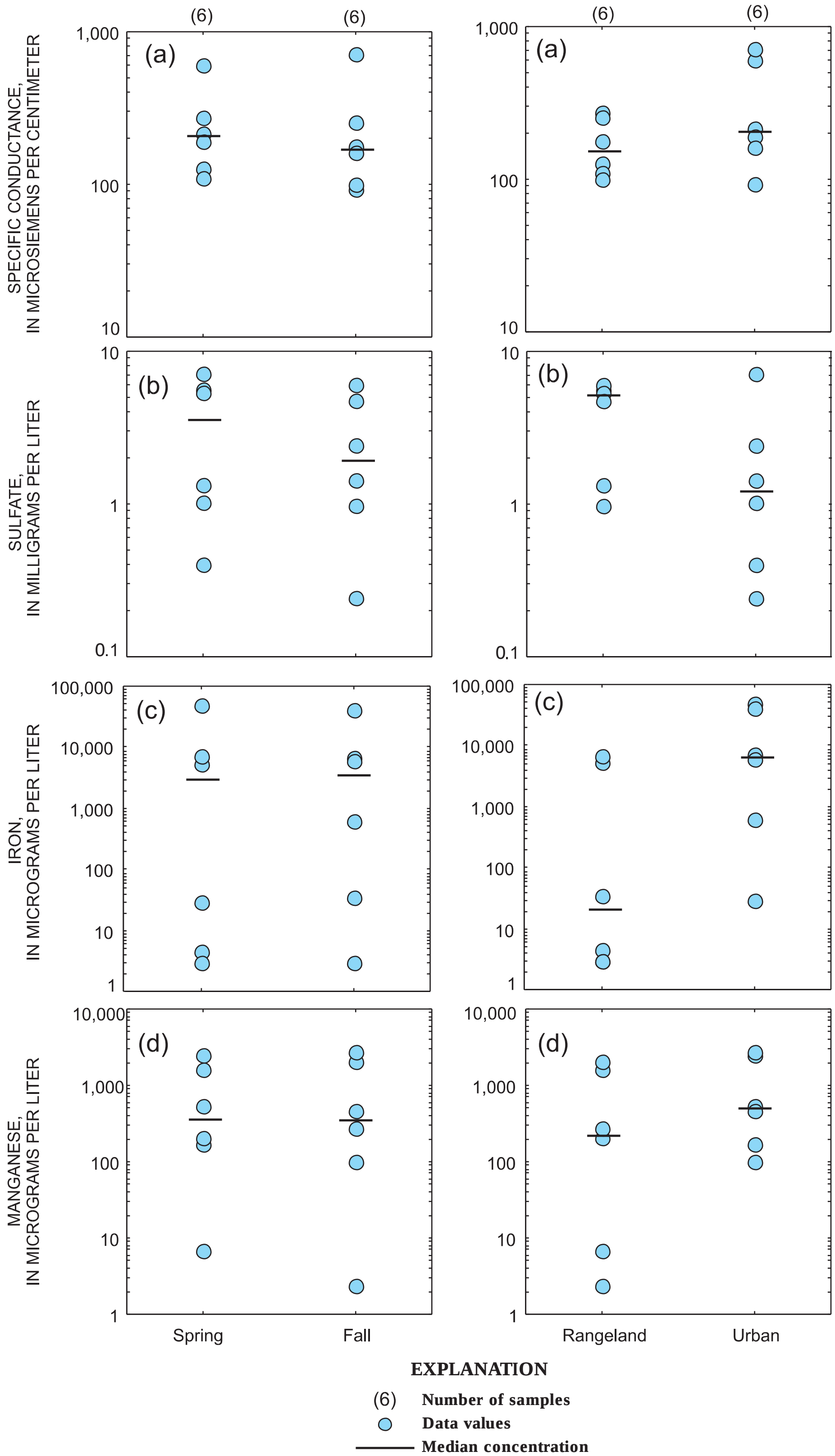

Figure 9. Distribution of (a) specific conductance, (b) sulfate, (c) iron, and (d) manganese for spring and fall sampling and by land-use/land-cover classifications for Upper Colorado River Basin (UCOL) NAWQA ground-water sites.

four VOC's were detected at site G1 in October, all at lower concentrations. The VOC's detected at this site are most likely associated with petroleum by-products, but the exact source is difficult to ascertain because the hydrocarbons are degraded. The presence of VOC's at site G1 probably is a result of the previous land use at this site. No drinking-water standards for VOC's were exceeded at this site. At site G2, no VOC's were detected in May, but two VOC's (methyl *tert*-butyl ether [MTBE] and 1,1-dichloroethane) were detected in October. Neither of these two VOC's were detected at site G1. MTBE is commonly used as a gasoline oxygenate and was detected at site G2 at concentrations less than the 20–40 µg/L DWA (U.S. Environmental Protection Agency, 1996). The compound 1,1-dichloroethane is a chlorinated solvent, which can be used as a degreaser and in the manufacture of some carbon-based products such as plastics, rubber, perfumes, and lacquers but has no drinking-water standard (Kolpin and others, 1997). The occurrence of VOC's at this site may be a result of stormwater runoff from roads and/or parking lots.

All eight ground-water sites sampled by the UCOL NAWQA Program were analyzed for total coliform and *E. coli* bacteria. Bacteria are analyzed to assess the sanitary quality of water and potential health risk from waterborne diseases (Meyers and Sylvester, 1997). Total coliform bacteria are not typically disease causing but are correlated to the presence of several waterborne disease-causing organisms (pathogens). The presence of *E. coli* is a better indication of fecal contamination. Of the 14 samples analyzed, 3 samples were positive for total coliform (21 percent). The sites that contained total coliform bacteria were sites G3 (rangeland site) and G4 (urban site) (fig. 5 and table 2). Total coliform bacteria were detected during the May and October sampling at site G4 and only detected in the May sampling at site G3. The concentrations for total coliform for these two sites ranged from 13 to 80 cols/100 mL. *E. coli* was not present at any of the sites sampled. Maximum contaminant level goals (MCLG's) for total coliform bacteria in a drinking-water supply are zero (U.S. Environmental Protection Agency, 1996). The detection of as few as 4 cols/100 mL of total coliform bacteria and 1 col/100 mL of *E. coli* warrants concern for public health (Meyers and Sylvester, 1997). Sources of fecal bacteria may include septic system failures, improper septic system construction or design, field runoff from rangeland sites, and wastewater-treatment facilities.

Four ground-water sites were analyzed for somatic coliphage. The highest concentration of coliphage in the ground water was from site G4 (urban site), which had a concentration of 37 plaque-forming units (pfu). Site G4 is located downstream from a wastewater-treatment facility. The other ground-water sites analyzed for coliphage were site G3 (6 pfu), site G6 (4 pfu), and site G7 (0 pfu). Coliphage generally is detected in high numbers in sewage and is thought to be a reliable indicator of sewage contamination of water. Monitoring for coliphage is an important indicator for the survival and transport of viruses in the environment. Viruses in drinking-water supplies have an MCLG of zero (U.S. Environmental Protection Agency, 1996).

Ground-water-monitoring wells also were analyzed for MBAS, which can be an indicator of nonpoint-source contamination by wastewater. The MBAS analysis tests for the presence of anionic sulfate- and sulfonate-based surfactants (Burkhardt and others, 1995) that are present in soaps and detergents. Concentrations for MBAS ranged from less than 0.02 to 0.12 mg/L with a median concentration of 0.03 mg/L. For 50 percent of the sites, MBAS concentrations were below the detection limit. The highest concentration was at site G2 (0.12 mg/L), followed by site G4 (0.08 mg/L). Sites G3 and G6 had concentrations at 0.03 mg/L, which is just above the detection limit. The detection of MBAS in the ground water and occurrence of bacteria and more elevated nutrients at the same sites may indicate the possible contamination by wastewater from septic systems or wastewater-treatment facilities.

In the Fraser River watershed, the limited number of ground-water sites (a total of nine sites) does not allow for a comprehensive analysis of the water-quality conditions on a watershed scale. Characterization of the water-quality conditions over time also cannot be effectively assessed with the available ground-water-quality data.

Dating Analysis

Chlorofluorocarbon concentrations can be used for dating young ground water (Plummer and others, 1993). CFC's, which are manmade and used as refrigerants, aerosol propellants, cleaning agents, solvents, and blowing agents in the production of foam rubber and plastics, were introduced into the atmosphere in the 1940's and atmospheric concentrations have increased through to the early 1990's. Ground water acquires CFC's through recharge; with knowledge of the temporal variations in the CFC concentrations in the atmosphere, the age of the ground water can be determined. Data for CFC's in the ground water are available from the six monitoring wells installed in the Fraser River watershed in 1996 (tables 2 and 5, fig. 5). CFC data for site G1 were not obtainable because the sample was contaminated with hydrocarbons. Sites G2 and G3 showed a similar age of the ground water from early 1990's to late 1980's, respectively. At sites G4 and G6 the age of the ground water was mid-1970's or younger. The CFC data for site G7 provides a ground-water age of early 1970's. Low dissolved oxygen, as measured at some of the sites, may result in a falsely old CFC age and also may result in degraded CFC's such as at sites G4 and G6. The initial results from the CFC data indicate that alluvial ground water is from 10 to 30 years old; that is, the water sample collected from the alluvial ground water was introduced into the aquifer as recharge from 10 to 30 years ago.

These dates indicate that changes in the land use in recharge areas may not affect the alluvial ground-water quality for 10 to 30 years. Supplementing water-quality data with the age of the ground water is important in order to provide a better understanding of the link between land use and the water quality in the underlying aquifers. In cases where water may have to travel over a long time and distance, the implementation of land-management practices may take many years to produce improvement in the water quality. In addition, the implementation of land-management practices before development may help to reduce the potential contamination from land-use practices. Ground-water dating can be used in conjunction with ground-water modeling to determine recharge areas and ground-water flow paths, so that managers can select strategies for maintaining or improving ground-water quality.

SURFACE WATER

Water Quantity

The major tributaries of the Fraser River include Vasquez Creek, St. Louis Creek, Crooked Creek, Pole Creek, Ranch Creek, Strawberry Creek, and Tenmile Creek (fig. 1). Hydrologic modification in the upper part of the Fraser River watershed affects the quality and beneficial uses of the Fraser River (Colorado Water Quality Control Division, 1989). Diversions at the headwaters of the Fraser River watershed at St. Louis and Vasquez Creeks reduce the flow and adversely affect water quality through nonpoint-source pollution. The Fraser River diversion system collects and conveys water from the Fraser River, its tributaries, and flow from the Vasquez water tunnel into the Moffat water tunnel.

For the Fraser River Valley the hydrologic characteristics can be represented in a generalized water budget (table 6). Average annual water input for the watershed is 392,200 acre-ft/yr, based on a weighted average precipitation of 25.6 inches distributed over the drainage area. The Fraser River watershed is a headwater system and there are no surface-water inflows to the basin except for small amounts of water from transmountain diversions. Ground-water inflow is assumed to be negligible. Water outputs from the watershed are more diverse; the predominant output is by evapotranspiration, which is calculated as the residual in the water balance and accounts for about 58 percent of the total water output. Surface-water outflow accounts for about 35 percent of the total water output. Consumptive water use, estimated to be 7,500 acre-ft/yr based on 1995 water-use data, accounts for less than 1 percent of the total water output (R.G. Dash, U.S. Geological Survey, written commun., 1998). Consumptive water use in the watershed is predominantly for irrigation. Transmountain diversions account for about 6 percent of the outputs for the watershed in 1995.

Streamflow measurements have been made at 12 gaging stations in the watershed, with 9 of the gaging stations active through water year 1997 (table 3). About 70 percent of the annual streamflow is derived from snowmelt and occurs in May, June, and July. During most of the year the daily flow is less than one-third of the mean annual streamflow, which ranged from 3.14 to 218 ft^3/s among selected sites in

Table 5. Chlorofluorocarbon data and calculated apparent ground-water recharge date for six monitoring wells sampled in the Fraser River watershed

[no., number; cont., contaminated; indet., indeterminable; pg/kg, picograms per kilogram; pptv, parts per trillion by volume; CFC, chlorofluorocarbon]

Site no. (fig. 5)	Site identification number (latitude-longitude)	Chlorofluorocarbon concentration in water (pg/kg)			Chlorofluorocarbon partial pressure (pptv)			Chlorofluorocarbon apparent CFC recharge date			Recharge temperature (degrees Celsius)	Recharge altitude (feet)	Estimated recharge date
		CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113			
G1	395507105470200	479.5	648.5	67.3	184.8	1,118.1	60.9	1981.5	cont.	1987.5	6.3	8,780	indet.
		182.8	1,207.4	113.4	70.5	2,082.7	102.7	1971.0	cont.	cont.	6.3	8,780	
		185.1	1,144.4	73.7	71.3	1,974.1	66.7	1971.0	cont.	1988.5	6.3	8,780	
G2	395605106473100	329.8	307.0	131.9	124.3	519.0	116.6	1975.5	1993.0	cont.	6.0	8,660	1992
		370.3	298.1	101.9	139.6	503.9	90.1	1976.5	1991.5	modern	6.0	8,660	
		354.7	352.5	147.8	133.7	595.8	130.7	1976.0	cont.	cont.	6.0	8,660	
G3	395623105481000	1,436.8	427.7	81.8	515.5	691.8	68.5	cont.	cont.	1988.5	5.2	8,620	1989
		1,246.8	438.2	79.4	447.3	708.7	66.5	cont.	cont.	1988.5	5.2	8,620	
		1,417.5	447.2	85.1	508.6	723.3	71.3	cont.	cont.	1989.0	5.2	8,620	
G4	395648105485300	83.2	112.0	0.72	38.8	229.0	0.8	1967.0	1975.0	1956.0	9.8	8,570	1974
		1,334.5	107.3	0.0	622.9	219.6	0.0	cont.	1974.5	1954.5	9.8	8,570	
G6	395706105485000	21.3	48.5	0.0	7.7	78.6	0.0	1958.0	1966.0	1954.5	5.3	8,520	1967
		30.5	55.1	0.0	11.0	89.3	0.0	1960.0	1967.0	1954.5	5.3	8,520	
		37.0	66.6	0.0	13.3	107.8	0.0	1961.0	1968.5	1954.5	5.3	8,520	
G7	395929105510300	120.8	97.3	7.84	44.2	159.9	6.7	1968.0	1971.5	1971.0	5.7	8,320	1972
		110.5	97.5	9.74	40.4	160.2	8.3	1967.5	1971.5	1972.5	5.7	8,320	
		121.2	107.6	12.7	44.3	176.7	10.9	1968.0	1972.5	1974.5	5.7	8,320	

Table 6. Generalized water budget for the Fraser River watershed

[<, less than]

Source	Inputs (acre-feet per year)	Percent	Source	Outputs (acre-feet per year)	Percent
Precipitation (25.6 inches)	391,900	100	Evapotranspiration from nonirrigated land (residual)	225,700	58
Surface-water inflow	negligible		Surface-water outflow	135,500 [a]	35
Transmountain diversions (Vasquez water tunnel)[c]	300	<1	Consumptive water use	7,500 [b]	0.02
Ground-water inflow	negligible		Transmountain diversions (Moffat water tunnel)	23,500 [c]	6
			Reservoir evaporation	negligible	
			Ground-water outflow	unknown	
			Change in ground-water storage	negligible	
Total (rounded)	392,200	100	Total (rounded)	392,200	100

[a] Data from the U.S. Geological Survey National Water Information System (site 67 in table 3) and Mark Leu, Northern Colorado Water Conservancy District, written commun., 1998.
[b] Based on 1995 data (R.G. Dash, U.S. Geological Survey, written commun., 1998).
[c] Based on 1995 data (R.C. Steger, Denver Water Board, written commun., 1998).

Table 7. Hydrologic characteristics for selected surface-water stations in the Fraser River watershed

[mi^2, square miles; ft^3/s, cubic feet per second]

Site no. (figs. 5 and 6)	Site name	Station identification number	Period of record, in water years	Drainage area (mi^2)	Mean annual streamflow (ft^3/s)	Coefficient of variation of annual streamflow	Mean annual runoff (inches)
3	Fraser River at Upper Station near Winter Park, CO	09022000	1969–73 1984–97	10.5	14.4	0.16	18.5
16	Fraser River at Winter Park, CO	09024000	1910–34	27.6	44.6	0.21	22.0
			1935–97	27.6	17.2	0.55	8.5
20	St. Louis Creek near Fraser, CO	09026500	1934–97	32.9	26.7	0.43	11.0
23	Elk Creek near Fraser, CO	09025400	1971–96	7.15	3.14	0.61	6.0
24	Vasquez Creek at Winter Park, CO	09025000	1934–97	27.8	14.4	0.69	7.0
40	Ranch Creek near Fraser, CO	09032000	1935–97	19.9	14.5	0.55	9.9
48	Cabin Creek near Fraser, CO	09032100	1984–97	4.87	6.50	0.38	18.1
67	Fraser River at Granby, CO	09034000	1904–09	297	218	0.27	10.0
			1937–55	297	148	0.35	6.8

the watershed (table 7). Mean annual runoff ranges from 6.0 to 22.0 inches and reflects the high amounts of precipitation in the watershed. Coefficient of variation, which is a measure of the variability of streamflow from year to year, ranges from about 0.16 to 0.69. As a result of the variability of the timing and magnitude of the streamflow from year to year, water quality can be affected. The removal of water from water diversions at the headwaters of the Fraser River also can affect the water quality.

Annual mean streamflow varies at four selected stations (fig. 10). Streamflow at the Fraser River at Upper Station near Winter Park (site 3, table 7) is unaffected by transmountain diversions, and the variability in the streamflow is low (coefficient of variance of 0.16). Fraser River at Winter Park (site 16, table 7), which has the longest period of record, is affected by transmountain diversions, and the coefficient of variance ranges from 0.21 prior to 1935 to 0.55 after 1935. In 1936 the first part of the Fraser River diversions, which divert water through the Moffat water tunnel, was completed. Streamflow at St. Louis Creek (site 20, fig. 10) and Vasquez Creek (site 24, fig. 10) is similar to the Fraser River at Winter Park station (site 16, fig. 10). Mean monthly flows for the four stations are similar, indicating that streamflow is dominated by snowmelt (fig. 11).

Water Quality

Water-quality property and constituent data available for the surface-water sites consist of field parameters (water temperature, specific conductance, dissolved oxygen, pH, and alkalinity), inorganic species (primarily chloride, some trace elements, and nutrients), and bacteria (table 8). The distribution of selected water-quality data for all surface-water sites (table 3 and fig. 12) are classified by land use (forest, rangeland, and urban). The pH values ranged from 5.5 to 9.9 with the highest median value of 7.9 associated with the urban land use. A few pH values were below (about 0.1 percent; 2 of 1,505) and above (about 0.3 percent; 4 of 1,505) the recommended stream water-quality standards for pH (6.5–9.0). Specific conductance ranged from 7 to 1,650 µS/cm, and the highest median concentration was associated with rangeland (90 µS/cm). The most frequently analyzed major ion was chloride, with concentrations ranging from less than 0.1 to 47 mg/L, and forested lands had the highest median concentration (6.6 mg/L). Chloride concentrations were below the stream-water-quality standards of 250 mg/L (Colorado Water Quality Control Commission, 1996). Dissolved manganese, which had fewer analyses than chloride, ranged in concentration from less than 4 to 55 µg/L, and the highest median concentration was associated with rangeland (35 µg/L). Only one analysis (about 2 percent; 1 of 53) for dissolved manganese exceeded the stream-water-quality standard of 50 µg/L (Colorado Water Quality Control Commission, 1996). Sedimentary rocks underlie rangeland in the watershed and may be the primary source of the manganese.

Distributions of the nutrient concentrations are represented in boxplots for ammonia, nitrite, nitrate, orthophosphate, and total phosphorus by land-use/land-cover classification (fig. 13). The majority of the surface-water-quality data are available for urban land use. In comparing ammonia concentrations among forest, rangeland, and urban land uses, the highest ammonia concentrations were associated with the urban land, which had a median concentration of 0.11 mg/L. Ammonia concentrations in the Fraser River watershed were higher in the urban setting than ammonia concentrations (median concentrations were less than 0.10 mg/L) from sites sampled in the Upper Colorado River Basin (Spahr and Wynn, 1997). Criteria exist for un-ionized ammonia concentrations based upon the chronic and acute exposure of an aquatic organism to un-ionized ammonia (Colorado Water Quality Control Commission, 1996). These criteria vary, depending on the pH and temperature of the water at the time of sampling. The criteria and stream concentrations for dissolved ammonia can be calculated for pH values ranging from 6.5 to 9.0 and temperatures ranging from 0 to 30°C. The Colorado Water Quality Control Commission has established a chronic criterion for un-ionized ammonia of 0.02 mg/L for the Fraser River. The un-ionized ammonia chronic criterion for cold-water biota was exceeded in one sample at site 43 and in one sample at site 49 (table 3 and fig. 5).

Nitrite concentrations for all land uses ranged from less than 0.001 to 0.4 mg/L, and the urban sites had the highest median nitrite concentration (0.005 mg/L). Nitrate concentrations ranged from 0.003 to 12.6 mg/L. In the Fraser River watershed only two analyses, which were associated with the urban land use, had nitrate concentrations that exceeded the

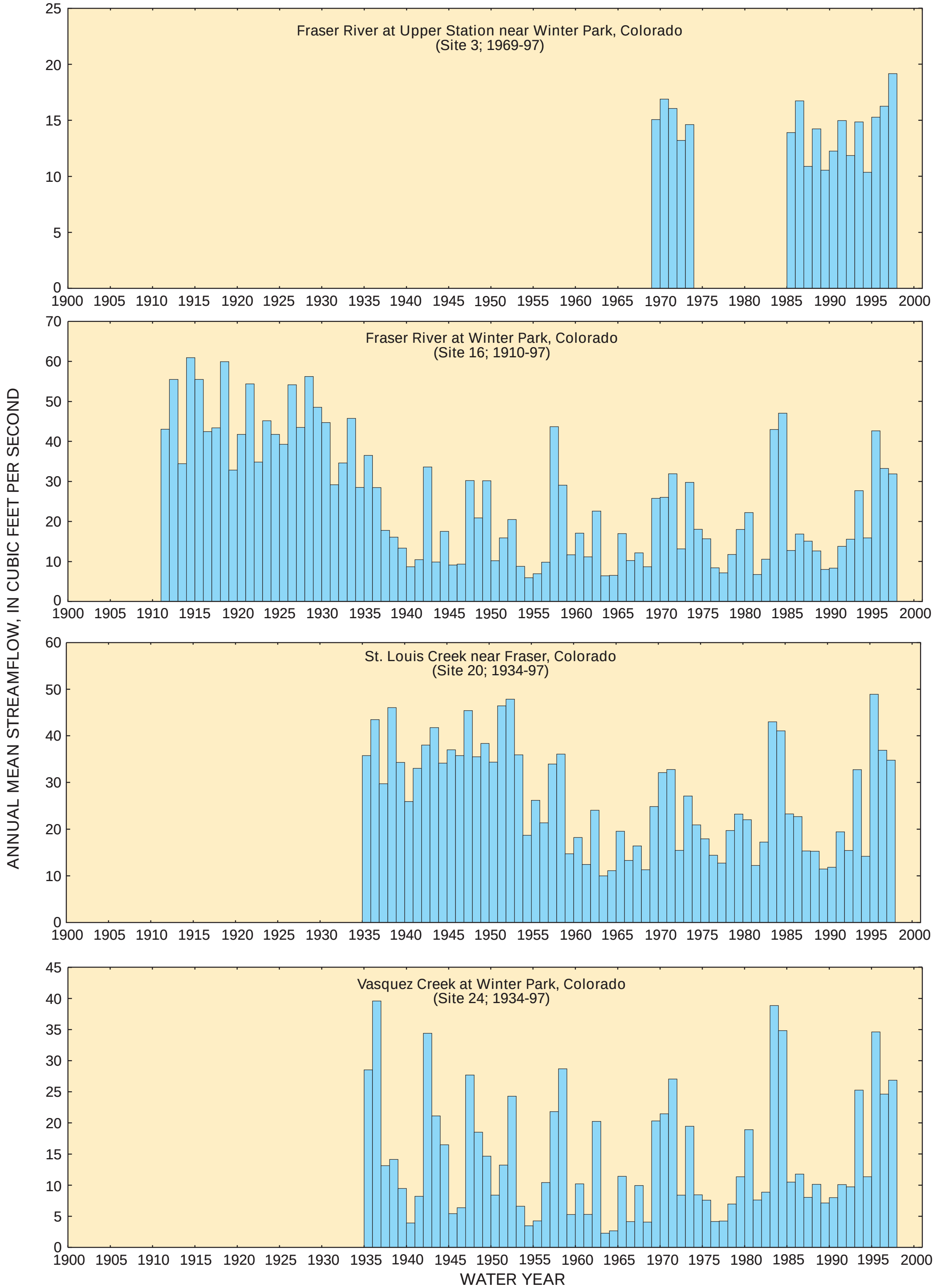

Figure 10. Annual mean streamflow at selected surface-water stations in the Fraser River watershed.

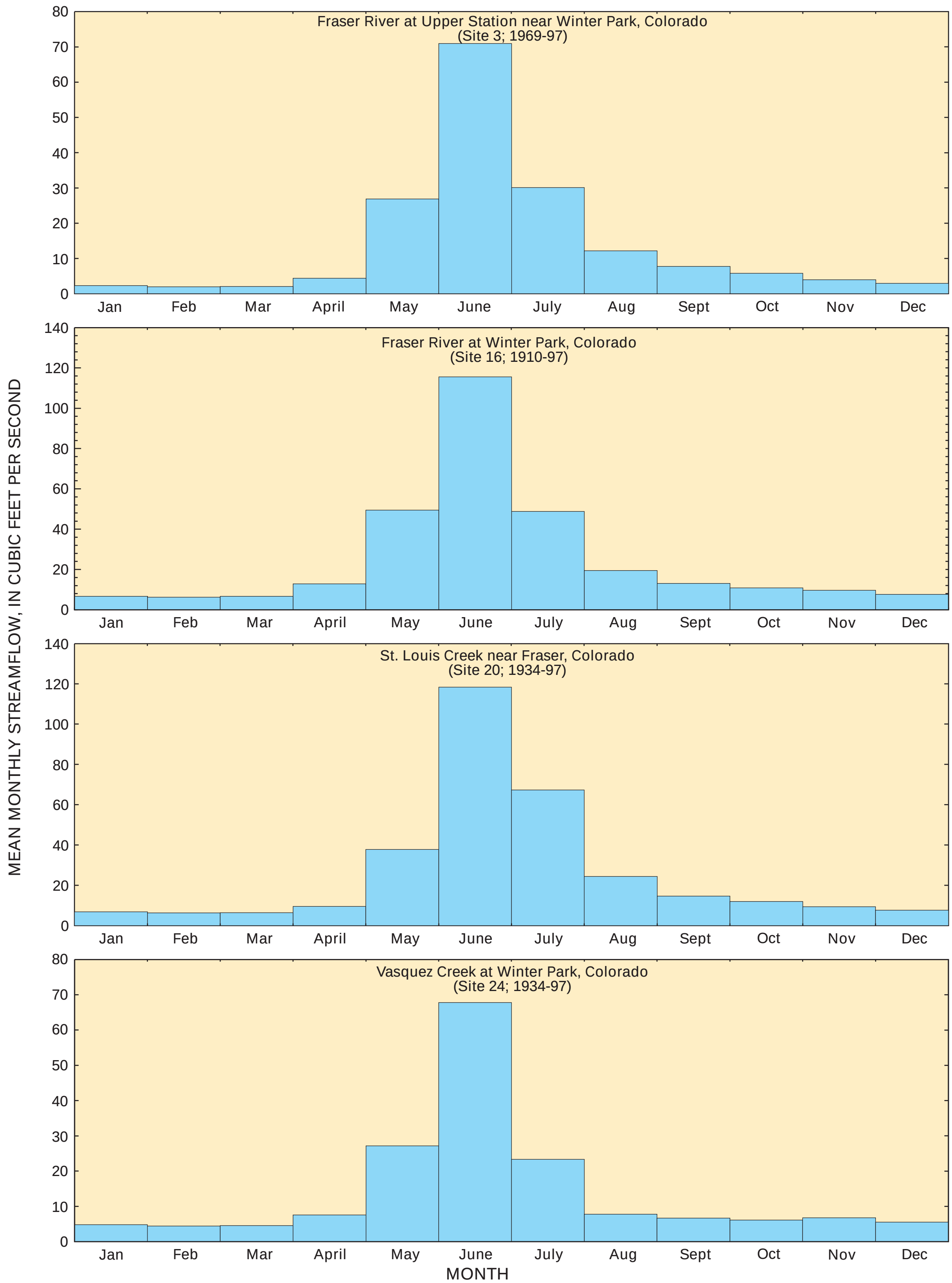

Figure 11. Mean monthly streamflow at selected surface-water stations in the Fraser River watershed.

Table 8. Summary of the minimum, median, and maximum values for the surface-water-quality properties and constituents for all sites sampled in the Fraser River watershed

[---, no data; <, less than; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; cols/100 mL, colonies per 100 milliliters; TVS, table value standard; ac, acute standard; ch, chronic standard]

Properties, constituents, and reporting units	Number of analyses	Number of censored analyses	Minimum	Median	Maximum	Stream-segment standards[1]
Water temperature (degrees Celsius)	2,951	0	0.0	4.0	19.5	---
Specific conductance, field (µS/cm)	2,584	0	7.0	75.0	1,650	---
Dissolved solids (mg/L)	17	0	44.0	68.0	106	---
Hardness, total (mg/L as $CaCO_3$)	102	0	8.0	46.0	140	---
Oxygen, dissolved (mg/L)	1,167	0	0.2	9.9	16.4	6.0-7.0
pH, field (standard units)	1,505	0	5.5	7.8	9.9	6.5-9.0
Alkalinity, field (mg/L as $CaCO_3$)	103	0	12.0	48.0	140	---
Major ions						
Calcium, dissolved (mg/L)	17	0	6.6	8.9	19.0	---
Chloride, dissolved (mg/L)	199	6	<0.1	5.5	47	250
Fluoride, total (mg/L)	84	0	24.0	365	2,900	---
Magnesium, dissolved (mg/L)	19	0	0.2	2.8	5.1	---
Potassium, dissolved (mg/L)	17	0	0.6	1.2	3.0	---
Sodium, dissolved (mg/L)	17	0	2.4	6.1	18.0	---
Silica, dissolved (mg/L)	17	0	6.6	10.0	15.0	---
Sulfate, dissolved (mg/L)	120	64	<5.0	<5.0	12.0	250
Nutrients						
Ammonia (mg/L)	495	101	<0.002	0.026	26.0	TVS
Nitrite (mg/L)	441	70	<0.001	0.004	0.40	0.005
Nitrate (mg/L)	432	0	0.003	0.087	12.6	10
Orthophosphate (mg/L)	156	31	<0.001	0.006	0.19	---
Total phosphorus (mg/L)	95	9	<0.01	0.06	0.33	---

Trace elements						
Arsenic, dissolved (µg/L)	19	16	<1.0	<1.0	5.0	---
Arsenic, total (µg/L)	3	0	1.0	1.0	1.0	50 (ac)
Boron, total (µg/L)	12	7	<12.0	<12.0	120	---
Cadmium, dissolved (µg/L)	47	29	<0.25	<0.25	3.0	TVS
Cadmium, total recoverable (µg/L)	4	0	1.0	1.0	3.0	TVS
Copper, dissolved (µg/L)	43	39	<4.0	<4.0	6.0	TVS
Copper, total recoverable (µg/L)	3	0	8.0	8.0	11.0	---
Iron, dissolved (mg/L)	33	0	20.0	180	450	300 (ch)
Lead, dissolved (µg/L)	33	29	<1.0	<1.0	4.0	TVS
Lead, total recoverable (µg/L)	3	0	1.0	5.0	7.0	---
Manganese, dissolved (µg/L)	53	7	<4.0	19.0	55.0	50 (ch)
Manganese, total recoverable (µg/L)	7	0	5.0	40.0	80	1,000 (ch)
Mercury, dissolved (µg/L)	33	33	<0.2	<0.2	<0.2	---
Mercury, total recoverable (µg/L)	26	25	<0.5	<0.5	0.5	0.01(ch)
Molybdenum, total recoverable (µg/L)	4	0	27.0	29.5	32.0	---
Selenium, dissolved (µg/L)	15	15	<1.0	<1.0	<1.0	---

Table 8. Summary of the minimum, median, and maximum values for the surface-water-quality properties and constituents for all sites sampled in the Fraser River watershed—Continued

[---, no data; <, less than; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; cols/100 mL, colonies per 100 milliliters; TVS, table value standard; ac, acute standard; ch, chronic standard]

Properties, constituents, and reporting units	Number of analyses	Number of censored analyses	Minimum	Median	Maximum	Stream-segment standards[1]
Trace elements—Continued						
Selenium, total (µg/L)	8	5	<2.0	<2.0	5.0	---
Silver, dissolved (µg/L)	17	17	<0.2	<0.2	<0.2	TVS
Uranium, dissolved (µg/L)	6	0	1.5	2.5	4.0	---
Zinc, dissolved (µg/L)	45	26	<8.0	<8.0	100	TVS
Zinc, total recoverable (µg/L)	49	30	<10.0	<10.0	400	---
Other constituents						
Sediment concentration (mg/L)	606	15	<0.001	1.81	164	---
Total coliforms (cols/100 mL)	20	5	<1	59.5	86,000	---
Fecal coliforms (cols/100 mL)	329	55	<1	1	78,000	2,000
Fecal streptococcus (cols/100 mL)	18	10	<1	9.5	840	---

[1] Stream-segment standards from Colorado Water Quality Control Commission, 1996.

USEPA 10-mg/L MCL criterion for nitrate in drinking water (U.S. Environmental Protection Agency, 1996). The urban land-use setting had the highest median nitrate concentration of 0.14 mg/L. Orthophosphate for the urban land-use classification had a higher median concentration (0.021 mg/L) than the median concentration for forest (0.001 mg/L). No national criteria have been established for phosphorus concentration in stream water. However, to control eutrophication, the USEPA recommends that total phosphorus concentrations should not exceed 0.1 mg/L for flowing waters that do not discharge directly into a lake or reservoir (U.S. Environmental Protection Agency, 1986). Total phosphorus concentrations that exceeded 0.1 mg/L were detected for about 23 percent of the analyses (22 of the 95 analyses). Concentrations that exceeded 0.1 mg/L were detected in all land-use/land-cover classifications from the available data, with median concentrations for rangeland and urban land uses being similar (about 0.07 mg/L). Higher concentrations of total phosphorus can result in increased algae in the streams, which can be undesirable esthetically.

Thirty surface-water sites, predominantly those associated with forest land-use classification, have been monitored for bacteria in the watershed. Microbial sampling has been completed for total coliform, fecal coliform, and fecal streptococcus. Most of the sampling (about 83 percent; 303 of 367 samples) occurred between 1974 and 1989. The most recent sampling from 1990 to 1997 accounts for the other 17 percent of the bacteria sampling in the watershed. Total coliform bacteria were measured 20 times from 1974 to 1981 with values ranging from less than 1 to 86,000 cols/100 mL; a median value for these 20 samples was about 60 cols/100 mL. Total coliform bacteria in fecal-contaminated surface water ranged from 1,200 to 4,000,000 cols/100 mL (Meyers and Sylvester, 1997). For the samples collected for total coliform, the largest number of bacteria colonies were associated with urban land use.

For the main stem of the Fraser River and its tributaries, the established stream-segment standard for fecal coliform is 2,000 cols/100 mL. In all, 329 analyses for fecal coliform bacteria were completed at sites on the Fraser River with concentrations ranging from less than 1 to 78,000 cols/100 mL; however, only two analyses at site 72 exceeded the standard of 2,000 cols/100 mL. These samples were collected in 1974 and 1983. In the watershed, 18 analyses (1976–81) were available for fecal streptococcus. Concentrations ranged from less than 1 to 840 cols/100 mL, and the median value was about 10 cols/100 mL. Fecal-contaminated surface water analyzed for fecal streptococcus generally ranged from 400 to more than 1,000,000 cols/100 mL (Meyers and Sylvester, 1997). Surface-water sites

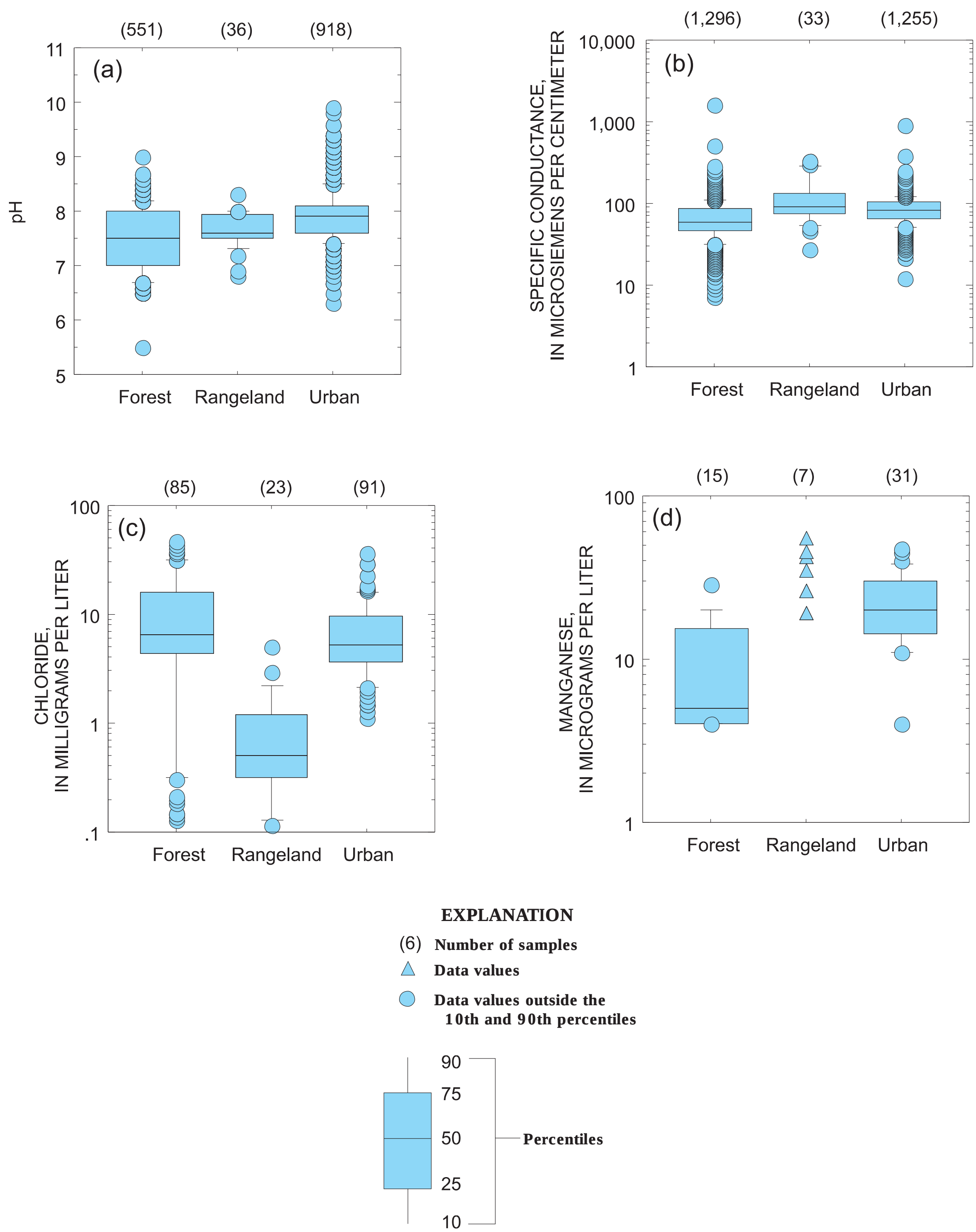

Figure 12. Distribution of (a) pH, (b) specific conductance, (c) chloride, and (d) manganese by land-use/land-cover classifications for all surface-water sites.

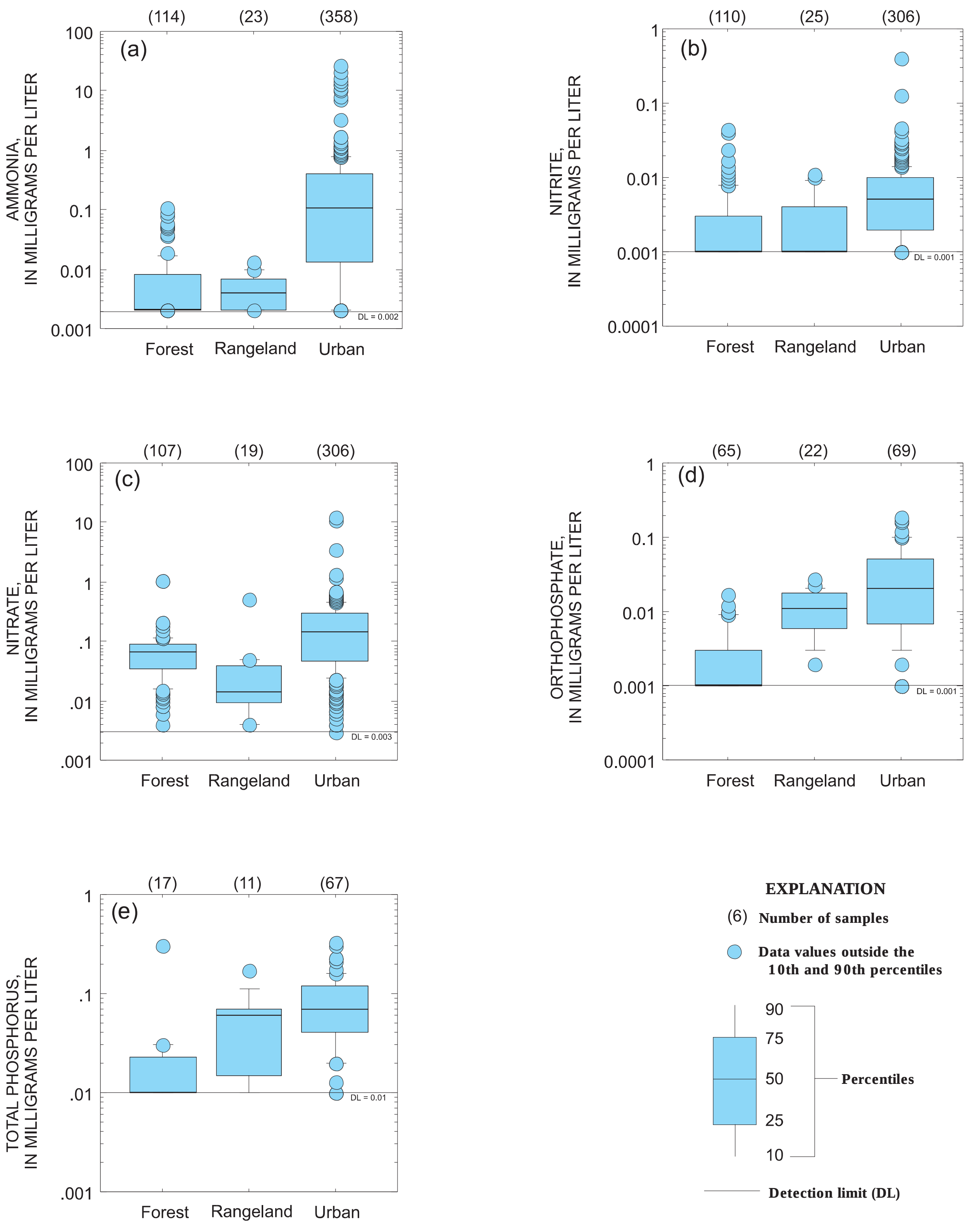

Figure 13. Distribution of (a) ammonia, (b) nitrite, (c) nitrate, (d) orthophosphate, and (e) total phosphorus by land-use/land-cover classifications for all surface-water sites.

sampled for bacteria in the 1990's had concentrations less than the established stream-segment standards.

Surface-water-quality data are limited in the watershed and provide only a general assessment of the water-quality conditions. For instance, additional water-quality data for the mouth of the Fraser River would provide a better understanding of the variation in chemical constituents for the Fraser River watershed. Currently, water-quality data are not being collected to assess water-quality conditions in the entire watershed since the water-quality-sampling site near the mouth of the Fraser River (site 63) was discontinued in water year 1992.

SPATIAL DISTRIBUTION OF CONCENTRATIONS

Spatial distribution of the median concentrations for specific conductance and nutrient species (ammonia, nitrite, nitrate, and total phosphorus) is shown in figures 14–18. Surface-water sites with more than five analyses are represented in these figures. Concentration intervals in the figures represent concentrations less than the 25^{th} percentile, concentrations between the 25^{th} and 50^{th} percentiles, concentrations between the 50^{th} and 75^{th} percentiles, and concentrations greater than the 75^{th} percentile.

Specific conductance in the Fraser River watershed increases in a downstream direction (fig. 14), probably because of changes in the geology; crystalline rocks are in the headwaters and sedimentary rocks are in the downstream valleys. However, specific-conductance values for the Fraser River watershed are relatively low (median concentrations of 75.0 μS/cm) when compared to the median concentration (254 μS/cm) for surface-water sites sampled in the Upper Colorado River Basin, Southern Rocky Mountains physiographic province, as part of the UCOL NAWQA Program.

The available nutrient data allow for only a general assessment of the spatial distribution for select nutrient concentrations in the watershed (figs. 15–18). In general, nutrient concentrations increase in the vicinity of urban centers. Sites located upstream from Winter Park on the Fraser River and upstream on St. Louis Creek have the lowest nutrient concentrations. Ammonia concentrations for the watershed overall are higher than the median ammonia concentration of 0.04 mg/L determined for urban sites in the basinwide assessment of nutrient species in the Upper Colorado River Basin (Spahr and Wynn, 1997). Nitrite concentrations in the watershed were low, with a median concentration of 0.004 mg/L. A median nitrate concentration of 0.3 mg/L was determined for urban sites in the Upper Colorado River Basin (Spahr and Wynn, 1997), and only one site in the Fraser River watershed had a concentration close to 0.3 mg/L in the urban setting. Nitrate concentrations were less than 0.3 mg/L at all other urban sites. Total phosphorus for urban sites in the Upper Colorado River Basin had a median concentration of 0.04 mg/L (Spahr and Wynn, 1997). In the Fraser River watershed concentrations were above this median value at one-half of the sites, and the other sites associated with urban development were comparable to the median value.

Only four sites in the watershed had sufficient data to plot concentration as a function of time (fig. 19). Overall, the ammonia concentrations appear to decrease from 1990 to 1997 for all sites. The highest ammonia concentrations were detected in 1990 and 1991. The principal change in the ammonia values appears to be the reduction in the higher winter concentrations. This could be due to changes in regulations because wastewater-treatment-plant operators change plant operations to comply with required limits. Total phosphorus concentrations appear fairly consistent over time, with no obvious changes in the phosphorus concentrations.

TEMPORAL TRENDS IN NUTRIENT SPECIES CONCENTRATIONS

Results of the trend analysis of nutrient species using the seasonal Kendall test (Helsel and Hirsch, 1992) are shown in table 9. For significant trends (p-values less than 0.05), the slope in units per year is indicated in this table. Ranges in slopes are given for sites with censored data, and the different slopes are computed with the censored data equal to the censored value and equal to zero. The true slope of the trend line would be in the range of these values. Analysis of temporal trends was completed for four sites in the watershed having sufficient data to meet the statistical requirements as outlined in the "Methods of Data Review and Analysis" section of this report. The sampling period varied between these sites but is comparable for three of the four sites with similar periods of records and common nutrient species.

Trend analysis is useful in determining if concentrations for selected constituents have changed

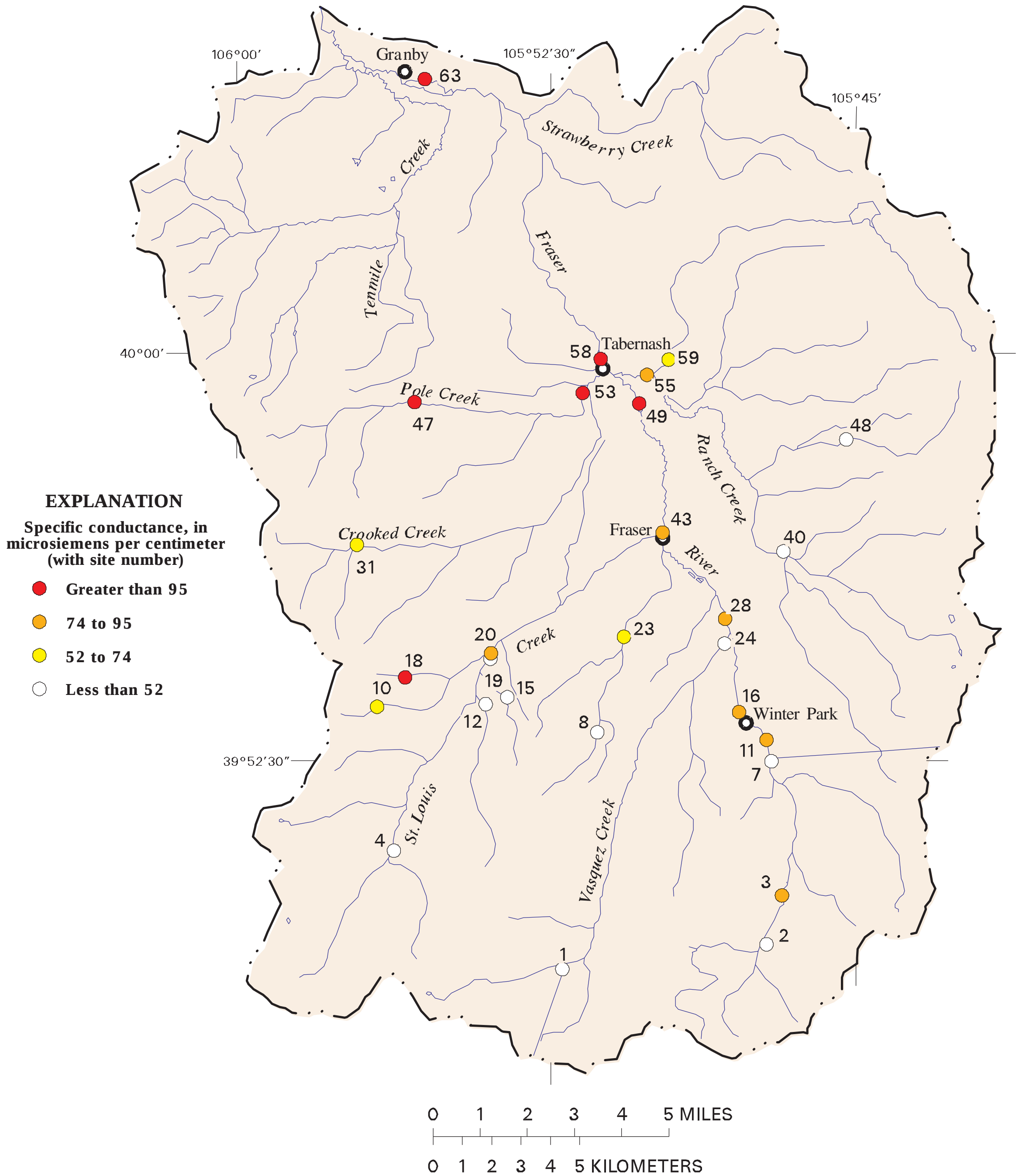

Figure 14. Spatial distribution of median concentrations for specific conductance.

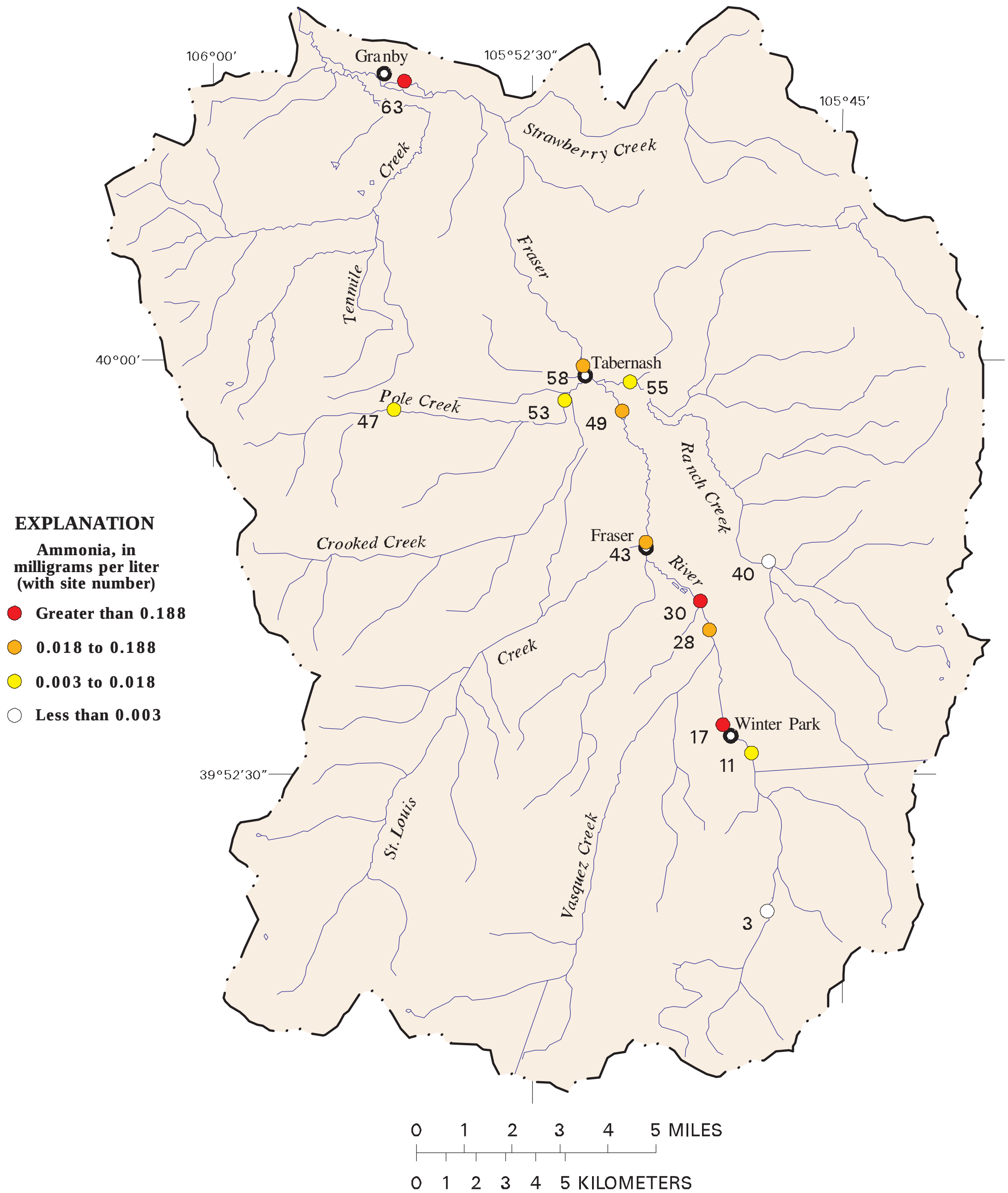

Figure 15. Spatial distribution of median concentrations for ammonia.

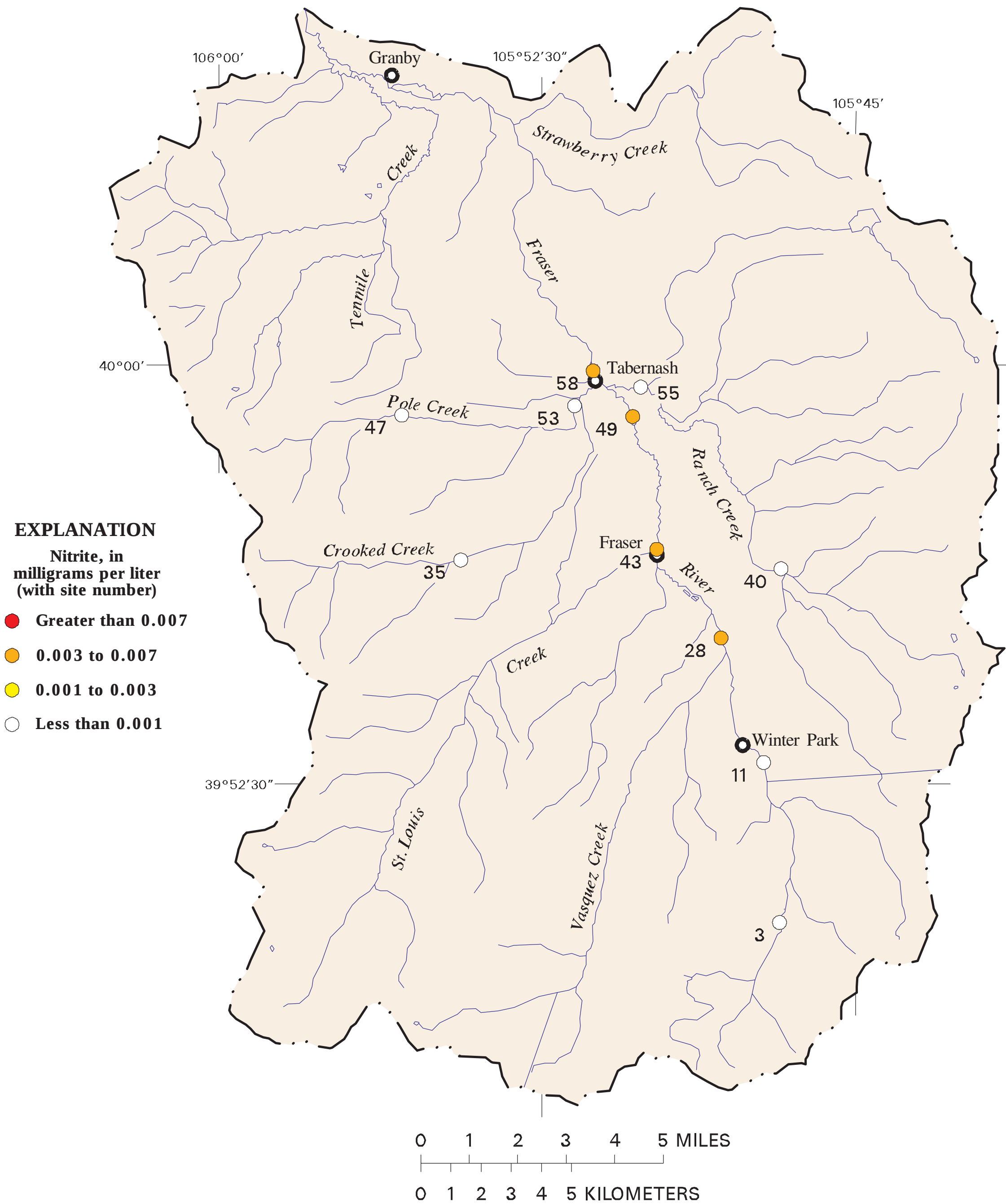

Figure 16. Spatial distribution of median concentrations for nitrite.

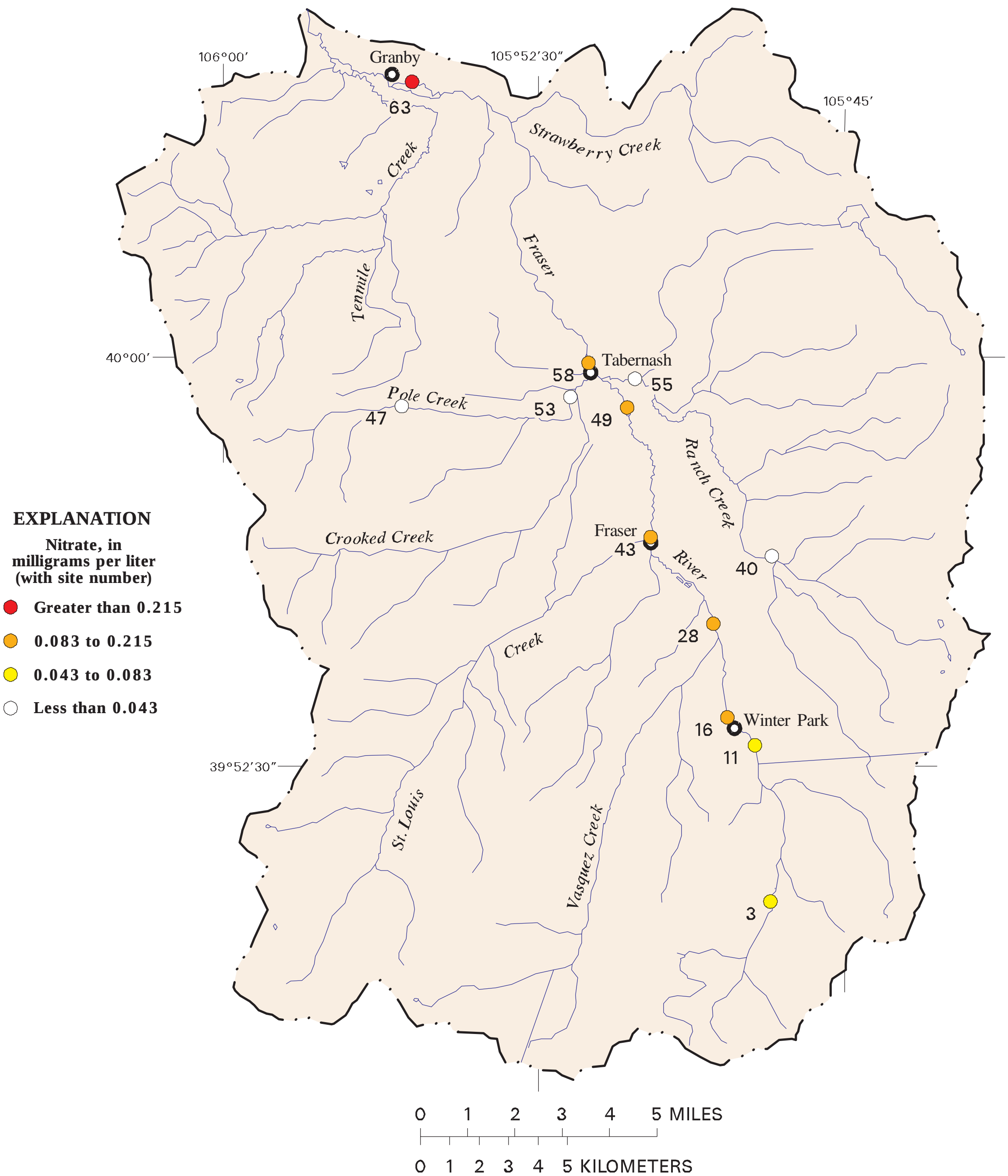

Figure 17. Spatial distribution of median concentrations for nitrate.

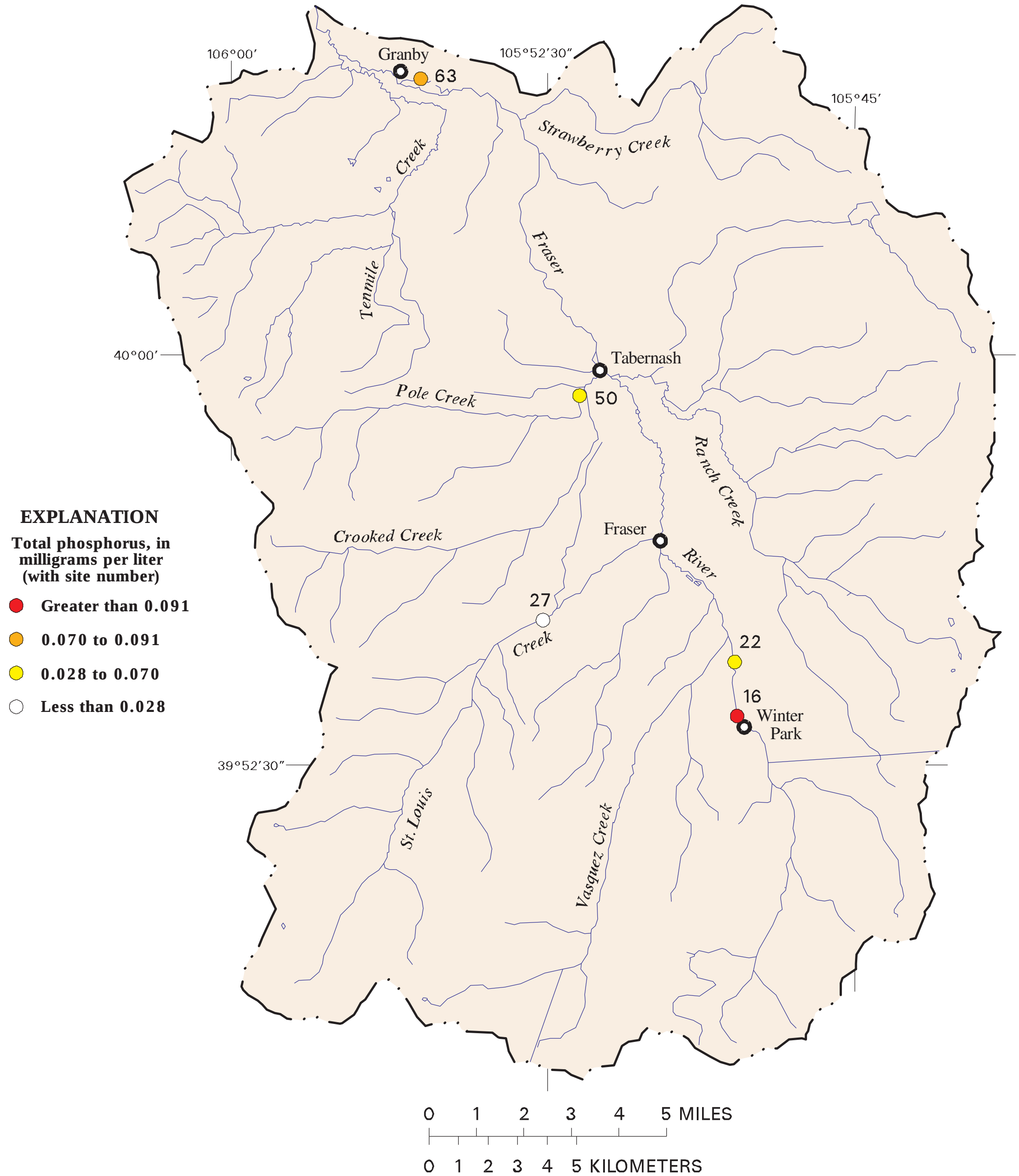

Figure 18. Spatial distribution of median concentrations for total phosphorus.

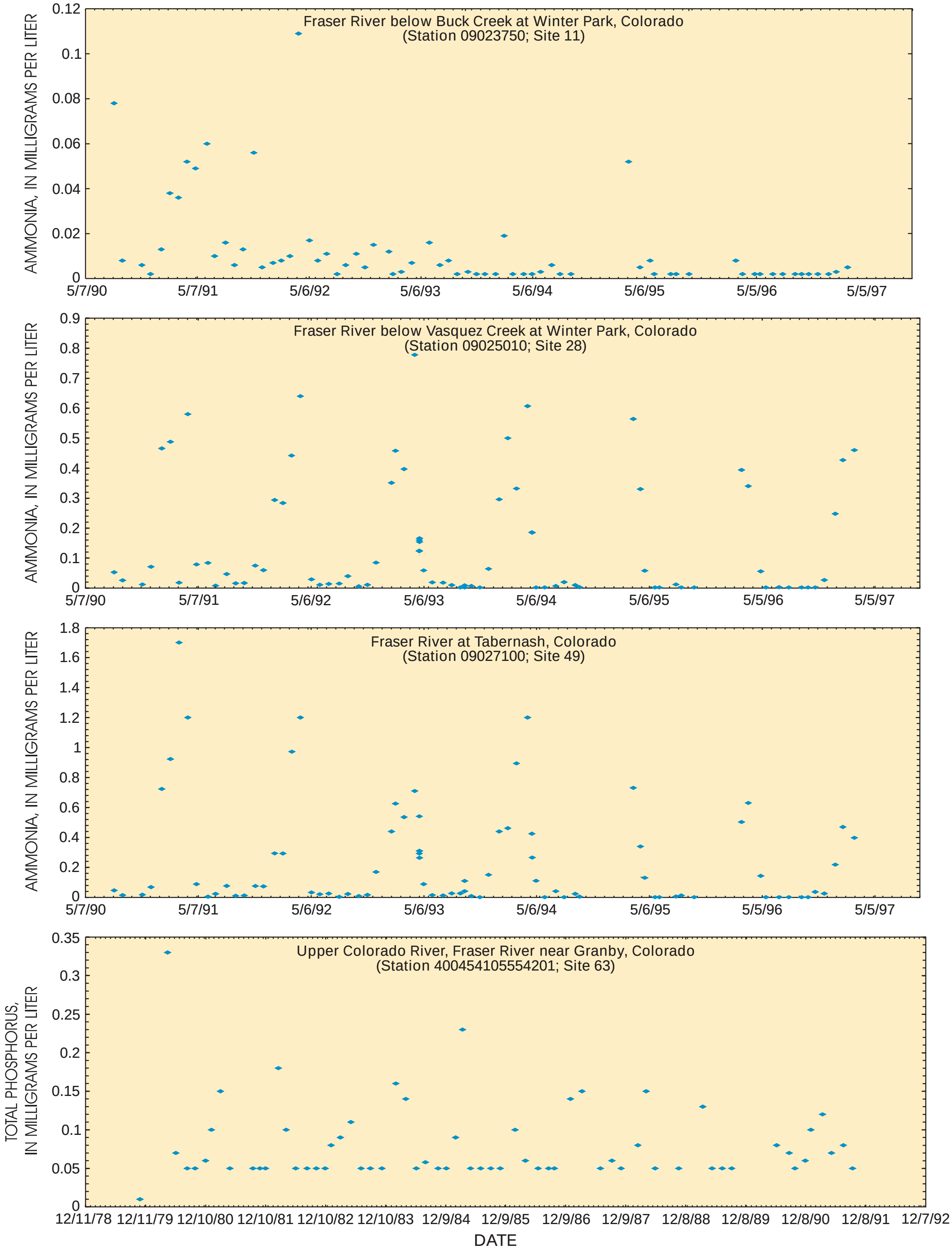

Figure 19. Temporal variations in ammonia and total phosphorus concentrations for selected sites in the Fraser River watershed.

Table 9. Results of the seasonal Kendall test for trends of selected nutrient species in the Fraser River watershed

[no., number; units/yr, units per year; mg/L, milligrams per liter; <, less than; ---, no data]

Site no. (figs. 5 and 6)	Site name	Number of analyses	Number of censored analyses	Censored value	Trend direction	p-value of tau test	Slope (units/yr)	Median concentration (mg/L)
				Ammonia, as nitrogen (water years 1991–96)				
11	Fraser River below Buck Creek at Winter Park, CO	60	22	<0.002	down	<0.0001	–0.002 to –0.0029	0.006
28	Fraser River below Vasquez Creek at Winter Park, CO	72	12	<0.002	down	0.0040	–0.0044 to –0.005	0.025
49	Fraser River at Tabernash, CO	72	8	<0.002	down	0.0004	–0.0065 to –0.0068	0.042
				Nitrite, as nitrogen (water years 1991–96)				
11	Fraser River below Buck Creek at Winter Park, CO	59	15	<0.001	down	0.0333	–0.0003 to –0.0008	0.002
28	Fraser River below Vasquez Creek at Winter Park, CO	70	8	<0.001	down	0.0026	–0.001 to –0.0008	0.004
49	Fraser River at Tabernash, CO	70	4	<0.001	down	<0.0001	–0.0017	0.006
				Nitrate, as nitrogen (water years 1991–96)				
11	Fraser River below Buck Creek at Winter Park, CO	58	0	none	none	0.9433	---	0.07
28	Fraser River below Vasquez Creek at Winter Park, CO	71	0	none	none	0.0815	---	0.088
49	Fraser River at Tabernash, CO	71	0	none	down	<0.0001	–0.0107	0.134
				Total phosphorus (water years 1980–91, quarterly sampling)				
63	Upper Colorado River, Fraser River near Granby, CO	63	29	<0.05	none	0.6687	---	0.055

over time. However, a trend may not be statistically significant if the rate of change (slope) is small for the trend line or if the constituents are very low in concentration. Downward trends were observed for ammonia and nitrite for sites 11, 28, and 49 (table 9). Nitrate showed no trend except for site 49, which showed a downward trend. No trend was observed for total phosphorus at site 63. The downward trends in the nutrient species probably reflect changes in wastewater-treatment facilities in the watershed.

In evaluating the median concentrations determined from the trend analysis, it is important to compare these results with other data from similar areas. Spahr and Wynn (1997) summarized the water quality in surface water of the Upper Colorado River Basin in relation to nitrogen and phosphorus species. They compared the median nutrient concentrations to different land uses in the basin. For ammonia as nitrogen, Spahr and Wynn (1997) determined concentrations of 0.02 mg/L for background sites and 0.04 mg/L for urban sites. From their study, the median nitrate as nitrogen concentrations for undeveloped and urban sites were 0.09 and 0.3 mg/L, respectively, and the median concentrations for total phosphorus at undeveloped and urban sites were 0.03 and 0.04 mg/L, respectively. Median concentrations, as determined for the water years used in the trend analysis, generally indicate that the surface-water quality at sites 49 and 63 is affected by land use.

SUMMARY

In order to evaluate the available water quantity and quality through water year 1997 of the ground-water and surface-water resources in the Fraser River watershed, data were obtained from Federal, State, and local agencies. The predominant sources of information were the U.S. Geological Survey National Water Information System (NWIS) and the U.S. Environmental Protection Agency Storage and Retrieval (STORET) data bases. Water quantity or quality data, or both, were collected at a total of 81 sites (9 ground water and 72 surface water) at various times from 1904 to 1997.

The Fraser River watershed has a drainage area of 287 mi^2 with its headwaters at the Continental Divide. The watershed is located at altitudes ranging from 8,000 to 12,800 ft and can receive more than 40 inches per year of precipitation along the Continental Divide. Ground-water resources are available for residential and municipal use. The alluvial and Troublesome Formation aquifers yield water more readily than other aquifers in the watershed. Surface-water resources in the area include the Fraser River and its tributaries. The major land use/land cover in the watershed is forested land; however, increasing urban development in the watershed has the potential to affect the water quantity and water quality of the resources.

From the limited water-level data, it can be stated that ground-water flow directions for the alluvial and Troublesome Formation aquifers generally follow topography upstream from Tabernash. Available ground-water-use information indicates yields for the alluvial aquifer of about 100 gallons per minute and for the Troublesome Formation aquifer of about 110 to 220 gallons per minute. However, additional information is needed to better estimate ground-water reserves for these aquifers, which may range from 1.6 to 2.7 million acre-feet.

Ground-water-quality data from nine sites generally consisted of field parameters, major ions, nutrients, trace elements, radon, dissolved organic carbon, pesticides, volatile organic compounds, bacteria, and methylene blue active substances. In addition, shallow ground water was dated at six sites using chlorofluorocarbons (CFC’s). In general, concentrations of water-quality constituents were less than U.S. Environmental Protection Agency (USEPA) drinking-water standards. However, iron and manganese concentrations in the shallow alluvial aquifer exceeded the USEPA secondary maximum contaminant level (SMCL) for drinking water. High concentrations of these two elements also were detected in the Middle Park Formation.

Concentrations of radon exceeded the USEPA proposed MCL for radon (which is currently being revised) at eight of the ground-water sites. The radon concentrations are derived from natural sources; in areas where the decay of uranium occurs, radon concentrations would be elevated. Uranium-bearing minerals are found in association with Precambrian rocks, which are present in the Fraser River watershed.

No pesticides were detected in the ground water. However, land-use effects on the shallow ground-water quality were indicated by the detection of volatile organic compounds (VOC’s) at two alluvial monitoring wells. Although the concentrations did not violate drinking-water standards or advisories, it is evident that the ground-water quality is vulnerable to land-use effects.

Microbial sampling also was completed for eight wells in the watershed. Total coliform and coliphage were detected in three samples in the watershed. The detection of bacteria and viruses indicates a concern for public health, if the water were to be used as a drinking supply. Methylene blue active substances (MBAS) also were analyzed and detected at four sites. The detection of MBAS, bacteria, and more elevated nutrients at the same sites may indicate the possible contamination by wastewater from septic systems or wastewater-treatment facilities.

Age of the alluvial ground water in the Fraser River watershed ranged from about 10 to 30 years. The age indicates that effects of land-use activities may take some time to affect the ground-water quality. Likewise, if a water-quality problem exists, results of land-management practices to improve water quality might not be apparent for many years.

For the Fraser River watershed, water input into the watershed is mainly from precipitation. Outputs from the watershed, in order of decreasing volume, include evapotranspiration, runoff, water diversions, and consumptive use. Streamflow in the watershed is dominated by snowmelt, and 70 percent of the flow occurs in May, June, and July. Coefficient of variation of the annual mean streamflows (ranging from 0.16 to 0.69) is largest for sites affected by transmountain diversions.

Surface-water-quality data for the Fraser River watershed were limited. In general, concentrations of surface-water-quality constituents were less than stream-segment standards. However, the available water-quality data indicate that elevated concentrations of selected constituents generally are related to specific land uses. For the surface-water sites only one sample exceeded the USEPA SMCL for manganese. Two samples from two surface-water sites in the watershed exceeded the un-ionized ammonia chronic criterion.

Nutrient species represent the most abundant data for examining the spatial and temporal variability and trends in the water quality. The effects of land use are apparent in the watershed as stream sites in the area associated with urban development have the highest median concentration of nutrient species. Spatial distribution of nutrient species (ammonia, nitrite, nitrate, and total phosphorus) shows that elevated concentrations occur primarily downstream from urban areas. Bacteria sampling completed in the watershed also indicates that the occurrence of bacteria in the water is related to urban land use.

Data at four surface-water sites were analyzed for temporal trends in nutrient concentrations. Downward trends were identified for ammonia and nitrite for three sites. Nitrate for two sites showed no trends, and one site showed a downward trend. The only site with total phosphorus data showed no trend. The downward trend in the nutrient species probably reflects changes in the wastewater-treatment facilities in the watershed.

Limited ground-water and surface-water data provide a general assessment of the water-quantity and water-quality resources of the Fraser River watershed. However, the available information indicates where concentrations of water-quality constituents historically and presently are less than or exceed water-quality standards in the watershed, which is important when devising watershed-management strategies. Concentrations of constituents in ground- and surface-water samples from the watershed generally are less than water-quality standards; however, manganese and iron exceeded the USEPA SMCL in the shallow ground-water sites and in one surface-water sample. The detection of bacteria in the ground and surface water and VOC's in the ground water is an indication that land use probably is affecting the water quality. Increased concentrations of nutrients in the surface water downstream from urban centers are another indication that urban land use in the watershed probably is affecting the water quality.

REFERENCES CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1992, Standard methods for the analysis of water and wastewater (18^{th} ed.): Washington, D.C., American Public Health Association, [variously paginated].

American Society for Testing and Materials, 1992, Annual book of ASTM standards, Section 11, Water and environmental technology: Philadelphia, American Society for Testing and Materials, v. 11.02, [pagination unknown].

Apodaca, L.E., Driver, N.E., Stephens, V.C., and Spahr, N.E., 1996, Environmental setting and implications on water quality, Upper Colorado River Basin, Colorado and Utah: U.S. Geological Survey Water-Resources Investigations Report 95–4263, 33 p.

Brenner, K.P., Rankin, C.C., Roybal, Y.R., Stelma, G.N., Jr., Pasquale, V.S., and Dufour, A.P., 1993, New medium for the simultaneous detection of total coliforms and *Escherichia coli* in water: Applied and Environmental Microbiology, v. 59, no. 11, p. 3534–3544.

Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of dissolved organic carbon by UV-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92–480, 12 p.

Britton, L.J., and Greeson, P.E., eds., 1989, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4, 685 p.

Burkhardt, M.R., Cinotto, P.J., Frahm, G.W., Woodworth, M.T., and Pritt, J.W., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of methylene blue active substances by spectrophotometry: U.S. Geological Survey Open-File Report 95–189, 16 p.

Colorado Climate Center, 1984, Colorado average annual precipitation 1951 to 1980: Fort Collins, Colorado Climate Center, scale 1:500,000.

Colorado Water Quality Control Commission, 1996, January 30 (1996) Classifications and numeric standards for Upper Colorado River Basin and North Platte River (Planning Region 12), 3.3.0: Colorado Department of Public Health, Water Quality Control Commission, [variously paginated].

Colorado Water Quality Control Division, 1989, Colorado nonpoint assessment report: Colorado Department of Health, Denver, Colorado, 189 p.

Fegeas, R.G., Claire, R.W., Guptil, S.C., Anderson, K.E., and Hallam, C.A., 1983, U.S. Geological Survey digital cartographic data standards—Land use and land cover digital data: U.S. Geological Survey Circular 895–E, 21 p.

Fetter, C.W., 1994, Applied hydrology, 3^{rd} edition: New Jersey, Prentice Hall, 691 p.

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

Green, G.N., 1992, The digital geological map of Colorado in Arc/Info format: Denver, U.S. Geological Survey (revised April 12, 1995), Open-File Report 92–0507, scale 1:500,000.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, The Netherlands, Elsevier, 522 p.

Hem, J.D., 1992, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hirsch, R.M., Alexander, R.B., and Smith, R.A., 1991, Selection methods for the detection and estimation of trends in water quality: Water Resources Research, v. 27, no. 5, p. 803–813.

Hitt, K.J., 1995, Refining 1970's land-use data with 1990 population data to indicate new residential development: U.S. Geological Survey Water-Resources Investigations Report 94–4250, 15 p.

Kolpin, D.W., Squillace, P.J., Zogorski, J.S., and Barbash, J.E., 1997, D.W., 1997, Pesticides and volatile organic compounds in shallow urban groundwater of the United States, *in* Chilton, John and others, eds., Groundwater in the Urban Environment, v. 1, Problems, Processes, and Management: A.A. Balkema Publishers, Rotterdam, The Netherlands, p. 469–474.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95–339, 113 p.

Lanfear, K.J., and Alexander, R.B., 1990, Methodology to derive water-quality trends for use by the National Water Summary Program of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 90–359, 10 p.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Selection, installation, and documenting of wells, and collection of related data: U.S. Geological Survey Open-File Report 95–398, 69 p.

Mars, J.P., 1979, Water quality investigations of the Fraser River, September 1977 through January 1978: Denver, Colorado Department of Health, Water Quality Control Division, 27 p.

Meyers, D.N., and Sylvester, M.A., 1997, Fecal indicator bacteria: U.S. Geological Survey Techniques of Water Resources Investigations, book 9, chap. A7, 38 p.

Mueller, D.K., Hamilton, P.A., Helsel, D.R., Hitt, K.J., and Ruddy, B.C., 1995, Nutrients in ground water and surface water of the United States—An analysis of data through 1992: U.S. Geological Survey, Water-Resources Investigations Report 95–4031, 74 p.

Paulsen, R.T., 1991, Radionuclides in ground water, rock, and soils and indoor air of the Northeastern United States and Southeastern Canada—A literature review and summary of data, *in* Gunderson, L.C.S., and Wanty, R.B., eds., Field studies of radon in rocks, soils, and water: U.S. Geological Survey Bulletin 1971, p. 195–225.

Plummer, L.N., Michel, R.L., Thurman, E.M., and Glynn, P.D., 1993, Environmental tracers for age dating young ground water, *in* Alley, W.D., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, p. 255–294.

Rose, D.L., and Schroeder, M.P., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of volatile organic compounds in water by purge and trap capillary gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 94–708, 26 p.

Sobsey, M., Battigelli, D., Handzel, T., and Schwab, K., 1995, Male-specific coliphages as indicators of viral contamination in drinking water: Denver, Colo., American Water Works Association, 149 p.

Spahr, N.E., and Wynn, K.H., 1997, Nitrogen and phosphorus in surface waters of the Upper Colorado River Basin: Journal of the American Water Resources Association, v. 33, no. 3, p. 547–560.

Tweto, Ogden, comp., 1979, Geologic map of Colorado: U.S. Geological Survey State Geologic Map, scale 1:500,000 (reprinted).

U.S. Bureau of the Census, 1970, 1990, 1994, 1970–1994 Census of population and housing, Washington, D.C.: U.S. Department of Commerce, Data on CD-ROM.

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986: Washington, D.C., U.S. Environmental Protection Agency Report 440/5–86–001, Office of Water, [variously paginated].

U.S. Environmental Protection Agency, 1991, Test methods for *Escherichia coli* in drinking water—EC medium with mug tube procedure and nutrient agar with mug membrane filter procedure: Cincinnati, Ohio, U.S. Environmental Protection Agency, EPA–600/4–85/076, 24 p.

U.S. Environmental Protection Agency, 1996, Drinking water regulations and health advisories: Washington, D.C., U.S. Environmental Protection Agency Report 822–B–96–002, Office of Water, [pagination unknown].

U.S. Environmental Protection Agency, U.S. Department of Health and Human Services, and U.S. Public Health Service, 1992, A citizens guide to radon—The guide to protecting yourself and your family from radon: U.S. Environmental Agency Air and Radiation (ANR–464) 402–K92–001, May 1992.

U.S. Geological Survey, 1985, National Water Summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, 467 p.

Voegeli, P.T., Sr., 1965, Ground-water resources of North Park and Middle Park, Colorado—A reconnaissance: U.S. Geological Survey Water-Supply Paper 1809–G, 54 p.

Wilson, W.W., 1965, Pumping tests in Colorado: Colorado Water Conservation Board, Ground-water Series, Circular 11, 361 p.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the National Water Quality Laboratory—Determination of pesticides in water by C–18 solid-phase extraction and capillary column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95–181, 60 p.

APPENDIX

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
FIELD PARAMETERS		
Water temperature (degrees Celsius)	00010	na
Specific conductance (µS/cm)	00095	na
Oxygen, dissolved (mg/L)	00300	na
pH, field (standard units)	00400	na
Alkalinity, lab (mg/L as $CaCO_3$)	90410	na
Alkalinity, field (mg/L as $CaCO_3$)	39086	na
Turbidity (NTU)	00076	na
INORGANICS		
Hardness total (mg/L as $CaCO_3$)	00900	computed
Dissolved solids (mg/L)	70300	computed
Major ions, in milligrams per liter Sample filtered through 0.45-micron filter		
Bicarbonate (mg/L as HCO_3)	00453	na
Calcium	00915	0.02
Chloride	00940	0.1
Fluoride	00950	0.1
Magnesium	00925	0.01
Potassium	00935	0.1
Silica	00955	0.01
Sodium	00930	0.2
Sulfate	00945	0.1
Nutrients, in milligrams per liter Sample filtered through 0.45-micron filter		
Ammonia, as N	00608	0.01
Nitrite, as N	00613	0.01
Nitrate, as N	00631	0.05
Orthophosphate, as P	00671	0.01
Trace elements, in micrograms per liter Sample filtered through 0.45-micron filter		
Aluminum	01106	1.0
Antimony	01095	1.0
Arsenic	01000	1.0
Barium	01005	1.0
Beryllium	01010	1.0
Boron	01020	16.0
Cadmium	01025	1.0
Chromium	01030	1.0

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
Trace elements, in micrograms per liter Sample filtered through 0.45-micron filter–Continued		
Cobalt	01035	1.0
Copper	01040	1.0
Iron	01046	3.0
Lead	01049	1.0
Manganese	01056	1.0
Molybdenum	01060	1.0
Nickel	01065	1.0
Selenium	01145	1.0
Silver	01075	1.0
Uranium	22703	1.0
Zinc	01090	1.0
Radionuclides, in pCi/L		
Radon-222	82303	26
ORGANICS		
Dissolved organic carbon	00681	0.1 mg/L
Pesticides, in micrograms per liter Sample filtered through 0.7-micron filter		
*2,4,5-T	39742	0.035
*2,4-D	39732	0.15
*2,4-DB	38746	0.24
*2-(2,4,5-Trichlorophenoxy) propionic acid	39762	0.021
2,6-Diethylaniline	82660	0.003
*3-Hydroxycarbofuran	49308	0.014
*4,6-Dinitro-2-methylphenol	49299	0.42
Acetochlor	49260	0.002
*Acifluorfen	49315	0.035
Alachlor	46342	0.002
*Aldicarb	49312	0.55
*Aldicarb sulfone	49313	0.10
*Aldicarb sulfoxide	49314	0.021
Atrazine	39632	0.001
Azinphos, methyl-	82686	0.001
Benfluralin	82673	0.002
*Bentazon	38711	0.014
*Bromacil	04029	0.035
*Bromoxynil	49311	0.035

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
Pesticides, in micrograms per liter Sample filtered through 0.7-micron filter–Continued		
Butylate	04028	0.002
Carbaryl	82680	0.003
*Carbaryl	49310	0.008
Carbofuran	82674	0.003
*Carbofuran	49309	0.12
*Chloramben	49307	0.42
Chloropyrifos	38933	0.004
*Chlorothalonil	49306	0.48
*Clopyralid	49305	0.23
Cyanazine	04041	0.004
DCPA (Dacthal)	82682	0.002
*Dacthal monoacid	49304	0.017
Deethylatrazine	04040	0.002
DDE, p,p'-	34653	0.006
Diazinon	39572	0.002
*Dicamba	38442	0.035
*Dichlobenil	49303	1.2
*Dichloroprop	49302	0.032
Dieldrin	39381	0.001
*Dinoseb	49301	0.035
Disulfoton	82677	0.017
*Diuron	49300	0.020
EPTC (Eptam)	82668	0.002
Ethalfluralin	82663	0.004
Ethoprophos	82672	0.003
*Fenuron	49297	0.013
*Fluometuron	38811	0.035
Fonofos	04095	0.003
HCH, alpha-	34253	0.002
Lindane	39341	0.004
Linuron	82666	0.002
*Linuron	38478	0.018
Malathion	39532	0.005
*MCPA	38482	0.17
*MCPB	38487	0.14
*Methiocarb	38501	0.026
Metolachlor	39415	0.002
*Methomyl	49296	0.017
Metribuzin	82630	0.004
Molinate	82671	0.004

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
Pesticides, in micrograms per liter Sample filtered through 0.7-micron filter–Continued		
Napropamide	82684	0.003
*Neburon	49294	0.015
*Norflurazon	49293	0.024
*Oryzalin	49292	0.31
*Oxamyl	38866	0.018
Parathion	39542	0.004
Parathion, methyl-	82667	0.006
Pebulate	82669	0.004
Pendimethalin	82683	0.004
Permethrin-cis	82687	0.005
Phorate	82664	0.002
*Picloram	49291	0.05
Prometon	04037	0.018
Propachlor	04024	0.007
Propanil	82679	0.004
Propargite	82685	0.013
*Propham	49236	0.035
*Propoxur	38538	0.035
Propyzamide	82676	0.003
Simazine	04035	0.005
Tebuthiuron	82670	0.010
Terbacil	82665	0.007
Terbufos	82675	0.013
Thiobencarb	82681	0.002
Triallate	82678	0.001
*Triclopyr	49235	0.25
Trifluralin	82661	0.002
Volatile organic compounds, in micrograms per liter		
1, 1, 1, 2-Tetrachloroethane	77562	0.044
1, 1, 1-Trichloroethane	34506	0.032
1, 1, 2, 2-Tetrachloroethane	34516	0.132
1, 1, 2-Trichloroethane	34511	0.064
1, 1, 2-Trichlorotrifluoroethane	77652	0.092
1, 1-Dichlororethane	34496	0.066
1, 1-Dichloroethylene	34501	0.044
1, 1-Dichloropropene	77168	0.026
1, 2, 3, 4-Tetramethylbenzene	49999	0.230
1, 2, 3, 5-Tetramethylbenzene	50000	0.240
1, 2, 3-Trichlorobenzene	77613	0.266

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
Volatile organic compounds, in micrograms per liter–Continued		
1, 2, 3-Trichloropropane	77443	0.077
1, 2, 3-Trimethylbenzene	77221	0.124
1, 2, 4-Trichlorobenzene	34551	0.188
1, 2, 4-Trimethylbenzene	77222	0.056
1, 2-Dibromo-3-chloropropane	82625	0.214
1, 2-Dibromoethane	77651	0.036
1, 2-Dichlorobenzene	34536	0.048
1, 2-Dichloroethane	32103	0.134
1, 2-Dichloropropane	34541	0.068
1, 3, 5-Trimethylbenzene	77226	0.044
1, 3-Dichlorobenzene	34566	0.054
1, 3-Dichloropropane	77173	0.116
1,4-Dichlorobenzene	34571	0.050
2, 2-Dichloropropane	77170	0.078
2-Butanone	81595	1.650
2-Chlorotoluene	77275	0.042
2-Hexanone	77103	0.746
3-Chloropropene	78109	0.196
4-Chlorotoluene	77277	0.056
4-Isopropyl-1-methylbenzene	77356	0.110
4-Methyl-2-pentanone	78133	0.374
Acetone	81552	4.900
Acrolein	34210	1.430
Acrylonitrile	34215	1.230
Benzene	34030	0.032
Bromobenzene	81555	0.036
Bromochloromethane	77297	0.044
Bromodichloromethane	32101	0.048
Bromoform	32104	0.104
Bromomethane	34413	0.148
Butylbenzene	77342	0.186
Carbon disulfide	77041	0.080
Chlorobenzene	34301	0.028
Chloroethane	34311	0.120
Chloroform	32106	0.052
Chloromethane	34418	0.254
Dibromochloromethane	32105	0.182
Dibromomethane	30217	0.050
Dichlorodifluoromethane	34668	0.096
Dichloromethane	34423	0.382
Diethyl ether	81576	0.170

Appendix I. List of properties and constituents for ground-water-quality data in the Fraser River watershed—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; cols/100 mL, colonies per 100 milliliters; pfu, plaque-forming unit; *, pesticides analyzed in only the monitoring wells]

Constituent	USGS NWIS parameter code	Reporting limit
Volatile organic compounds, in micrograms per liter–Continued		
Diisopropyl ether	81577	0.098
Ethyl metracrylate	73570	0.278
Ethyl tert-butyl ether	50004	0.054
Ethylbenzene	34371	0.030
Hexachlorobutadiene	39702	0.142
Hexachloroethane	34396	0.362
Isopropylbenzene	77223	0.032
Methyl acrylate	49991	0.612
Methyl acrylonitrile	81593	0.570
Methyl iodide	77424	0.076
Methyl methacrylate	81597	0.350
Napthalene	34696	0.250
Propylbenzene	77224	0.042
Styrene	77128	0.042
Tetrachloroethylene	34475	0.038
Tetrachloromethane	32102	0.088
Tetrahydrofuran	81607	1.150
Toluene	34010	0.038
Trichloroethylene	39180	0.038
Trichlorofluoromethane	34488	0.032
Vinyl acetate	77057	5.0
Vinyl bromide	50002	0.100
Vinylchloride	39175	0.112
cis-1, 2-Dichloroethylene	77093	0.038
cis-1, 3-Dichloropropene	34704	0.092
m- and p-Xylene	85795	0.064
o-Ethyl toluene	77220	0.100
o-Xylene	77135	0.064
sec-Butylbenzene	77350	0.048
tert-Butyl methyl ether	78032	0.112
tert-Butylbenzene	77353	0.096
tert-Pentyl methyl ether	50005	0.112
trans-1, 2-Dichloroethylene	34546	0.032
trans-1, 3-Dichloropropene	34699	0.134
trans-1, 4-Dichloro-2-butene	73547	0.692
OTHER CONSTITUENTS		
Coliform, total, m-ENDO agar	31501	0 cols/100 mL
Coliform, total, MI agar	90900	0 cols/100 mL
Coliphage, *E. coli*	90903	0 pfu
Methylene blue active substances	38260	0.02 mg/L