National Water-Quality Assessment Program

Water-Quality Assessment of the Yellowstone River Basin, Montana and Wyoming—Water Quality of Fixed Sites, 1999-2001

Scientific Investigations Report 2004-5113

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

Front cover photograph: Aerial image of the Crazy Mountains, Montana, northwest of Billings, Montana (*used with permission from Larry Mayer, larrymayer.com*).

Water-Quality Assessment of the Yellowstone River Basin, Montana and Wyoming—Water Quality of Fixed Sites, 1999-2001

By Kirk A. Miller, Melanie L. Clark, and Peter R. Wright

Scientific Investigations Report 2004-5113

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

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2005

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

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: *http://www.usgs.gov/*

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (*http://www.usgs.gov/*). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (*http://water.usgs.gov/nawqa/*). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (*http://water.usgs.gov/nawqa/nawqamap.html*). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (*http://water.usgs.gov/nawqa/natsyn.html*).

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water

Contents

Figures

Figures—Continued

Figures—Continued

Tables

Conversion Factors and Datum

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
pound (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. For example, the water year ending September 30, 1999 is called water year 1999.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviated Water-Quality Units

col/100 mL	colonies per 100 milliliters
ft^3/sec	cubic feet per second
mg/L	milligrams per liter
µg/g	micrograms per gram
µg/L	micrograms per liter
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius
<	less than
>	greater than
°C	degrees Celsius

Abbreviations

B	Bighorn River at Kane, Wyoming
CF	Clarks Fork Yellowstone River at Edgar, Montana
DOC	Dissolved organic carbon
E. coli	*Escherichia coli*
GCMS	Gas chromatography and mass spectrometry
IQR	Interquartile range
LP	Little Powder River above Dry Creek near Weston, Wyoming
MCL	Maximum Contaminant Level
MRA	Mineral resource area
NAWQA	National Water-Quality Assessment Program
NED	National Elevation Database
NLCD	National Land Cover Data
P	Powder River near Locate, Montana
RPD	Relative percent difference
RSD4	Risk-specific dose associated with an excess cancer risk of 1 in 10,000 for a concentration in drinking water equal to the risk-specific dose
RSD5	Risk-specific dose associated with an excess cancer risk of 1 in 100,000 for a concentration in drinking water equal to the risk-specific dose
SB	Soda Butte Creek at Yellowstone National Park boundary near Silver Gate, Montana
SMCL	Secondary Maximum Contaminant Level
T	Tongue River at Dayton, Wyoming
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
YELL	Yellowstone River Basin Study Unit
YNP	Yellowstone National Park
YCS	Yellowstone River at Corwin Springs, Montana
YB	Yellowstone River at Billings, Montana
YF	Yellowstone River at Forsyth, Montana
YS	Yellowstone River near Sidney, Montana

Water-Quality Assessment of the Yellowstone River Basin, Montana and Wyoming—Water Quality of Fixed Sites, 1999-2001

By Kirk A. Miller, Melanie L. Clark, and Peter R. Wright

Abstract

The National Water-Quality Assessment Program of the U.S. Geological Survey initiated an assessment in 1997 of the quality of water resources in the Yellowstone River Basin. Water-quality samples regularly were collected during 1999-2001 at 10 fixed sites on streams representing the major environmental settings of the basin. Integrator sites, which are heterogeneous in land use and geology, were established on the mainstem of the Yellowstone River (4 sites) and on three major tributaries—Clarks Fork Yellowstone River (1 site), the Bighorn River (1 site), and the Powder River (1 site). Indicator sites, which are more homogeneous in land use and geology than the integrator sites, were located on minor tributaries with important environmental settings—Soda Butte Creek in a mineral resource area (1 site), the Tongue River in a forested area (1 site), and the Little Powder River in a rangeland area (1 site). Water-quality sampling frequency generally was at least monthly and included field measurements and laboratory analyses of fecal-indicator bacteria, major ions, dissolved solids, nutrients, trace elements, pesticides, and suspended sediment.

Median concentrations of fecal coliform and *Escherichia coli* were largest for basins that were predominantly rangeland and smallest for basins that were predominantly forested. Concentrations of fecal coliform and *Escherichia coli* significantly varied by season (*p*-value <0.001); the smallest median concentrations were during January–March and the largest median concentrations were during April–June. Fecal-coliform concentrations exceeded the U.S. Environmental Protection Agency recommended limit for a single sample of 400 colonies per 100 milliliters in 2.6 percent of all samples. *Escherichia coli* concentrations exceeded the U.S. Environmental Protection Agency recommended limit for a single sample of 298 colonies per 100 milliliters for moderate use, full-body contact recreation in 7.6 percent of all samples.

Variations in water type in the basin are reflective of the diverse geologic terrain in the Yellowstone River Basin. The water type of Soda Butte Creek and the Tongue River was calcium bicarbonate. These two sites are in forested and mountainous areas where igneous rocks and Paleozoic-era and Mesozoic-era sedimentary rocks are the dominant geologic groups. The water type of the Little Powder River was sodium sulfate. The Little Powder River originates in the plains, and geology of the basin is nearly homogenous with Tertiary-period sedimentary rocks. Water type of the Yellowstone River changed from a mixed-cation bicarbonate type upstream to a mixed-cation sulfate type downstream. Dissolved-solids concentrations ranged from fairly dilute in Soda Butte Creek, which had a median concentration of 118 milligrams per liter, to concentrated in the Little Powder River, which had a median concentration of 2,840 milligrams per liter.

Nutrient concentrations generally were small and reflect the relatively undeveloped conditions in the basin; however, some correlations were made with anthropogenic factors. Median dissolved-nitrate concentrations in all samples from the fixed sites ranged from 0.04 milligram per liter to 0.54 milligram per liter. Flow-weighted mean dissolved-nitrate concentrations were positively correlated with increasing agricultural land use and rangeland on alluvial deposits upstream from the sites and negatively correlated with increasing forested land. Ammonia concentrations generally were largest in samples collected from the Yellowstone River at Corwin Springs, Montana, which is downstream from Yellowstone National Park and receives discharge from geothermal waters that are high in ammonia. Median total-phosphorus concentrations ranged from 0.007 to 0.18 milligram per liter. Median total-phosphorus concentrations exceeded the U.S. Environmental Protection Agency's recommended goal of 0.10 milligram per liter for preventing nuisance plant growth for samples collected from the Bighorn River, Powder River, and Yellowstone River. Seasonal variations were observed in nutrient concentrations. Dissolved-nitrate concentrations generally were largest during October to March when plant uptake of nitrate is lowest. In contrast, total-phosphorus concentrations were largest during April–June when sediment concentrations, which contribute to the total-phosphorus concentrations, are largest.

Concentrations of trace elements generally were small in samples for sites in the Yellowstone River Basin. Soda Butte Creek, which is in a mineral resource area with historical mining in the basin upstream from the sampling site, did not have elevated concentrations of trace elements compared to other sites. On the Yellowstone River, median concentrations of dissolved arsenic of 21 micrograms per liter at Corwin Springs, Montana, and 10.5 micrograms per liter at Billings, Montana,

exceeded the drinking-water Maximum Contaminant Level of 10 micrograms per liter. Geothermal waters from Yellowstone National Park are a significant source of arsenic in the Yellowstone River. Concentrations of dissolved selenium were largest in the Powder River, ranging from 0.48 microgram per liter to 4.6 micrograms per liter. Concentrations were smaller than the aquatic-chronic criterion of 5 micrograms per liter; however, other studies have shown that concentrations of total selenium larger than 2 micrograms per liter may produce adverse effects on some fish and wildlife species.

Pesticide concentrations generally were small in samples for three sites on the Yellowstone River, one site on the Clarks Fork Yellowstone River, and one site on the Bighorn River. Herbicides were more frequently detected than insecticides. Atrazine was the most commonly detected herbicide and was detected in 74.8 percent of the samples. Concentrations of all compounds generally were smaller than 0.01 microgram per liter and substantially smaller than aquatic-life or human-health criteria. Mixtures of two or more pesticides were detected in 75 percent of the samples.

Suspended-sediment concentrations were seasonally variable and were largest during April–June during snowmelt runoff. Suspended-sediment concentrations were smallest for the fixed sites on Soda Butte Creek and the Tongue River because of the resistant geology in the mountainous settings. Reservoir-adjusted yields were largest for the Clarks Fork Yellowstone River, Bighorn River, and the Powder River, which have large drainage areas with mixed geology that includes Tertiary-period sedimentary rocks. On the Yellowstone River, suspended-sediment loads increased in the downstream direction.

Introduction

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) was designed to: 1) assess the status in quality of the Nation's water resources, 2) describe the trends in quality of these resources over time, and 3) improve the understanding of natural and anthropogenic influences on the quality of these resources (Hirsch and others, 1988). To implement this design, the NAWQA Program initiated more than 50 interdisciplinary assessments of the Nation's most important stream and aquifer systems. These systems—referred to as Study Units—include more than 60 percent of water used by all sectors and populations served by public water supplies.

Study-Unit assessments are implemented using a consistent design to allow for comparison of data and results on a National scale. As such, a Study-Unit assessment consists of four components: retrospective analysis, occurrence and distribution assessment, trends assessment, and detailed studies of selected constituents. Within the occurrence and distribution component, physical and chemical properties of dissolved and total constituents in streams are assessed at fixed sampling sites to address water-column characteristics (Gilliom and others, 1995).

In 1997, the NAWQA Program initiated an assessment of the quality of the streams and aquifers for the Yellowstone River Basin Study Unit (YELL). The YELL was defined as the entire Yellowstone River drainage basin, including the Yellowstone River and its major tributaries: Clarks Fork Yellowstone, Wind/Bighorn, Tongue, and Powder Rivers (Miller and Quinn, 1997). To assess the status of water-quality conditions in the YELL, 10 fixed sites were established on streams representing most of the environmental settings in the Study Unit. Water-quality samples generally were collected at least monthly at the fixed sites from January 1999 through September 2001 for use in describing the occurrence and distribution of water-column characteristics in the YELL.

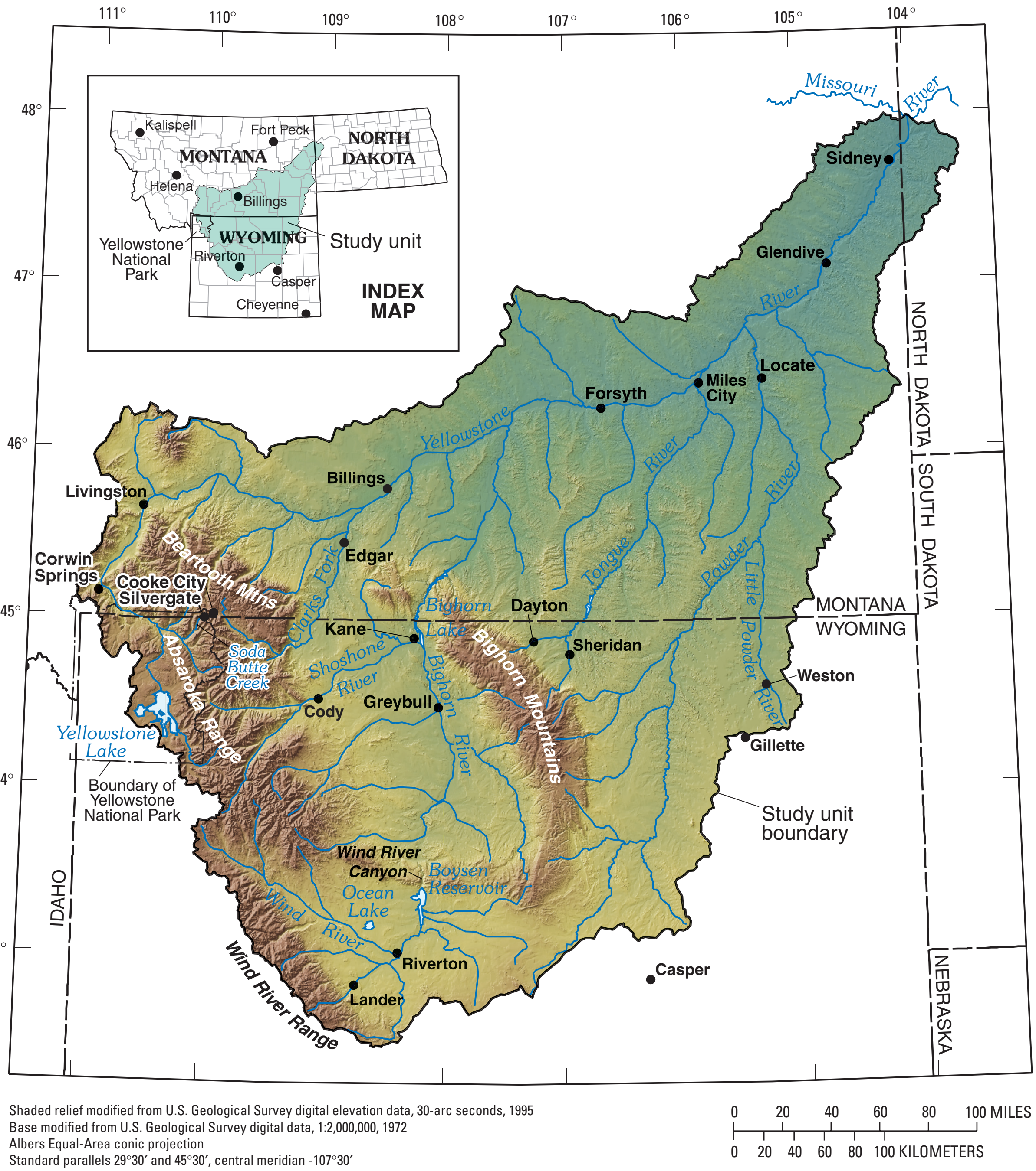
Purpose and Scope

This report summarizes the environmental settings and water-quality characteristics at 10 fixed sites in the YELL in Montana and Wyoming. Fixed sites were on Soda Butte Creek (1 site), Yellowstone River (4 sites), Clarks Fork Yellowstone River (1 site), Bighorn River (1 site), Tongue River (1 site), Little Powder River (1 site), and Powder River (1 site). The water-quality characteristics described in the report include field measurements, fecal-indicator bacteria, major ions, dissolved solids, nutrients, trace elements, pesticides, and suspended sediment. Analyses of water-quality data for the fixed sites generally are limited to those samples collected during the study period from January 1, 1999 through September 30, 2001. Water-quality characteristics are summarized in the context of the fixed-site environmental settings.

Description of Study Unit

The YELL extends from central Wyoming north to include most of southeastern Montana and a small part of western North Dakota (fig. 1). Drainage area for the YELL is about 70,100 square miles (mi^2). The entire Yellowstone River drainage basin defines the YELL boundaries and includes all of the Clarks Fork Yellowstone, Wind/Bighorn, Tongue, and Powder River Basins. Topography of the YELL varies from mountain ranges and high plateaus, including the Wind River Range, Bighorn Mountains, and Absaroka Range, to intermontane basins, such as the Wind River and Bighorn Basins. Elevations in the YELL range from more than 13,800 feet above the North American Vertical Datum of 1988 (NAVD 88) to about 1,900 feet above NAVD 88. Mean annual precipitation ranges from more than 60 inches in the mountains near Yellowstone National Park (YNP) to less than 6 inches in parts of the Bighorn River Basin (Oregon Climate Service, 1998).

Rangeland is the dominant land use and land cover in the YELL, which includes about 47 percent herbaceous grasslands and 27 percent shrublands (U.S. Geological Survey, 1992). The remaining land uses and land covers include about



Shaded relief modified from U.S. Geological Survey digital elevation data, 30-arc seconds, 1995
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area conic projection
Standard parallels 29°30′ and 45°30′, central meridian -107°30′

Figure 1. Location of the Yellowstone River Basin.

14 percent forested lands, 9 percent agricultural lands, and 3 percent other uses. Urban areas compose about 0.2 percent of the YELL. Total population of the Yellowstone River Basin was about 323,000 during 1990 (Zelt and others, 1999, p. 57). About 30 active mines remove low-sulfur coal by surface strip-mining methods from the large coal reserves in the Tongue and Powder River Basins. Most of the metals mining was in the mountainous regions of the Study Unit. Oil and gas are produced from reservoirs in the Powder River and Bighorn Basins (Miller and Quinn, 1997).

Streamflow in all the major drainage basins is affected by diversions. Although there are no reservoirs on the Yellowstone River, several reservoirs regulate flow in the Wind/Bighorn and Tongue River drainage basins. About 98 percent of the total water used in the Study Unit in 1990 was surface water (Miller and Quinn, 1997). Most of this water—about 99 percent—was used by the agricultural industry for crops and livestock. Public supply, mining, power generation, and industry made up most of the remaining uses of water in the YELL (Miller and Quinn, 1997).

Acknowledgments

USGS hydrologic technicians, in particular Stacy Kinsey, and hydrologists that collected water-quality samples and streamflow data are gratefully acknowledged; without their dedication, this report would not have been possible. All the local, State, and Federal agencies that contribute to the operation of streamflow gages in the basin are acknowledged. Reviews by Kent Becher, Janet Carter, and Norm Spahr improved the report. D. Kirk Nordstrom, USGS, is acknowledged for his insight into the water quality of the geothermal resources of Yellowstone National Park. David Peterson, USGS, is acknowledged for his assistance in evaluating nutrients in the Yellowstone River and his direction as project chief. Thomas Quinn, formerly USGS, is acknowledged for his guidance and support. The compilation and reduction of digital geographic data by Ronald Zelt, USGS, and Robert Kirkwood, formerly USGS, made possible many of the analyses in this report. In addition, Sue Roberts and Emily Sabado are acknowledged for their assistance in the preparation of the report.

Environmental Settings of Fixed Sites

Natural and anthropogenic factors, such as geology and land use, affect the water quality of streams. These factors can be combined to create environmental settings for the drainage basins that can be used for designing sampling networks and making water-quality assessments (Gilliom and others, 1995). This section describes the design and characteristics of the fixed-site network for the YELL and the characteristics for each of the sites in the network.

Design and Characteristics of the Fixed-Site Network

Zelt and others (1999) used three factors in a layered—or stratified—approach to create environmental settings that are believed to be important in assessing water-quality conditions in the YELL (fig. 2). Ecoregions—the first factor—were determined from a modification of mapping by Omernik (1987) (U.S. Environmental Protection Agency, 1996). Geology—the second factor—was determined from a reduction of multiple sources to generalized geologic groups. An additional geologic group—mineral resource area (MRA)—was defined for areas where minerals (for example, metals, coal deposits, or oil and gas fields) occur and (or) extraction activities have occurred or are likely to occur. Alluvium and other Quaternary-period unconsolidated deposits compose a small component of surficial geology and are not included with the consolidated geologic groups in table 1; however, these deposits typically are close to the stream and may be important to water quality, so they are discussed in the text in some places. Land use and land cover classification—the third factor—was determined from Anderson and others (1976).

The fixed-site network has two general types of sites. Integrator sites are used to characterize water quality in larger basins with a heterogeneous environmental setting, potentially consisting of multiple land covers, land uses, and geologic groups in more than one ecoregion. Integrator sites are located near the Study Unit outlet and near important confluences. By comparison, indicator sites are used to characterize water-quality in smaller basins with a relatively homogeneous environmental setting. Indicator sites are selected to represent environmental settings that may have an important influence on water quality in the YELL.

Of the 10 sites that were established as part of the YELL fixed-site network (table 1), 4 integrator sites were established on the Yellowstone River to directly describe downstream water-quality gradients on the mainstem. Sites were established at Corwin Springs (site YCS) downstream from YNP, Billings (site YB) downstream from the Clarks Fork Yellowstone River, Forsyth (site YF) downstream from the Bighorn River, and Sidney (site YS) near the mouth. Three additional integrator sites were established on major tributaries to augment information from the mainstem integrator sites. A site was established near the mouth of the Clarks Fork Yellowstone River (site CF) to characterize the contribution of nutrients and sediment to the mainstem. A site was established on the Bighorn River (site B) to characterize water-quality conditions in the largest and most regulated tributary. A site was established near the mouth of the Powder River (site P), which is a substantial source of sediment to the mainstem. Three indicator sites were established to characterize the water-quality conditions of important environmental settings in more homogeneous basins. A site was established on Soda Butte Creek (site SB) to characterize water-quality conditions of a MRA; on the Tongue River (site T) to characterize water-quality conditions for forested land; and on the Little Powder River (site LP) to characterize water-quality conditions for rangeland.

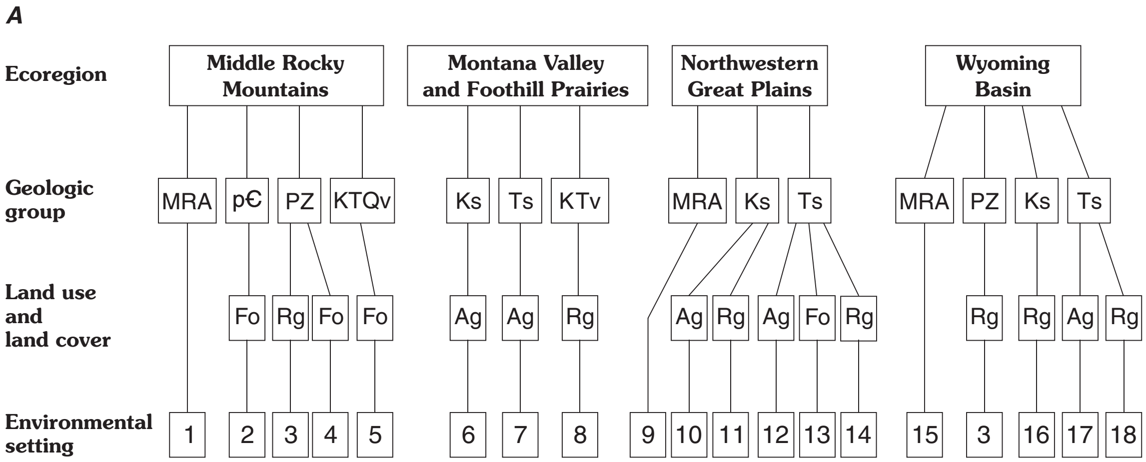
Environmental settings also were used to help determine sampling frequency and select constituents for analysis. Basic fixed sites were sampled monthly during the study with additional samples collected during extreme flows. Intensive fixed sites were sampled monthly during the study with additional samples collected during extreme flows and during the growing season where agriculture was an important land use. Fixed-site type for each site is listed in table 1. Constituents selected for analysis may be targeted to assess a specific land use. For example, trace elements may be analyzed in samples collected from basins where a MRA is a part of the environmental setting, but not analyzed in samples collected from a forested basin.

The simple one-, two-, or three-letter identifiers that were defined for each site are used in text, figures, and tables throughout the report for the benefit of the reader. Shading used in figures corresponds to the site groups (table 1) of mainstem integrator (gray shading), major tributary integrator (blue shading), and minor tributary indicator (white or no shading).

The land use and land cover distributions in table 1 were determined using the National Land Cover Data (NLCD) (U.S. Geological Survey, 1992). General differences between the NLCD and the Anderson and others (1976) classifications are described by the U.S. Geological Survey (1992). For land use and land cover information over small areas in the YELL, the NLCD probably is more accurate than the previous data, because of enhanced spatial resolution and updated mapping techniques as well as being more contemporaneous with this study. Because of the generalized, composite nature of the stratification process, however, differences between the land use and land cover data and the resulting differences in the environmental settings at the basin scale for the YELL are small. In this report, rangeland is the combined area of the shrubland and herbaceous grassland land covers.

Land-use and land-cover classifications are general descriptors of land characteristics that often are interpreted differently. Such interpretations can exclude detailed characteristics that are important in water-quality assessments. For example, rangelands typically are associated with minimal use as well as livestock grazing of native grasslands. In the YELL, however, land uses on rangelands also include vegetation management to improve forage and dispersed development of oil and gas. Similarly, in addition to the natural conditions in forested lands, forest uses also include logging, livestock grazing, and recreational activities. In addition, for rangelands as well as forested lands, increasing low-density, unsewered domestic development is a changing land use in the YELL. Finally, some land uses that do not compose a large percentage of any given basin can be important in water-quality assessments. For example, much of the agricultural land uses in the YELL are concentrated near water sources because of the semi-arid climate.

Other basin or stream characteristics are useful in describing the environmental setting of the fixed sites. Area-weighted mean basin elevations (table 1) were determined using the National Elevation Database (NED) (U.S. Geological Survey, 1999) and other digital spatial data. Area-weighted mean annual and monthly precipitation values were calculated using digital spatial data by Daly and others (1994) and Oregon Climate Service (1998). Streamflow statistics for the fixed sites were determined using gaging-station data from USGS databases (table 2). Because of the short period of record (1999-2001) for site SB, the streamflow statistics might not be representative of historical or future streamflows. These streamflow data are available from the USGS on the Internet at *http://waterdata.usgs.gov/nwis/sw*. Stream classifications and corresponding quality or use classifications that are used by the States of Montana and Wyoming for regulatory concerns were simplified for this report and are listed in table 3. The stream classifications and supporting uses are described with the environmental setting for the site.



EXPLANATION

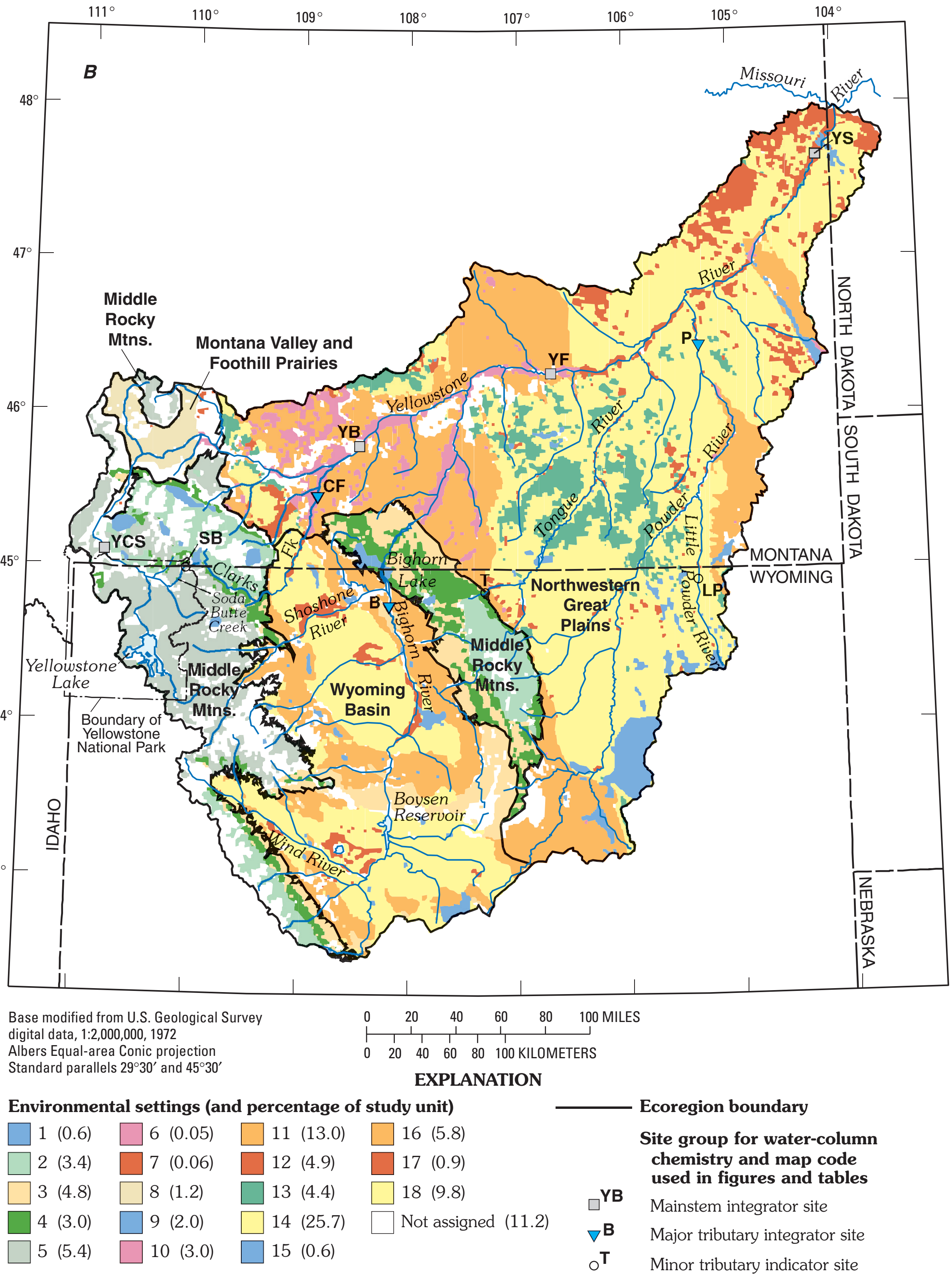
Geologic group

MRA	Mineral resource area
Ts	Tertiary sedimentary rocks
KTv	Tertiary and Cretaceous volcanic rocks
KTQv	Cretaceous, Tertiary, and Quaternary volcanic rocks
Ks	Cretaceous sedimentary rocks
PZ	Paleozoic and Mesozoic sedimentary rocks
p€	Precambrian crystalline rocks

Land use and land cover

Ag	Agricultural
Fo	Forest
Rg	Range

Figure 2. Schematic diagram and map of environmental settings and fixed sites of the Yellowstone River Basin.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′

Figure 2. Continued.

Table 1. Selected basin characteristics for fixed sites in the Yellowstone River Basin.

[NAVD 88, North American Vertical Datum of 1988; YNP, Yellowstone National Park; p€, Precambrian crystalline; PZ, Paleozoic and Mesozoic sedimentary; Ks, Cretaceous sedimentary; Ts, Tertiary sedimentary; KTv, Cretaceous and Tertiary volcanic; KTQv, Cretaceous, Tertiary, and Quaternary volcanic]

Site report identifier (fig. 2)	Station number	Station name	Drainage area (square miles)[1]	Mean basin elevation (feet above NAVD 88)	Site group	Fixed-site type	Predominant environmental characteristics (percent of drainage area)			Mean annual precipitation (inches)[4]
							Ecoregion[2]	Simplified geologic groups[2]	Land use and land cover[3]	
SB	06187915	Soda Butte Creek at YNP boundary, near Silver Gate, Mont.	31.2	8,900	Minor tributary indicator	Basic indicator (mineral resource area)	Middle Rocky Mountains (100)	KTv (68), PZ (31), p€(1)	Evergreen forest (77), Transitional (9), Shrubland (9), Herbaceous grassland (3)	38
YCS	06191500	Yellowstone River at Corwin Springs, Mont.	2,619	8,300	Mainstem integrator	Basic integrator	Middle Rocky Mountains (100)	KTQv (77), p€(8), PZ (5), Ks (2)	Evergreen forest (49), Transitional (23), Shrubland (11), Herbaceous grassland (9)	32
CF	06208500	Clarks Fork Yellowstone River at Edgar, Mont.	2,022	6,300	Major tributary integrator	Basic integrator	Middle Rocky Mountains (47), Wyoming Basin (40), Northwestern Great Plains (13)	Ts (33), Ks (19), KTv (18), p€(18), PZ (11)	Shrubland (42), Evergreen forest (27), Herbaceous grassland (19), Transitional (3)	22
YB	06214500	Yellowstone River at Billings, Mont.	11,805	6,500	Mainstem integrator	Basic integrator	Middle Rocky Mountains (55), Northwestern Great Plains (24), Montana Valley and Foothill Prairies (13), Wyoming Basin (7)	KTv (35), Ks (22), p€ (16), Ts (15), PZ (5), KTQv (5)	Herbaceous grassland (33), Evergreen forest (31), Shrubland (15), Transitional (6)	24

Table 1. Selected basin characteristics for fixed sites in the Yellowstone River Basin—Continued.

Site report identifier (fig. 2)	Station number	Station name	Drainage area (square miles)[1]	Mean basin elevation (feet above NAVD 88)	Site group	Fixed-site type	Predominant environmental characteristics (percent of drainage area)			Mean annual precipitation (inches)[4]
							Ecoregion[2]	Simplified geologic groups[2]	Land use and land cover[3]	
B	06279500	Bighorn River at Kane, Wyo.	15,762	6,400	Major tributary integrator	Intensive integrator	Wyoming Basin (74), Middle Rocky Mountains (26)	Ts (43), Ks (23), PZ (18), p€ (9), KTQv (6)	Shrubland (60), Herbaceous grassland (25), Evergreen forest (9), Pasture/hay (2)	14
YF	06295000	Yellowstone River at Forsyth, Mont.	40,146	5,800	Mainstem integrator	Intensive integrator	Wyoming Basin (35), Middle Rocky Mountains (33), Northwestern Great Plains (27), Montana Valley and Foothill Prairies (4)	Ks (34), Ts (27), KTv (16), PZ (13), p€ (8), KTQv (1)	Herbaceous grassland (36), Shrubland (33), Evergreen forest (17), Small grains (3)	18
T	06298000	Tongue River near Dayton, Wyo.	206	8,500	Minor tributary indicator	Basic indicator (forested)	Middle Rocky Mountains (100)	PZ (53), p€(46)	Evergreen forest (60), Herbaceous grassland (23), Shrubland (7), Deciduous forest (5)	27
LP	06324970	Little Powder River above Dry Creek, near Weston, Wyo.	1,237	4,100	Minor tributary indicator	Basic indicator (rangeland)	Northwestern Great Plains (100)	Ts (100)	Herbaceous grassland (81), Shrubland (11), Evergreen forest (3), Small grains (1), Emergent herbaceous wetlands (1)	14

Table 1. Selected basin characteristics for fixed sites in the Yellowstone River Basin—Continued.

Site report identifier (fig. 2)	Station number	Station name	Drainage area (square miles)[1]	Mean basin elevation (feet above NAVD 88)	Site group	Fixed-site type	Predominant environmental characteristics (percent of drainage area)			Mean annual precipitation (inches)[4]
							Ecoregion[2]	Simplified geologic groups[2]	Land use and land cover[3]	
P	06326500	Powder River near Locate, Mont.	13,068	4,600	Major tributary integrator	Basic integrator	Northwestern Great Plains (88), Middle Rocky Mountains (7), Wyoming Basin (5)	Ts (65), Ks (24), PZ (7), p€ (4)	Herbaceous grassland (59), Shrubland (29), Evergreen forest (6), Small grains (1), Fallow (1), Pasture/hay (1)	14
YS	06329500	Yellowstone River near Sidney, Mont.	69,083	5,000	Mainstem integrator	Intensive integrator	Northwestern Great Plains (55), Middle Rocky Mountains (22), Northwestern Great Plains (21), Montana Valley and Foothill Prairies (2)	Ts (48), Ks (26), KTv (9), PZ (9), p€ (6)	Herbaceous grassland (47), Shrubland (27), Evergreen forest (13), Small grains (3), Fallow (3)	17

[1] Source U.S. Geological Survey National Water Information System.

[2] Modified from Zelt and others, 1999; only the four largest (by total basin area) geologic groups are listed.

[3] Modified from U.S. Geological Survey, 1992; only the four largest (by total basin area) land use/land cover classifications are listed.

[4] Modified from Oregon Climate Service, 1998.

Table 2. Selected streamflow statistics for fixed sites in the Yellowstone River Basin.

Site report identifier (fig. 2)	Period of record (water years)[1]	Mean annual streamflow (cubic feet per second)	Streamflow percent exceedance (cubic feet per second)			Annual runoff (acre- feet)
			10th	50th	90th	
SB	1999-2001	52.7	203	8.2	1.8	38,000
YCS	1890-2001	3,125	8,490	1,400	760	2,264,000
CF	1922-2001	1,035	2,850	470	275	749,800
YB	1929-2001	6,996	17,700	3,730	2,180	5,069,000
B	1930-2001	2,160	[2]3,000	[2]2,100	[2]1,400	1,565,000
YF	1978-2001	10,800	22,900	7,380	4,600	7,822,000
T	1920-2001	180	479	73	48	130,100
LP	1973-2001	21.8	35	3.0	.03	15,780
P	1939-2001	583	1,370	241	42	422,300
YS	1911-2001	12,550	[3]27,000	[3]8,740	[3]5,000	9,095,000

[1] Based on complete water years. May include intervening water years with no record.

[2] Based on period of record after regulation began by Boysen Reservoir, water years 1952-2001.

[3] Based on period of record after Bighorn Lake reached operational level, water years 1967-2001.

Table 3. State water-quality classifications of surface waters, Montana and Wyoming.

Class	Quality or use	Comments
	Montana[1]	
A	Very high quality	[3]Montana surface-water classification includes a nondegredataion policy for "Outstanding Resource Waters"
B	High quality	Majority of surface waters in Montana.
C	Low quality	Same uses as class B waters except unsuitable for drinking.
I	Impaired	Generally unsuitable for any use.
	Wyoming[2]	
1	Outstanding waters	Includes all waters in Teton and Yellowstone National Parks and designated wilderness areas.
2	Fisheries and drinking waters	Known to support or have the potential to support fish populations or drinking water supplies.
3	Aquatic life other than fish	Basic default classification for all waters; provides minimum protection for aquatic life and recreation uses.
4	Agriculture, industry, recreation, and wildlife	Aquatic life not protected.

[1] Source: Bryan and Kakuk, 1997.

[2] Source: Wyoming Department of Environmental Quality, 2001a.

[3] Bryan and Kakuk, p. 11, 1997.

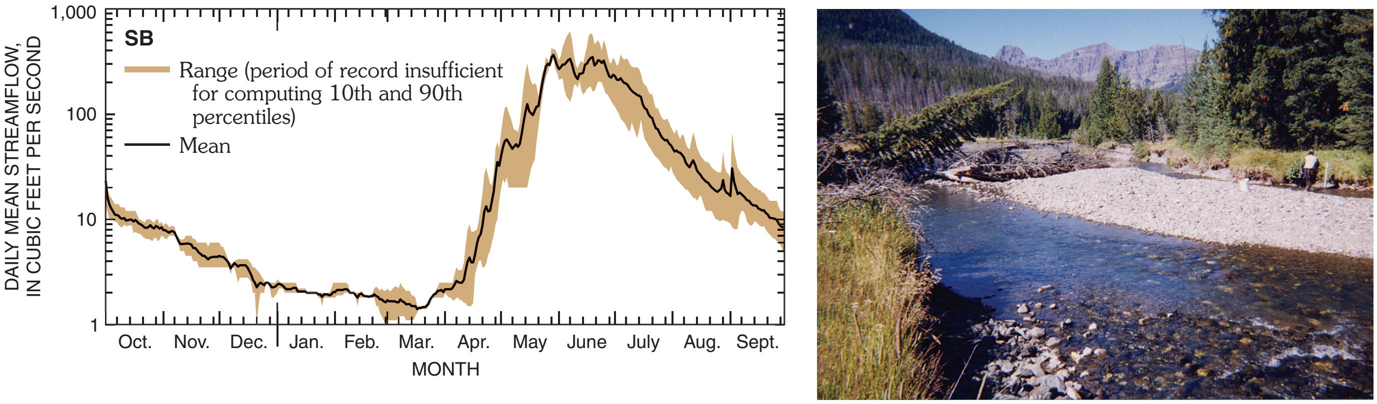
Soda Butte Creek at YNP boundary near Silver Gate, Montana (SB)

Soda Butte Creek is located in the Absaroka Range of southwestern Montana where it flows west-southwest into YNP and Wyoming to its confluence with the Lamar River, a tributary to the Yellowstone River. Site SB (fig. 2) is downstream from Silver Gate, Montana, at the boundary of YNP. The drainage area for the site is located entirely within the Middle Rocky Mountains ecoregion. Mean basin elevation is the highest of the fixed-site basins (8,900 feet above NAVD 88), with elevations ranging from more than 11,000 feet above NAVD 88 in the headwaters to about 7,300 feet above NAVD 88 near site SB. Mean annual precipitation of 38 inches in the Soda Butte Creek Basin is the highest for the fixed-site basins. The geologic groups generally are composed of mostly Cretaceous- and Tertiary-period volcanic rocks and Paleozoic-era and Mesozoic-era sedimentary rocks (Elliott, 1979). About 33 percent of the basin upstream from site SB was included by Zelt and others (1999) in the MRA geologic group, which is predominantly associated with the Paleozoic-era and Mesozoic-era sedimentary rocks, based on descriptions of historical and recent metals mining and other mineral resource assessments.

About 77 percent of the land cover of the basin upstream from site SB is evergreen forest (table 1). An important historical land use in the basin has been the mining of gold, silver, copper, and other metals. Ore from the McLaren Mine was processed at a mill located next to Soda Butte Creek until 1953 (Boughton, 2001). Much of the mining occurred at or near timberline in the upper part of the basin. Disposal of mine tailings included an in-channel impoundment in the headwaters of Soda Butte Creek. Subsequent exploration continued until 1996 when private mining interests were bought out by the U.S. Government (U.S. Forest Service, 2003). The communities of Cooke City and Silver Gate, Montana (fig. 1), which have a combined population of 140 people (U.S. Census Bureau, 2000), are located in the basin along Soda Butte Creek.

The hydrology of site SB is characteristic of small streams with headwaters in the mountainous areas of the YELL. Annual streamflows are dominated by a snowmelt peak of moderate duration during late spring through early summer with low variability in daily mean streamflow throughout the year (fig. 3). Compared to rainstorms in the basins and plains areas, mountain snowpacks are relatively consistent in spatial extent and between years, resulting in low variability in annual streamflows (Miller, 1999).

Soda Butte Creek upstream from site SB is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). Soda Butte Creek upstream from site SB to a tailings impoundment is listed as only partially supporting aquatic life and cold-water fishes because of metals from abandoned mining activities (Montana Department of Environmental Quality, 2002b).



Photograph from U.S. Geological Survey files.

Figure 3. Annual hydrograph (1999-2001) and photograph for Soda Butte Creek, Montana (site SB).

Yellowstone River at Corwin Springs, Montana (YCS)

The headwaters of the Yellowstone River are near the Continental Divide in the Absaroka Range of northwestern Wyoming and from there the river generally flows north-northwest into YNP, through Yellowstone Lake and the Grand Canyon of the Yellowstone, and into Montana. Site YCS (fig. 2) is located at Corwin Springs about 8 miles (mi) north of the Wyoming-Montana state line and about 550 river miles upstream from the confluence with the Missouri River (Shields and others, 2001). The basin upstream from the site is located entirely within the Middle Rocky Mountains ecoregion. Elevations in the basin range from more than 12,100 feet above NAVD 88 in the headwaters to about 5,100 feet above NAVD 88 near site YCS. Mean annual precipitation for the basin is about 32 inches; most of the annual precipitation occurs as snow during the winter months, with November through January accumulations equaling about 30 percent of the total annual precipitation. The geologic groups in the basin upstream from site YCS are composed mostly of Cretaceous-, Tertiary-, and Quaternary-period volcanic rocks (77 percent). YNP and the surrounding region are considered an active volcanic area; Yellowstone Lake is located in a collapsed caldera measuring 45 mi by 30 mi (U.S. Geological Survey, 2003b; Yellowstone National Park, 2001).

About 49 percent of the land cover of the basin upstream from site YCS is evergreen forest and about 23 percent is classified as transitional (table 1). The transitional classification includes areas of sparse vegetative cover that are in the process of changing from one land cover to another. Examples include forest clearcuts and changes due to natural causes (for example, fire). During 1988, forest fires burned large areas of YNP and the surrounding region. About 46 percent of the basin upstream from site YCS was within the perimeters of these fires (Yellowstone National Park, 1995).

The hydrology of site YCS is characteristic of large streams with headwaters in the mountainous areas of the YELL. Annual streamflows are dominated by a single snowmelt peak of moderate duration during late spring through early summer with low variability in daily mean streamflow throughout the year (fig. 4). Compared to rainstorms in the basins and plains areas, mountain snowpacks vary little in spatial extent and between years, resulting in low variability in annual streamflows (Miller, 1999). Annual mean streamflow at site YCS is about 25 percent of the annual mean streamflow at site YS near the mouth; however, drainage area at site YCS accounts for only about 4 percent of the drainage area at site YS.

In YNP, the Yellowstone River and its tributaries are classified by the States of Wyoming and Montana as Class 1 and A waters, respectively, because all waters within national parks and wilderness areas are classified as such (Wyoming Department of Environmental Quality, 2001a; Montana Department of Environmental Quality, 2002a). The Yellowstone River downstream from YNP to site YCS is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a).

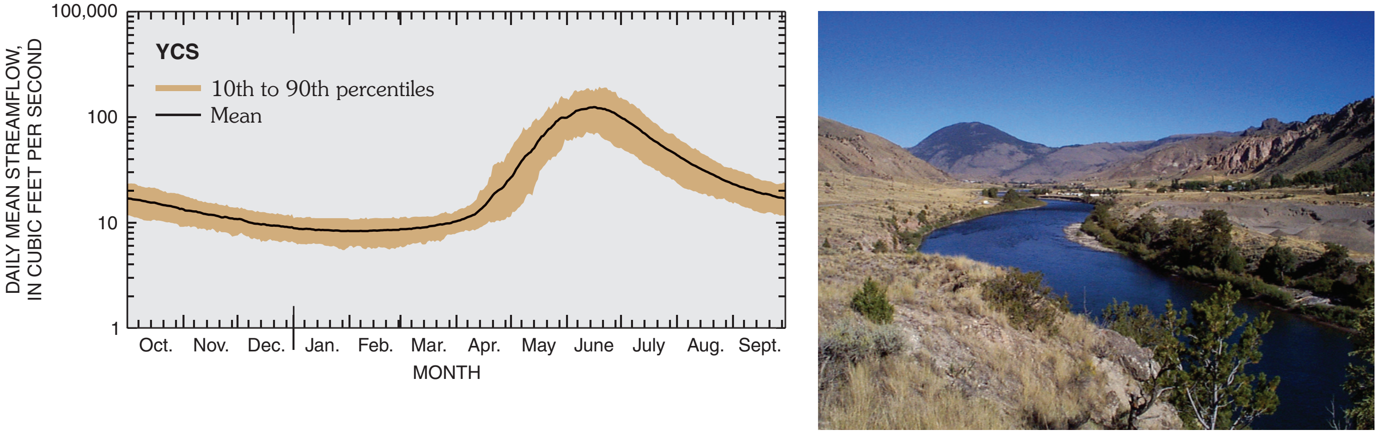


Figure 4. Annual hydrograph (1890-2001) and photograph for the Yellowstone River at Corwin Springs, Montana (site YCS).

Photograph by Gregory K. Boughton, U.S. Geological Survey

Clarks Fork Yellowstone River at Edgar, Montana (CF)

The Clarks Fork Yellowstone River flows east-southeast from its headwaters in the Beartooth Mountains and the Absaroka Range of southwestern Montana and northwestern Wyoming before flowing north-northeast to its confluence with the Yellowstone River. Site CF (fig. 2) is located at Edgar, Montana, about 22 river miles upstream from the confluence (Shields and others, 2001). The drainage area for the site is located mostly within the Middle Rocky Mountains (47 percent; upper part of the basin) and Wyoming Basin (40 percent; lower part of the basin) ecoregions. Elevations in the basin range from more than 12,500 feet above NAVD 88 in the headwaters to about 3,500 feet above NAVD 88 near site CF. Annual precipitation in the basin varies substantially, ranging from about 65 inches at the higher elevations in the western part of the basin to about 7 inches in the east-central part of the basin. Precambrian-era crystalline rocks (18 percent of the drainage area) and Cretaceous- and Tertiary-period volcanic rocks (18 percent) are the dominant geologic groups in the upper part of the basin in the Middle Rocky Mountains ecoregion. Cretaceous- (19 percent) and Tertiary-period (33 percent) sedimentary rocks are the dominant geologic groups in the lower part of the basin in the Wyoming Basin ecoregion.

The dominant land cover in the basin upstream from site CF is rangeland, which includes shrubland and herbaceous grassland (table 1). Most of the rangeland is in the lower part of the basin in the Wyoming Basin ecoregion. The agricultural land cover generally is in the lower part of the basin near the streams (fig. 2). About 16 percent of the alluvial deposits in the basin have agricultural uses on them; 53 percent of all agricultural land uses in the basin are on alluvial deposits. The dominant land cover in the upper part of the basin in the Middle Rocky Mountains ecoregion is evergreen forest (table 1).

The hydrology of site CF is characteristic of large streams with headwaters in the mountainous areas of the YELL. Annual streamflows are dominated by a single snowmelt peak of moderate duration during late spring through early summer (fig. 5). Variability in daily mean streamflow during the spring, summer, and fall months is larger at site CF than other snowmelt-dominated streams because of the variability in rainstorms in the lower part of the basin. Irrigation withdrawals in the lower part of the basin also affect variability in daily mean streamflow.

The upper reaches of the Clarks Fork Yellowstone River in Wyoming are the State's only reaches with National Wild and Scenic Rivers designation (Interagency Coordinating Council, 2003) and are classified by the State of Wyoming as Class 1 waters. The Clarks Fork Yellowstone River upstream from site CF is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). From the headwaters to the state line, the river is listed as only partially supporting aquatic life and cold-water fishes, because of metals from abandoned mining activities (Wyoming Department of Environmental Quality, 2002, Montana Department of Environmental Quality, 2002b).

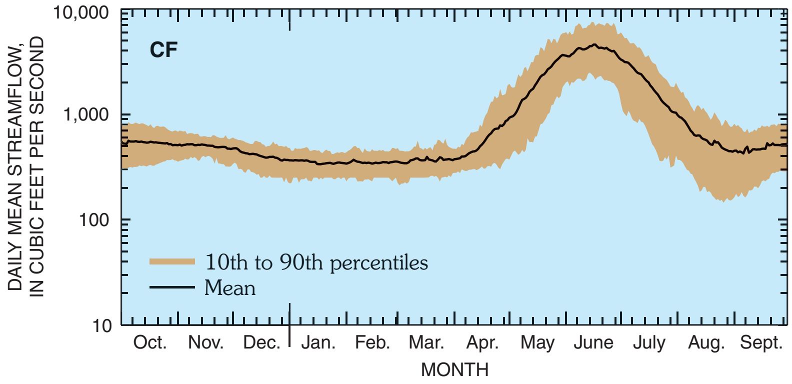


Figure 5. Annual hydrograph (1922-2001) and photograph for the Clarks Fork Yellowstone River, Montana (site CF).

Photograph by Gregory K. Boughton, U.S. Geological Survey

Yellowstone River at Billings, Montana (YB)

From site YCS, the Yellowstone River flows north to Livingston, Montana, then east through southern Montana to Billings, Montana, about 360 river miles upstream from the confluence with the Missouri River (Shields and others, 2001). Billings, Montana, the largest city in the YELL with a population of 89,847 (U.S. Census Bureau, 2000), is located at site YB (fig. 2). The drainage area for the site is located mostly within the Middle Rocky Mountains (55 percent) ecoregion. Mean basin elevation is about 6,500 feet above NAVD 88, with elevations ranging from more than 12,500 feet above NAVD 88 in the headwaters to about 3,100 feet above NAVD 88 near site YB. Mean annual precipitation for the basin is about 24 inches, ranging from about 65 inches at the higher elevations in the basin to about 7 inches in the Clarks Fork Yellowstone River part of the basin. The geologic groups in the basin upstream from site YB are composed mostly of Cretaceous- and Tertiary-period volcanic rocks (35 percent of the basin). Cretaceous-period sedimentary rocks compose 22 percent of the total basin.

Land cover in the basin upstream from site YB is dominated by rangeland and forested land (table 1). About 33 percent of the drainage area land cover is herbaceous grassland and 15 percent is shrubland (table 1). The percentage of forested land decreases and the percentage of rangeland increases downstream along the Yellowstone River between sites YCS and YB as proportionally less of the total drainage area is from mountain areas and more is from basin and plains areas. Land cover adjacent to streams in the basin upstream from site YB is mostly rangeland. About 44 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands. Agricultural land uses are more prevalent adjacent to streams than for the distant parts of the basin. About 13 percent of the alluvial deposits in the basin have agricultural uses on them.

The hydrology of site YB is characteristic of large streams with headwaters in the mountainous areas of the YELL. Annual streamflows are dominated by a single snowmelt peak of moderate duration during late spring through early summer with low variability in daily mean streamflow throughout the year (fig. 6). Annual mean streamflow at site YB is about 56 percent of the annual mean streamflow at site YS near the mouth; drainage area at site YB accounts for only about 17 percent of the drainage area at site YS.

The Yellowstone River at site YB is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). The Yellowstone River downstream from Billings is listed as only partially supporting warm-water fishery probably because of habitat alterations (Montana Department of Environmental Quality, 2002b).

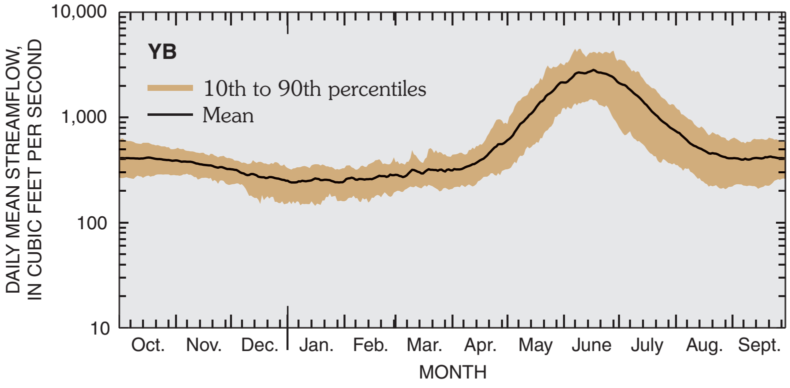


Figure 6. Annual hydrograph (1929-2001) and photograph for the Yellowstone River at Billings, Montana (site YB).

Photograph from U.S. Geological Survey files

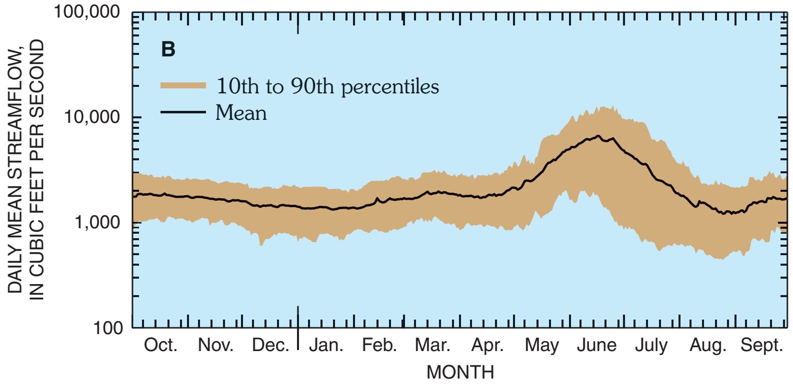
Bighorn River at Kane, Wyoming (B)

The headwaters for the Bighorn River are the streams in the mountains rimming the southern, eastern, and western margins of the basin. The principal headwater stream—the Wind River—flows east-southeast from the Continental Divide in Wyoming into the Wind River Basin before flowing north into Boysen Reservoir and through Wind River Canyon. Near the mouth of Wind River Canyon at Wedding of the Waters, the Wind River becomes the Bighorn River and flows north through the Bighorn Basin and into Bighorn Lake (a reservoir) and Bighorn Canyon National Recreation Area. Site B (fig. 2) is located at Kane, Wyoming, about 0.5 mi upstream from the normal highwater line for Bighorn Lake (Swanson and others, 2001). The drainage area for site B is mostly within the Wyoming Basin (74 percent) ecoregion (table 1). Elevations in the basin range from more than 13,800 feet above NAVD 88 in the Wind River Range to about 3,700 feet above NAVD 88 near site B. Annual mean precipitation varies with elevation, ranging from about 47 inches in the western mountains of the basin to less than 6 inches in the central part of the Bighorn Basin. The geologic groups in the basin upstream from site B are composed mostly of Tertiary-period sedimentary rocks (43 percent of the drainage area), which occur mostly in the central, lower-elevation parts of the Wind River and Bighorn Basins. Cretaceous-period and Paleozoic- and Mesozoic-era sedimentary rocks are exposed on the flanks of the mountain uplifts at the basin margins.

The dominant land cover in the basin upstream from site B is rangeland. About 60 percent of the drainage area land cover is shrubland and 25 percent is herbaceous grassland (table 1). Evergreen forest land cover is at higher elevations in the basin in contrast to agricultural covers, which generally are located in the lower elevations of the basin. About 70 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands. About 16 percent of the alluvial deposits in the basin have agricultural uses on them. About 74 percent of all agricultural land uses in the basin are on alluvial deposits.

Streamflows in the Bighorn River are affected substantially by modifications in the form of releases from Boysen Reservoir as well as irrigation diversions and return flows. Streamflow statistics for the period of record following regulation by Boysen Reservoir (water years 1952-2001) show the effects of streamflow modification in the large variability in streamflows during the summer months (fig. 7). Annual mean streamflow at site B is about 17 percent of the annual mean streamflow at site YS near the mouth of the Yellowstone River; drainage area at site B accounts for about 23 percent of the drainage area at site YS.

The Bighorn River is classified as Class 2 waters (Wyoming Department of Environmental Quality, 2001a). A reach of the Bighorn River downstream from Greybull, Wyoming, to an undetermined distance upstream from Kane, Wyoming, is classified as impaired for contact recreation because of fecal-coliform bacteria (Wyoming Department of Environmental Quality, 2002).



Photograph from U.S. Geological Survey files

Figure 7. Annual hydrograph (1952-2001) and photograph for the Bighorn River at Kane, Wyoming (site B).

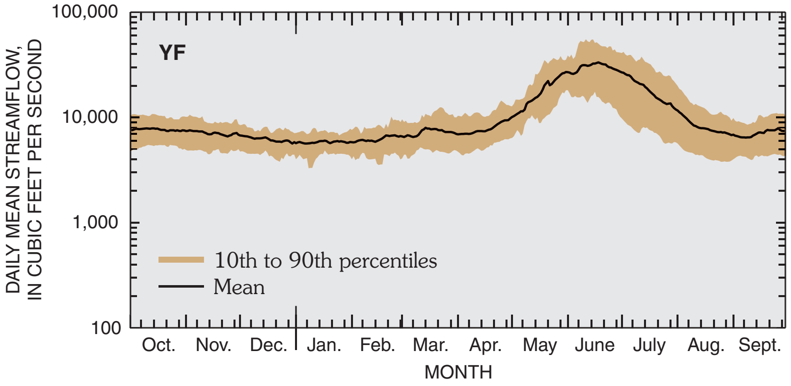
Yellowstone River at Forsyth, Montana (YF)

The Yellowstone River flows east-northeast from site YB through southern Montana. Site YF (fig. 2) is located at Forsyth, Montana, downstream from the confluence with the Bighorn River and about 240 river miles upstream from the confluence with the Missouri River (Shields and others, 2001). The basin upstream from site YF is located mostly within the Wyoming Basin (35 percent), Middle Rocky Mountains (33 percent), and Northwestern Great Plains (27 percent) ecoregions. Mean basin elevation is about 5,800 feet above NAVD 88, with elevations ranging from more than 13,800 feet above NAVD 88 in the Wind River Range to about 2,500 feet above NAVD 88 near site YF. Mean annual precipitation for the basin is about 18 inches. The geologic groups in the basin upstream from site YF are dominated by Cretaceous-period and Tertiary-period sedimentary rocks that generally extend over the basins and plains, including the area along the mainstem of the Yellowstone River and the lower-elevation areas in the Wind River and Bighorn Basins. The volcanic rocks that dominated the geologic groups of the Yellowstone River Basin at site YCS and site YB compose less than 16 percent of the basin at site YF.

The dominant land cover in the basin upstream from site YF is rangeland. About 36 percent of the drainage area land cover is herbaceous grassland and another 33 percent is shrubland (table 1). The shift in land cover from forested land to rangeland along the Yellowstone River between sites YCS and YB continues between sites YB and YF. Land cover adjacent to streams in the basin upstream from site YF also is dominated by rangeland; about 57 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands. Agricultural land uses are more prevalent adjacent to streams than for the distant parts of the basin; about 19 percent of the alluvial deposits in the basin have agricultural uses on them.

The hydrology of site YF is similar to the upstream site YB, where annual streamflows are dominated by a single snowmelt peak of moderate duration during late spring through early summer with low variability in daily mean streamflow throughout the year (fig. 8). The larger drainage area at site YF results in lower variability in streamflows at YF compared to YB. Annual mean streamflow at site YF is about 86 percent of the annual mean streamflow at site YS near the mouth; drainage area at site YF accounts for about 58 percent of the drainage area at site YS.

The Yellowstone River at site YF is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). The Yellowstone River in this area only partially supports warm water fishery, possibly because of habitat alteration from stream modification and dam construction (Montana Department of Environmental Quality, 2002b).




Photograph from U.S. Geological Survey files

Figure 8. Annual hydrograph (1978-2001) and photograph for the Yellowstone River at Forsyth, Montana (site YF).

Tongue River at Dayton, Wyoming (T)

The Tongue River flows east-northeast from the northeast flank of the Bighorn Mountains in northern Wyoming and through the plains of southeastern Montana to its confluence with the Yellowstone River at Miles City, Montana. Site T (fig. 2) is located near Dayton, Wyoming, at the mouth of a canyon; the drainage area for the site is located entirely within the Middle Rocky Mountains ecoregion (table 1). Mean basin elevation is about 8,500 feet above NAVD 88, with elevations ranging from more than 10,800 feet above NAVD 88 in the headwaters to about 4,100 feet above NAVD 88 near site T. Mean annual precipitation for the basin is about 27 inches, with about 34 percent of the total annual precipitation occurring on average during April through June. The geologic groups are composed of Precambrian-era crystalline rocks (46 percent) in the headwaters of the basin and upturned Paleozoic- and Mesozoic-era sedimentary rocks (53 percent) in the lower reaches of the basin. Included in these sedimentary units are carbonate rocks such as the Madison Limestone. Dissolution of these carbonates along fault zones and fold fractures has developed karstic features in some areas.

The dominant land cover in the basin upstream from site T is forested land (table 1). About 60 percent of the drainage area land cover is evergreen forest and 5 percent is deciduous forest. Other land cover in the basin includes rangeland (about 30 percent). The U.S. Forest Service (USFS) manages about 98 percent of the lands in the basin for multiple uses, including logging, grazing, and recreation (U.S. Bureau of Land Management, 2002).

The hydrology of site T is characteristic of streams with headwaters in the mountainous areas of the YELL. Annual streamflows are dominated by a single mountain snowmelt peak of moderate duration during late spring through early summer with low variability in daily mean streamflow throughout the remainder of the year (fig. 9). Compared to rainstorms in the basins and plains areas, mountain snowpacks are relatively consistent in spatial extent and between years, resulting in low variability in annual streamflows (Miller, 1999). Streamflows resulting from spring rain events upstream from site T generally are attenuated because of the low intensity and moderate duration of those events as well as geologic features. Streamflows at site T also are influenced by karstic features in the basin.

The Tongue River upstream from site T is classified by the State of Wyoming as Class 1 waters. A tributary to the Tongue River was previously listed as only partially supporting aquatic life because of residual chlorine in waste-water discharge from a USFS facility in the basin (Wyoming Department of Environmental Quality, 1998).

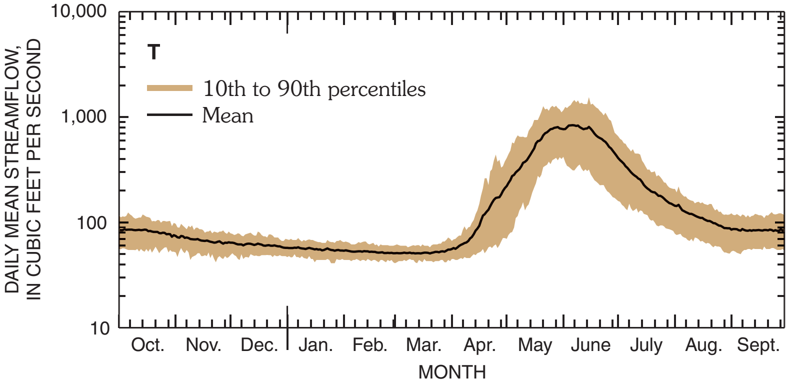


Figure 9. Annual hydrograph (1920-2001) and photograph for the Tongue River, Wyoming (site T).

Photograph by Gregory K. Boughton, U.S. Geological Survey

Little Powder River above Dry Creek, near Weston, Wyoming (LP)

The Little Powder River flows north through the plains of northeastern Wyoming and southeastern Montana to its confluence with the Powder River. Site LP (fig. 2) is located about 5 mi south of the Wyoming-Montana state line. The drainage area for the site is located entirely within the Northwestern Great Plains ecoregion (table 1). Mean basin elevation is about 4,100 feet above NAVD 88, with elevations ranging from about 4,900 feet above NAVD 88 to about 3,400 feet above NAVD 88 near site LP. Mean annual precipitation for the basin is about 14 inches; about 39 percent of the total annual precipitation occurs on average during May and June. The geologic groups for the basin are composed of flat to gently dipping Tertiary-age sandstones, shales, coal beds, and clinker. Clinker refers to sedimentary rocks that have been thermally altered by fires in underlying coal beds. These distinctive red-colored rocks that cap topographic highs cover about 1,600 mi^2 in northeastern Wyoming and southeastern Montana, much of which includes the Tongue and Powder Rivers of the Yellowstone River Basin. Clinker is characterized by high permeability and infiltration rates and large transmissivity and storage values (Heffern and Coates, 1997, 1999; Bartos and Ogle, 2002).

The dominant land cover in the basin upstream from site LP is rangeland (fig 2). About 81 percent of the drainage area land cover is herbaceous grassland and 11 percent is shrubland (table 1). Important land uses of these rangelands include grazing by livestock and wildlife, oil and gas development, and surface coal mining. Land cover adjacent to streams in the basin upstream from site LP also is dominated by rangeland. About 72 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands.

The hydrology of site LP generally is characteristic of small streams with headwaters in the plains areas of the YELL and streamflow is highly variable. Isolated precipitation events can substantially influence average daily mean streamflows. Annual streamflows at site LP consist of a plains (lowland) snowmelt peak during late winter through early spring (fig. 10). Several short to moderate duration rainstorm peaks are superimposed on the snowmelt peak and throughout the remainder of the summer. The hydrology of site LP is unique in some respects when compared to similar streams in the YELL. The occurrences and properties of clinker is important to the hydrology of site LP, attenuating streamflows from rainfall and snowmelt runoff, maintaining streamflows during low-flow periods, functioning as local aquifers, recharging underlying regional aquifers, and generally resulting in improved water quality (Lowry and Rankl, 1987; Heffern and Coates, 1997, 1999; Bartos and Ogle, 2002).

The Little Powder River is classified by the State of Wyoming as Class 2 waters (Wyoming Department of Environmental Quality, 2001a). A reach of the Little Powder River upstream from the Wyoming-Montana state line to an undetermined distance upstream is classified as threatened for contact recreation because of fecal-coliform bacteria (Wyoming Department of Environmental Quality, 2002).

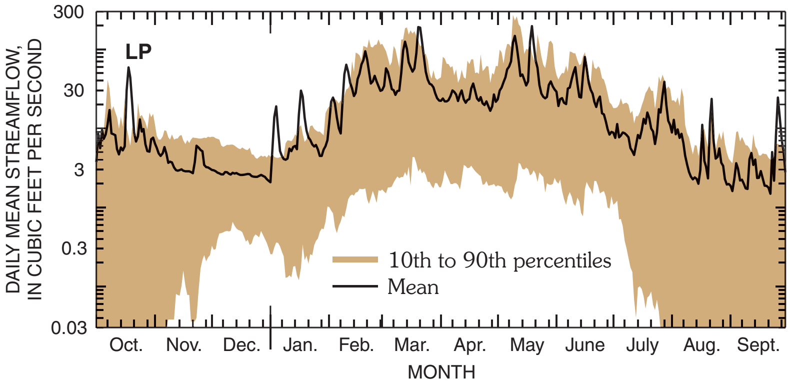


Figure 10. Annual hydrograph (1973-2001) and photograph for the Little Powder River, Wyoming (site LP).

Photograph from U.S. Geological Survey files

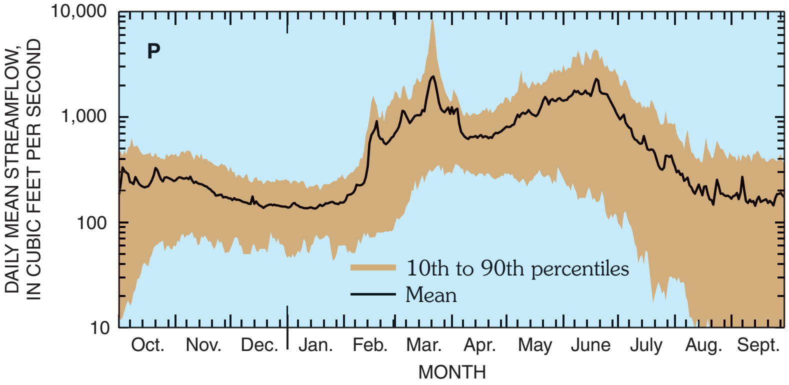
Powder River near Locate, Montana (P)

Headwaters for the Powder River are in the plains and mountains of central and north-central Wyoming. The Powder River flows north through the plains of northeastern Wyoming and southeastern Montana to its confluence with the Yellowstone River. Site P (fig. 2) is near Locate, Montana, about 25 mi east of Miles City, Montana, and 29 river miles upstream from the confluence with the Yellowstone River (Shields and others, 2001). The drainage area for the site predominantly is located within the Northwestern Great Plains (88 percent) ecoregion (table 1). Mean elevation in the basin is about 4,600 feet above NAVD 88 and ranges from more than 13,100 feet above NAVD 88 in the Bighorn Mountains to about 2,400 feet above NAVD 88 near site P. Mean annual precipitation for the basin is about 14 inches. The geologic groups for the basin include flat to gently dipping Tertiary-period sedimentary rocks that compose 65 percent of the drainage area. Cretaceous-period sedimentary rocks compose 24 percent of the drainage area. Like the Little Powder River Basin, clinker exists in the basin, particularly along the eastern margin of the basin. Paleozoic- and Mesozoic-era sedimentary rocks and Precambrian-era crystalline rocks are exposed in the mountains along the western margin of the basin.

The dominant land cover in the basin upstream from site P is rangeland; about 59 percent of the drainage area land cover is herbaceous grassland and another 29 percent is shrubland (table 1). Important land uses of these rangelands include grazing by livestock and wildlife, oil and gas development, and surface coal mining. Land cover adjacent to streams in the basin upstream from site P also is dominated by rangeland. About 71 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands. About 12 percent of the alluvial deposits in the basin have agricultural uses on them.

The hydrology of site P is characteristic of large streams with headwaters in the mountainous areas of the YELL that flow across the basins and plains. Annual streamflow characteristics are a combination of the annual streamflow characteristics of mountain streams and basin and plains streams. Annual streamflows at site P consist of a plains (lowland) snowmelt peak during late winter through early spring followed by a peak from the mountain snowmelt during late spring through early summer (fig. 11). Several short to moderate duration rainstorm peaks are superimposed on the snowmelt peak and throughout the remainder of the summer. Annual mean streamflow at site P is only about 5 percent of the annual mean streamflow at site YS near the mouth of the Yellowstone River; drainage area at site P accounts for about 19 percent of the drainage area at site YS.

The Powder River downstream at site P is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). The Powder River in this reach was not assessed by the State of Montana for impairments (Montana Department of Environmental Quality, 2002b).



Photograph from U.S. Geological Survey files

Figure 11. Annual hydrograph (1939-2001) and photograph for the Powder River, Montana (site P).

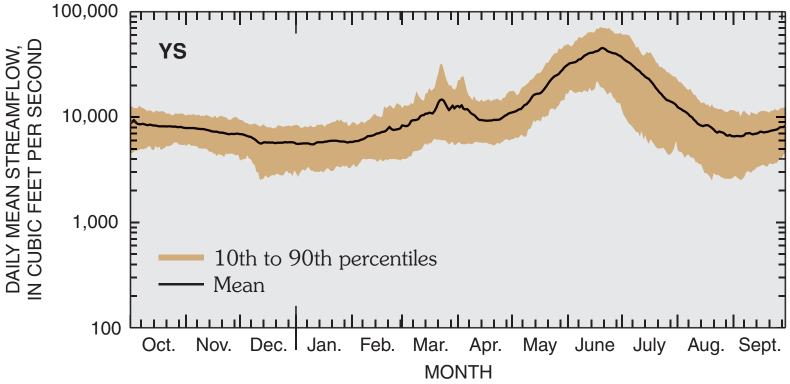
Yellowstone River near Sidney, Montana (YS)

The Yellowstone River flows east from site YF then northeast through the plains of southeastern Montana and into western North Dakota to its confluence with the Missouri River. The Tongue and Powder Rivers are major tributaries to the Yellowstone River in this part of the YELL. Site YS (fig. 2) is located near Sidney, Montana, about 29 river miles upstream from the confluence with the Missouri River (Shields and others, 2001). About 55 percent of the basin is located within the Northwestern Great Plains ecoregion (table 1). Mean basin elevation is about 5,000 feet above NAVD 88, with elevations ranging from more than 13,800 feet above NAVD 88 in the Wind River Range to about 1,900 feet above NAVD 88 near site YS. Mean annual precipitation for the basin is about 17 inches, which is substantially less than the mean annual precipitation at the mainstem sites (site YCS and site YB) in the upper basin. The geologic groups for the basin at site YS reflect the diverse geology of the sub-basins and ranges from Precambrian-era rocks and Tertiary-period volcanic rocks in the high mountains to predominantly Tertiary-period sedimentary rocks (48 percent) in the eastern part of the basin near Sidney, Montana. Cretaceous-period sedimentary rocks that generally are exposed along the flanks of uplifted areas compose 26 percent of the drainage area for the basin.

The dominant land cover in the basin upstream from site YS is rangeland. About 47 percent of the drainage area land cover is herbaceous grassland and 27 percent is shrubland (table 1). The shift in land cover characteristics downstream along the Yellowstone River from forested land to rangeland continues between sites YF and YS. Land cover adjacent to streams in the basin upstream from site YS also is dominated by rangeland. About 58 percent of the land cover on alluvial deposits in the basin is herbaceous grasslands and shrublands. About 20 percent of the alluvial deposits in the basin have agricultural uses on them.

The hydrology of site YS is characteristic of large streams with headwaters in the mountainous areas of the YELL that flow across the basins and plains. Annual streamflow characteristics are a combination of the annual streamflow characteristics of mountain streams and basin and plains streams. Annual streamflow statistics at site YS (water years 1967-2001) consist of a plains (lowland) snowmelt peak during late winter through early spring followed by a peak from the mountain snowmelt during late spring through early summer (fig. 12). The larger drainage area at site YS results in lower variability in streamflow.

The Yellowstone River at site YS is classified by the State of Montana as Class B waters (Montana Department of Environmental Quality, 2002a). The river upstream from Sidney, Montana is listed as only partially supporting warm-water fishery probably because of habitat alterations from stream modification and dam construction (Montana Department of Environmental Quality, 2002b).



Photograph from U.S. Geological Survey files

Figure 12. Annual hydrograph (1967-2001) and photograph for the Yellowstone River near Sidney, Montana (site YS).

Data Collection and Analysis

Stream-water quality of the YELL was assessed through the collection of samples generally on a monthly basis from January 1999 to September 2001. A summary of the data set used during analysis of the fixed sites by constituent grouping and calendar year is presented in table 4. In addition to the collection of environmental samples, quality-control samples were collected to estimate the bias and variability that result from sample collection, processing, and analysis. Sampling methods, data-analysis methods, and quality-control data are described in this section of the report.

Sampling Methods

One of the design components of the NAWQA Program is the use of nationally consistent methods for sample collection, field measurements, sample processing, and laboratory analyses. Samples were collected in accordance with established USGS methods and NAWQA protocols (Edwards and Glysson, 1988; Ward and Harr, 1990; Horowitz and others, 1994; Shelton, 1994, 1997; U.S. Geological Survey, 1997-2004). During normal streamflow conditions, samples generally were collected using depth-integrated samplers, using the equal-width-integrated method that is described in Edwards and Glysson (1988) and Ward and Harr (1990). When samples were collected from streams during extreme conditions, such as hazardous ice conditions and very low flows, traditional depth- and width-integrating techniques may not have been used. During these conditions, multiple-vertical or dip-sampling techniques were used. Dissolved organic carbon (DOC) and microbiological samples were collected separately from the primary sample with dip-sampling techniques. When a wading sample could not be collected, a weighted bottle sampler was used to obtain the DOC sample from the centroid of flow.

Field measurements of streams made at the time of sampling included instantaneous streamflow, water temperature, specific conductance, pH, dissolved oxygen, and alkalinity. Air temperature also was measured. All of the fixed sites were located at streamflow-gaging stations, so generally gage heights were measured and the instantaneous streamflow was determined using the most current streamflow rating curve. Stream temperature and dissolved oxygen were measured in-stream using a multi-parameter water-quality probe. A composite sample taken from the cone splitter was analyzed for specific conductance, pH, and alkalinity.

Water samples to be analyzed for inorganic and organic constituents were processed onsite using standard methods and equipment described by Horowitz and others (1994), Shelton (1994, 1997), and the U.S. Geological Survey (1997-2004).

Table 4. Summary of data collected by constituent grouping and calendar year for fixed sites in the Yellowstone River Basin, 1999-2001.

[X; at least one sample collected during calendar year]

Site report identifier (fig. 2)	Field measurements, major ions, nutrients, iron, manganese, and suspended sediment			Bacteria			Trace elements (other than iron and manganese)			Pesticides		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
SB	X	X	X		X	X	X	X	X			
YCS	X	X	X		X	X	X					
CF	X	X	X		X	X	X			X		
YB	X	X	X		X	X	X			X		
B	X	X	X		X	X	X			X		
YF	X	X	X		X	X	X	X	X	X	X	X
T	X	X	X		X	X	X					
LP	X	X	X		X	X	X	X	X			
P	X	X	X		X	X	X	X	X			
YS	X	X	X		X	X	X	X	X	X	X	X

Samples that were analyzed for dissolved-inorganic constituents were filtered with a 0.45 micrometer (µm) disposable filter. Samples that were analyzed for dissolved-organic constituents were filtered with a 0.70 µm glass filter. Samples that were analyzed for total-constituent concentrations, which include dissolved and particulate forms, were unfiltered. Samples for fecal coliform and *Escherichia coli* (*E. coli*) were processed onsite using sterile techniques and membrane-filtration methods. Subsamples over a range of volumes were filtered in order to obtain countable plates within the ideal ranges of 20 to 60 colonies per 100 milliliters (col/100 mL) for fecal coliform and 20 to 80 col/100 mL for *E. coli*. Filters were plated, processed, and enumerated according to Myers and Wilde (1997).

Water samples were sent to the USGS National Water Quality Laboratory in Lakewood, Colorado, for analysis using standard USGS analytical methods (Fishman and Friedman, 1989; Faires, 1993; Fishman, 1993; McLain, 1993; Zaugg and others, 1995; Jones and Garbarino, 1999; Patton and Truit, 2000). Sediment samples were sent to the USGS sediment laboratory in Helena, Montana, and were analyzed for concentration in accordance with methods described in Guy (1969) and Lambing and Dodge (1993).

Data-Analysis Methods

Data in this report are summarized using parametric and nonparametric statistics. Descriptive summary statistics were computed using standard methods. Some constituent concentrations were less than laboratory reporting levels (censored data). Statistics of constituent concentrations that included censored data were estimated using robust methods (Helsel and Cohn, 1988; Helsel and Hirsch, 1992). Robust methods use distributions fit to data that are greater than the reporting level(s) to estimate summary statistics. In this report, summary statistics for most data sets with censored values were estimated using log-probability regression. In some cases, data were censored to a consistent reporting level in order to compare data through time or across constituents. Summary statistics are shown using boxplots for some constituents. For boxplots, the lower and upper edges of the box indicate the 25th and 75th percentiles, respectively. The median is a line within the box, and whiskers extend to the 10th and 90th percentiles. For some boxplots, values outside the 10th and 90th percentiles are shown as individual points. Laboratory reporting levels are indicated on the boxplots that were produced from data sets with censored values.

Parametric statistical techniques (Pearson's r) were used to test for correlations between data sets when data were normally distributed. Transformation of a data set may have been used to achieve a normal distribution. Nonparametric statistical techniques were used to test for correlations between data sets when the data distributions were unknown. For data sets where the sample size was less than 20, Kendall's tau was used to measure the strength and direction of the relation between variables. Spearman's correlation coefficient (Spearman's rho) was used to measure the strength and direction of the relation between variables of larger data sets (Helsel and Hirsch, 1992). Kendall's tau and Spearman's Rho use rank-based procedures rather than actual data values and are resistant to the effects of outliers. The nonparametric Kruskal-Wallis test was used to compare whether concentrations for selected constituents varied seasonally or annually. The Kruskal-Wallis test uses data ranks rather than actual data values to reduce the effect of outliers. In the most general form, the Kruskal-Wallis test determines whether three or more groups of ranked data have similar distributions or at least one group differs in its distribution (Helsel and Hirsch, 1992). Data are presented with *p*-values for correlations and statistical tests. The *p*-value for correlations indicates the probability of determining the correlation strength by chance alone. Statistical significance for tests was determined using a 95 percent confidence level (p-values <0.05).

Water quality is discussed in terms of constituent concentrations, loads, and yields. Constituent concentrations define the water-quality conditions at a point in time and generally are used for assessing the suitability of the water for aquatic life and other uses. For selected constituents, statistics of flow-weighted mean concentrations and estimated loads and yields also are summarized. Flow-weighted mean concentrations were computed from the sum of estimates of daily concentrations divided by the sum of daily streamflows. Estimates of daily concentrations were computed using the rating-curve method (Cohn and others, 1989) and the computer program LOADEST (Crawford, 1991). The LOADEST program uses robust estimation methods for data that are censored. Because streamflow data are typically skewed, statistics of sample concentrations collected at equal intervals (for example, monthly) can be skewed depending on the relation of the constituent concentration with streamflow. A flow-weighted concentration is influenced less by this skew because it is representative of the concentration of the total mass discharge (load) of the constituent. Similarly, flow-weighted concentrations allow for comparisons between sites with differing sampling frequencies. Estimates of daily concentrations using this method are subject to large errors; as such, only annual and seasonal statistics are used in this report. Estimated constituent loads and yields (load divided by drainage area) also were computed using the rating-curve method (Cohn and others, 1989) and the computer program LOADEST (Crawford, 1991).

Quality Control

The data-quality objectives of the NAWQA Program include the collection of field quality-control samples for inorganic and organic constituents as part of the fixed-site sampling. Quality-control samples, including equipment blanks, replicates, and matrix spikes, are used to estimate the extent to which contamination, measurement variability, and matrix interference affect the interpretation of the environmental data

(Mueller and others, 1997). Equipment blank samples were prepared in the field at each of the fixed sites by processing inorganic-grade or pesticide-grade deionized water through the sampling equipment immediately before collecting the environmental sample. Replicate samples were prepared at each of the fixed sites by splitting the environmental sample into duplicate samples. Matrix spikes were prepared by injecting a laboratory-prepared spike solution of pesticide compounds into replicate environmental samples at sites where samples for pesticides were collected. In addition to field quality-control samples for pesticides, surrogate solutions were added to all of the pesticide samples at the laboratory before solid-phase extraction of pesticides and were used to measure the extraction efficiency of each individual sample.

Summary statistics of the concentrations of major ions, nutrients, dissolved organic carbon, and selected trace elements for field equipment blank samples collected at all 10 of the fixed sites are presented in table 5. Concentrations of constituents in equipment blank samples were smaller than the reporting level for the 90th percentile for all the constituents in table 5, except silica. The detectable concentrations of silica in blank samples were an order of magnitude smaller than silica concentrations in environmental samples. The results of the blank samples indicate that sampling collection, processing, and analysis methods and equipment were not routinely introducing contaminants that would cause a substantial positive bias in the environmental samples and affect the interpretation of the environmental data.

Field equipment blanks for pesticide samples were processed at site CF, site YF, and site YS. None of the 47 pesticides that were analyzed were detected at concentrations larger than the reporting level in any of the 9 equipment blank samples. An estimated concentration of 0.001 microgram per liter (µg/L) of one pesticide, tebuthiuron, was detected in one of the equipment blank samples. Tebuthiuron is a broad spectrum herbicide used to control weeds in noncropland areas, rangelands, rights-of-way, and industrial sites (Meister Publishing Company, 2001). Because the environmental sample collected with this blank sample at site YS also contained an estimated concentration of tebuthiuron, the environmental sample analysis of tebuthiuron was not included in the pesticide summary in this report because the sample potentially could have been contaminated with a low-level concentration of tebuthiuron.

Measurement variability was determined for constituents using environmental and replicate samples from the 10 fixed sites by calculating a relative percent difference (RPD) when concentrations of the constituent were detected in both the environmental sample (*sample 1*) and the replicate sample (*sample 2*) or the constituent was censored at a common level in both samples. The RPD was calculated using the equation:

$$\mathrm{RPD} = \left(\frac{\left| sample1 - sample2 \right|}{\left(\dfrac{sample1 + sample2}{2} \right)} \right) \times 100$$

Summary statistics of the RPD for major ions, nutrients, and selected trace elements indicate that variability was minimal for most constituents (table 6). The median RPD in replicate samples was less than 5 percent for 20 of the 24 major-ion, nutrient, and trace-element constituents. A few constituents had an occasional large value for the RPD for some replicate samples, but this generally occurred when concentrations were small and near the reporting level. For example, the RPD for total ammonia plus organic nitrogen was 39.4 percent when the environmental sample had a concentration of 0.218 milligrams per liter (mg/L) and the replicate had a concentration of 0.325 mg/L.

Replicate samples also were collected to measure variability of pesticide compounds. Out of 47 pesticide compounds, 35 compounds were reported as less than the reporting level in both the environmental and replicate sample in all eight of the replicate sample sets. Four compounds were detected in one of the samples but concentrations were less than the reporting levels in the replicate, so the RPDs could not be determined. The RPD was determined for eight compounds that had a measurable concentration in both the environmental sample and the replicate sample (table 6). Atrazine, the most commonly detected pesticide in the replicate samples, had a median RPD of 5.21 percent. The larger median RPD for pesticide compounds compared to the other constituents is probably because concentrations were small and near reporting levels.

Field matrix-spike samples were collected to determine the effects of matrix interference or analyte degradation on concentrations of pesticides in environmental samples. During method development, average mean recovery was about 83 percent in laboratory spike samples for all pesticides combined at low-level concentrations (Zaugg and others, 1995). The average median recovery for the field matrix spikes was 98 percent (fig. 13) and the average mean recovery was 101 percent for all pesticide compounds in the YELL matrix-spike samples. Deethylatrazine demonstrated a small recovery (9 to 19 percent) during method development (Zaugg and others, 1995), but had a mean recovery of 57 percent in field matrix spikes; however, environmental concentrations from this breakdown product may still be biased low. Carbaryl, carbofuran, methyl azinphos, and terbacil were identified during method development as having variable performance (Zaugg and others, 1995). The range in percent recovery for spiked samples from the YELL was variable for these compounds, particularly for carbaryl, carbofuran, and methyl azinphos, which had percent recoveries larger than 200 percent for some samples. These compounds with variable performance, however, were detected infrequently in the environmental samples. The laboratory reported all concentrations for carbaryl, carbofuran, and deethylatrazine as estimated concentrations in spiked and environmental samples because of their variable performance during method development (Zaugg and others, 1995). The low mean recoveries for *p'p*-DDE in field matrix spikes were consistent with low mean recoveries during method development. The poor recovery of atrazine in two

Table 5. Statistical summary for concentrations of selected constituents in field equipment blank samples for fixed sites in the Yellowstone River Basin, 1999-2001.

[<, less than]

Constituent	Number of samples	10th percentile	50th percentile (median)	90th percentile
Major ions and dissolved solids, in milligrams per liter				
Calcium, dissolved	17	<0.02	<0.02	<0.02
Magnesium, dissolved	17	<.014	<.014	<.014
Potassium, dissolved	16	<.24	<.24	<.24
Sodium, dissolved	17	<.09	<.09	<.09
Chloride, dissolved	16	<.29	<.29	<.29
Flouride, dissolved	16	<.2	<.2	<.2
Silica, dissolved	17	<.09	<.09	.40
Sulfate, dissolved	16	<.3	<.3	<.3
Solids, dissolved, residue on evaporation	16	<10	<10	<10
Nutrients, in milligrams per liter				
Ammonia plus organic nitrogen, dissolved as nitrogen	18	<0.1	<0.1	<0.1
Ammonia plus organic nitrogen, total as nitrogen	18	<.1	<.1	<.1
Ammonia, dissolved as nitrogen	19	<.04	<.04	<.04
Nitrite, dissolved as nitrogen	19	<.01	<.01	<.01
Nitrite plus nitrate, dissolved as nitrogen	19	<.05	<.05	<.05
Orthophosphate, dissolved as phosphorus	19	<.02	<.02	<.02
Phosphorus, dissolved as phosphorus	18	<.006	<.006	<.006
Phosphorus, total as phosphorus	18	<.05	<.05	<.05
Organic carbon, dissolved	19	<.3	<.3	<.3
Trace elements, in micrograms per liter				
Arsenic, dissolved	12	<2	<2	<2
Copper, dissolved	12	<1	<1	<1
Iron, dissolved	17	<10	<10	<10
Manganese, dissolved	21	<3	<3	<3
Selenium, dissolved	11	<1	<1	<1
Zinc, dissolved	12	<2	<2	<2

Table 6. Statistical summary of the relative percent difference determined for selected constituents in replicate samples for fixed sites in the Yellowstone River Basin, 1999-2001.

[--, not applicable]

Constituent	Number of samples	Relative percent difference: 10th percentile	Relative percent difference: 50th percentile (median)	Relative percent difference: 90th percentile
Major ions and dissolved solids				
Calcium, dissolved	20	0.26	0.94	2.36
Magnesium, dissolved	20	.20	.89	2.46
Potassium, dissolved	20	.31	1.14	4.00
Sodium, dissolved	20	.15	1.35	3.03
Chloride, dissolved	20	.05	1.35	4.18
Flouride, dissolved	20	.0	.74	3.19
Silica, dissolved	20	.09	.29	1.69
Sulfate, dissolved	20	.11	.40	1.66
Solids, dissolved, residue on evaporation	20	.0	.51	1.22
Nutrients				
Ammonia plus organic nitrogen, dissolved as nitrogen	20	1.15	4.13	23.9
Ammonia plus organic nitrogen, total as nitrogen	21	1.23	8.60	39.4
Ammonia, dissolved as nitrogen	21	.0	.0	2.96
Nitrite, dissolved as nitrogen	21	.0	.0	10.5
Nitrite plus nitrate, dissolved as nitrogen	20	.0	.69	3.36
Orthophosphate, dissolved as phosphorus	20	.0	.0	19.5
Phosphorus, dissolved as phosphorus	21	.0	5.53	28.6
Phosphorus, total as phosphorus	21	.0	3.17	12.9
Organic carbon, dissolved	20	.0	2.14	5.68
Trace elements				
Arsenic, dissolved	12	.097	4.46	12.0
Copper, dissolved	9	--	7.18	--
Iron, dissolved	19	.0	.0	16.8
Manganese, dissolved	23	.0	1.22	18.2
Selenium, dissolved	10	.0	.0	25.8
Zinc, dissolved	5	--	32.6	--
Pesticides				
Atrazine, dissolved	7	--	5.21	--
Cyanazine, dissolved	2	--	[1]6.84	--
Deethylatrazine, dissolved	3	--	.98	--
Malathion, dissolved	1	--	[2]11.3	--
Metolachlor, dissolved	2	--	[1]1.15	--
Prometon, dissolved	2	--	[1]14.5	--
Triallate, dissolved	3	--	12.2	--
Trifluralin, dissolved	1	--	[2]7.87	--

[1] Average of two relative percent differences

[2] Relative percent difference for one sample

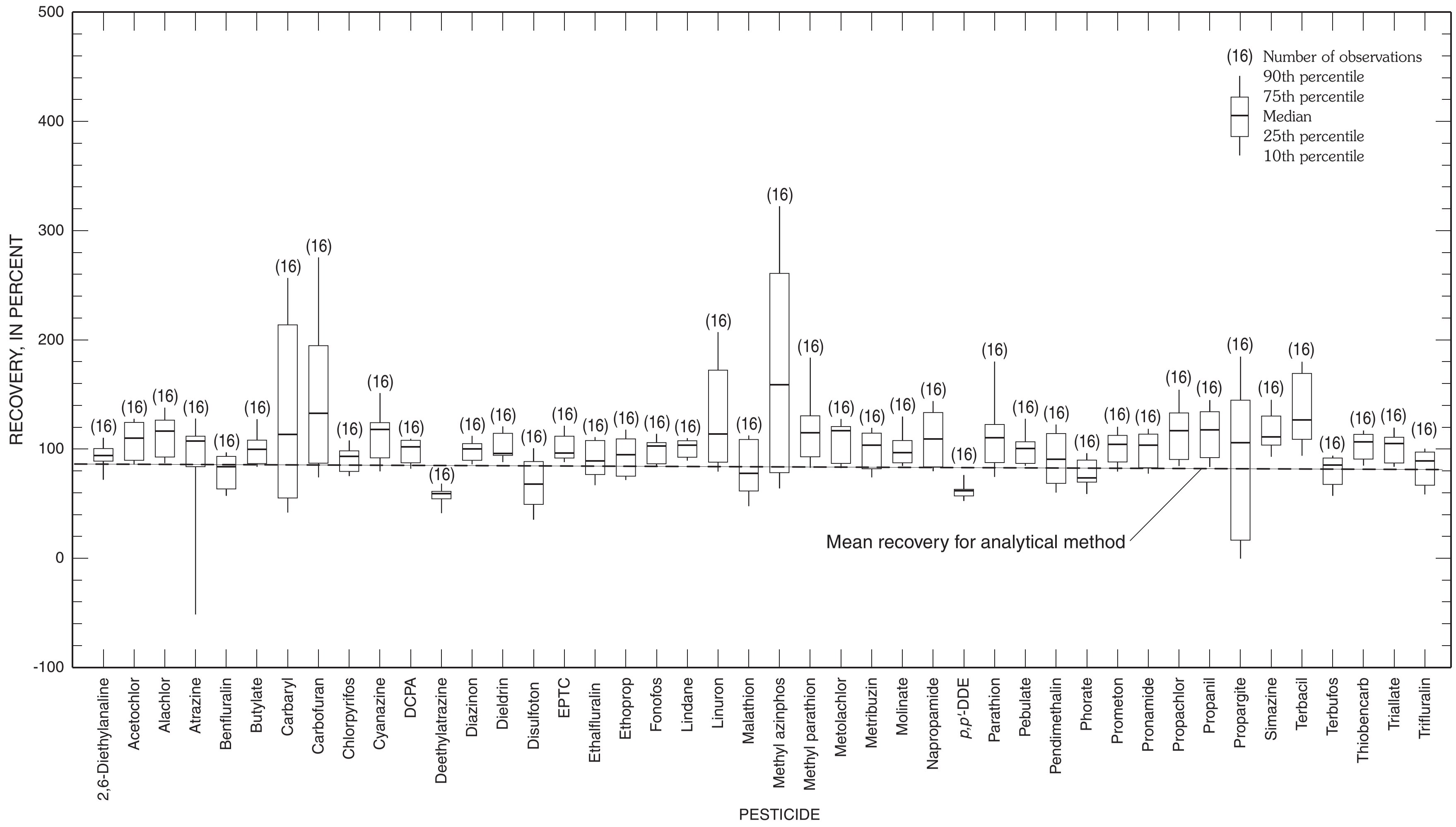


Figure 13. Recovery of pesticide compounds in field matrix spikes for fixed sites in the Yellowstone River Basin, 1999-2001.

of the field matrix-spike samples was in a spike set where the concentration in the environmental sample was larger than the associated spike samples.

In addition to the field matrix-spike samples, surrogate compounds are added to environmental samples at the laboratory and are used for assessing pesticide recoveries. Surrogate compounds are compounds that are not expected to be in the environmental sample, but are expected to behave like pesticide compounds that may be found in environmental samples. The gas chromatography-mass spectrometry (GCMS) method of pesticide analysis for data in this report uses diazinon-d10 and *alpha*-HCH-d6 as surrogates. The median recoveries for the surrogate compounds in the fixed-site samples were about 105 percent for diazinon-d10 and about 99 percent for *alpha*-HCH-d6, indicating good extraction efficiency of the environmental samples (fig. 14).

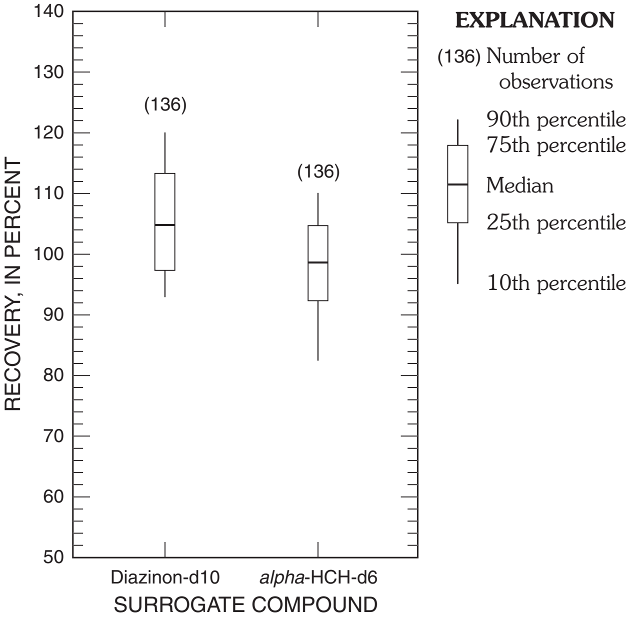


Figure 14. Recovery of surrogate compounds in pesticide samples for fixed sites in the Yellowstone River Basin, 1999-2001.

Fixed-Site Water Quality, 1999-2001

The hydrologic conditions during sampling events and results for field measurements and analyses for fecal-indicator bacteria, major ions, dissolved solids, nutrients, trace elements, pesticides, and suspended sediment for the samples collected at the 10 fixed sites in the YELL during 1999-2001 are summarized in this section of the report. Results for 400 samples are included in the data analysis for this report. The number of results for individual constituents may be slightly different because field equipment malfunctioned or only partial laboratory results were received for a few samples. The discrete data values are presented in Swanson and others (2000, 2001, 2002). In addition, data are available online at URL *http://nwis.waterdata.usgs.gov/nwis*.

Hydrology

Streamflows at the fixed sites during the study period generally ranged from slightly greater than average during water year 1999 to much less than average during the drought conditions of water years 2000 and 2001. Streamflow records indicate that water year 2001 was one of the driest years in the last century for the YELL. For some of the fixed sites, annual mean streamflows for water year 2001 were the lowest on record (site CF, 63 years; site YB, 73 years; site YF, 24 years; site T, 70 years). For the period following regulation by major reservoirs, annual mean streamflows in water year 2001 were the third lowest at site B (50 years) and the lowest at site YS (35 years). For other fixed sites, annual mean streamflows for water year 2001 were the third (site YCS, 95 years; site P, 63 years) or fourth (site LP, 29 years) lowest on record. Streamflow records at site SB were only available for the sampling period (1999-2001). Water-quality samples collected at the fixed sites during the study period generally covered the range of streamflows that have been recorded at the sites (fig. 15) and were representative of historical streamflow conditions in spite of the drought conditions of water years 2000 and 2001.

Field Measurements

Field measurements of streams made at the time of sampling included water temperature, specific conductance, pH, dissolved oxygen and alkalinity. All of these measurements were collected onsite and provide a general picture of the water-quality conditions at the fixed sites. Boxplots of water temperature, specific conductance, pH, and dissolved-oxygen concentrations are shown in figure 16. Alkalinity is discussed in the “Major Ions and Dissolved Solids” section of this report.

Water temperature is an important field measurement because it has a direct influence on the physical, chemical, and biological processes that occur in streams. Some of the physical properties that are affected by temperature include density, surface tension, gas solubility, and diffusibility. The gain and loss of dissolved gases, such as dissolved oxygen and dissolved nitrogen, are in part controlled by these physical properties. The rates at which chemical reactions proceed are influenced by temperature, with higher temperatures generally increasing chemical reaction rates (Stevens and others, 1975). Biological processes that are affected by water temperature include the metabolism of aquatic organisms and their ability to survive and reproduce. Water temperatures in streams are affected by solar radiation, precipitation, air and ground temperature, and the temperature of tributary and ground-water inflows.

Median stream temperatures varied among sites in the YELL, ranging from 2.5 degrees Celsius (°C) at site SB to 15°C at site YS (fig. 16). The low median temperatures at site SB, site YCS, and site T result from cooler air temperatures at the higher elevations and less solar radiation reaching streams in forested areas in comparison to conditions at other sites in the YELL. The maximum temperature at site YCS (22°C) was higher compared to the maximum temperatures at site SB (12°C) and site T (17.5°C), which probably reflects inputs from the thermal springs upstream from site YCS. Median stream temperatures in the Yellowstone River increased as it flowed from the forested area onto the plains. The median temperature more than doubled from site YCS (7.0°C) to site YS (15°C). These changes in the stream temperature are likely due to combinations of natural causes, such as increased solar radiation as a result of fewer trees, increased air temperatures at lower elevations, and human causes, including irrigation return flows. Site B had the most variability in stream temperature, ranging from 0°C to 27.5°C, probably mostly due to the wide range of air temperatures that are characteristic of the Bighorn River Basin, which ranged from –10°C to 35°C during sampling events. Irrigation return flows also are common in the Bighorn River. Stream temperatures are not compared to water-quality criteria for temperature in this report because water-quality criteria for stream temperatures in Montana and Wyoming primarily are not a single value, but rather are related to allowable increases to stream temperatures resulting from anthropogenic inputs, such as waste effluent (Wyoming Department of Environmental Quality, 2001b; Montana Department of Environmental Quality, 2002a).

Specific conductance is a measure of a substance's ability to conduct an electrical current at a specific temperature. Pure water has a very low electrical conductance; as concentrations of dissolved solids that carry an ionic charge increase in a stream, the specific conductance increases. Therefore, specific conductance can be used as an indication of the concentration of dissolved solids in a stream. The conversion factor from specific conductance to dissolved-solids concentrations for natural waters is about 0.54 to about 0.96 (Hem, 1985). The median conversion factor between specific conductance and dissolved-solids concentrations varied for sites in the YELL and ranged from about 0.57 for site T to about 0.81 for site LP. For example, a sample with a specific conductance of 100 microsiemens per centimeter at 25°C (μS/cm) for site T would have a corresponding dissolved-solids concentration of about 57 mg/L, and a sample with a specific conductance of 1,000 μS/cm for site LP would have a corresponding dissolved-solids concentration of about 810 mg/L. Conversion factors tend to be larger for streams that have large sulfate concentrations, like site LP. Water-quality criteria for specific conductance have not been established for most streams by the States of Montana and Wyoming (Wyoming Department of Environmental Quality, 2001b, Montana Department of Environmental Quality, 2002a). A numeric standard for a single sample of 2,500 μS/cm has been established for the Powder River and Little Powder River in Montana (Montana Department of Environmental Quality, 2002a).

Median specific conductance values varied substantially at fixed sites, ranging from 202 μS/cm at site SB to 3,400 μS/cm at site LP (fig. 16). Maximum specific-conductance values for sites near mountainous areas (site SB, site YCS, and site T) were lower than median specific-conductance values for streams that flow primarily through the basins and plains (site CF, site YB, site B, site YF, site LP, site P, and site YS), owing to higher precipitation and more resistant rock types in mountainous areas. Specific-conductance values had the largest range at the rangeland indicator site, site LP (358 μS/cm to 4,460 μS/cm), where Tertiary-period sedimentary rocks are the predominant rock type in the basin. Specific conductance was larger than the numeric standard of 2,500 μS/cm in more than 75 percent of the samples from site LP and about 18 percent of the samples at site P.

Hydrogen-ion activity is a measure of the acidic or alkaline character of the stream and is expressed in terms of pH, which is the negative base-10 log of the hydrogen-ion activity. A pH value of 7 is considered neutral, whereas a pH value greater than 7 is considered alkaline and a pH value less than 7 is considered acidic. Water-quality criteria for pH are not a single number. In the State of Montana, criteria for pH for Class B waters are based on levels of induced variation in pH of less than 0.5 pH units, within the range of 6.5 to 8.5 or 9.0 (Montana Department of Environmental Quality, 2002a). In the State of Wyoming, chronic values of pH in the range of 6.5 to 9.0 are allowed (Wyoming Department of Environmental Quality, 2001b). Values for pH that are outside of these ranges are considered harmful to aquatic life.

All stream measurements of pH at fixed sites in the YELL were alkaline, indicating that the soils and rocks naturally buffer the atmospheric waters, which typically have a pH of 5.65 (Hem, 1985). The median pH values at the fixed sites ranged from 7.8 at site T to 8.4 at site YS (fig. 16). The minimum pH value that was measured was 7.2 at site YCS and site T, and the maximum pH value that was measured was 8.9 at site YF. All values for pH were within the water-quality criteria established by the States of Montana and Wyoming.

Dissolved-oxygen analysis is the measure of gaseous oxygen dissolved in an aqueous solution. Oxygen, although soluble in water, is considered poorly soluble because it does not react chemically with water (Stednick, 1991). Concentra-

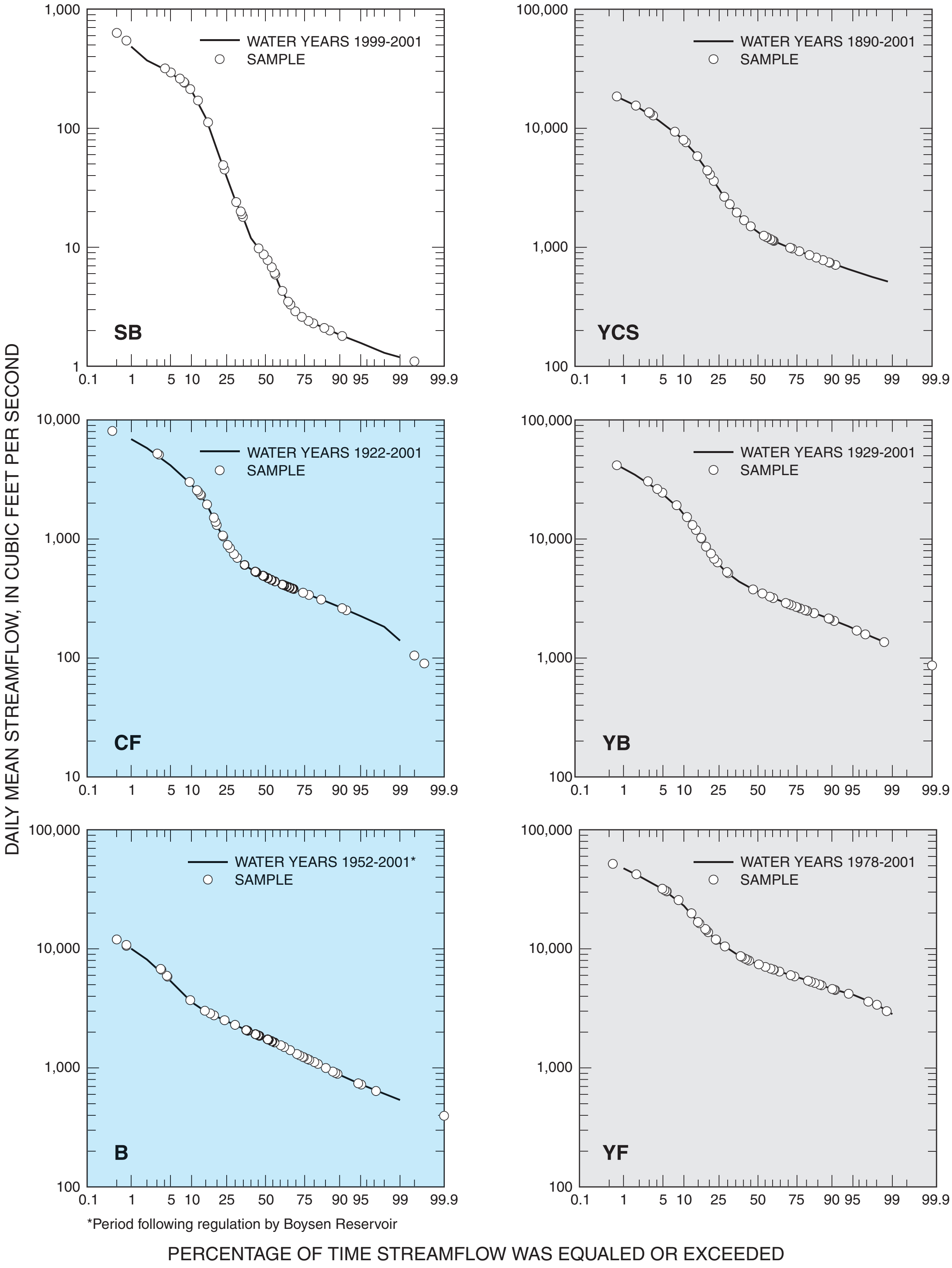


Figure 15. Distribution of samples relative to daily mean streamflow duration for fixed sites in the Yellowstone River Basin, 1999-2001.

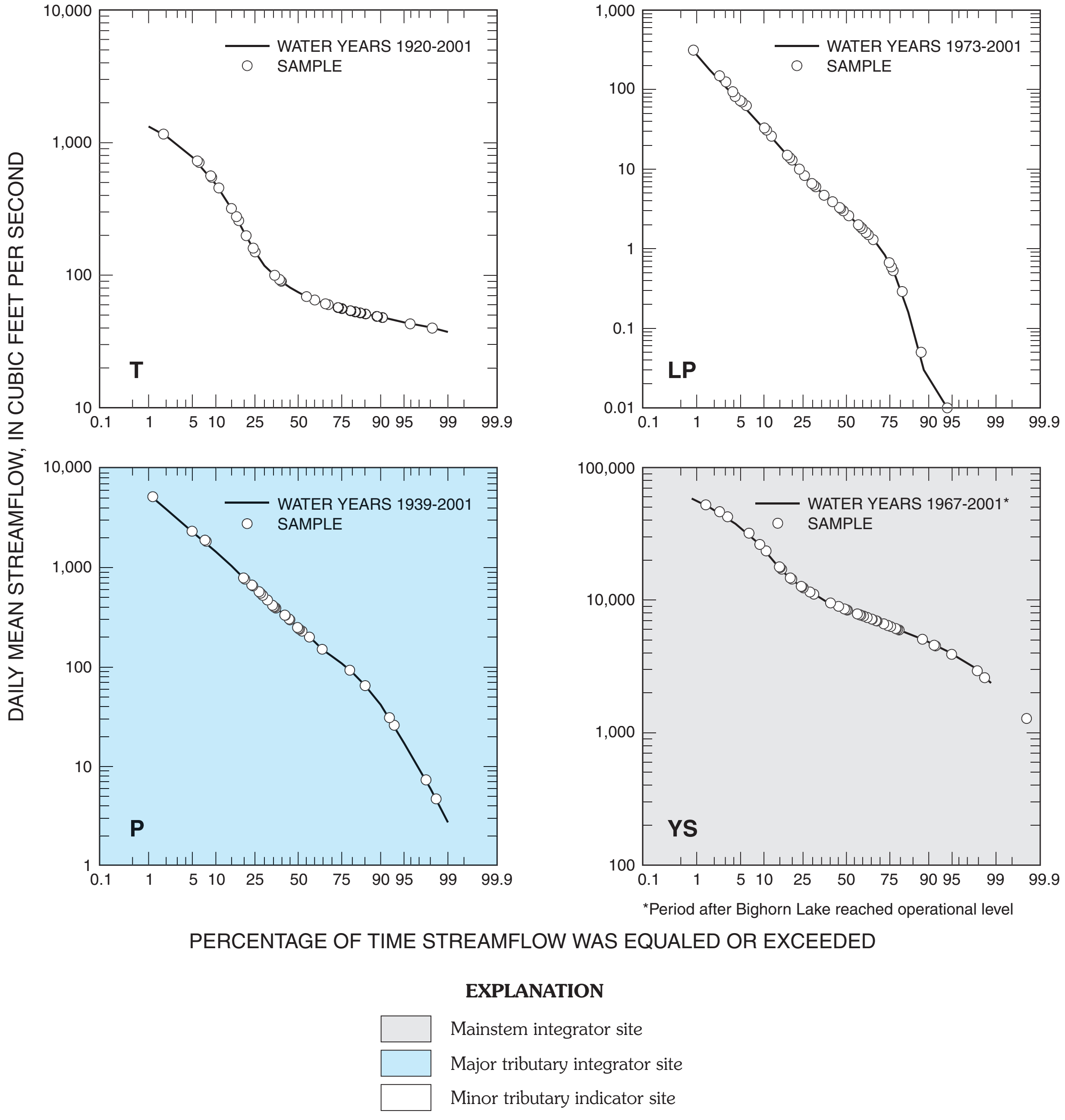


Figure 15. Continued.

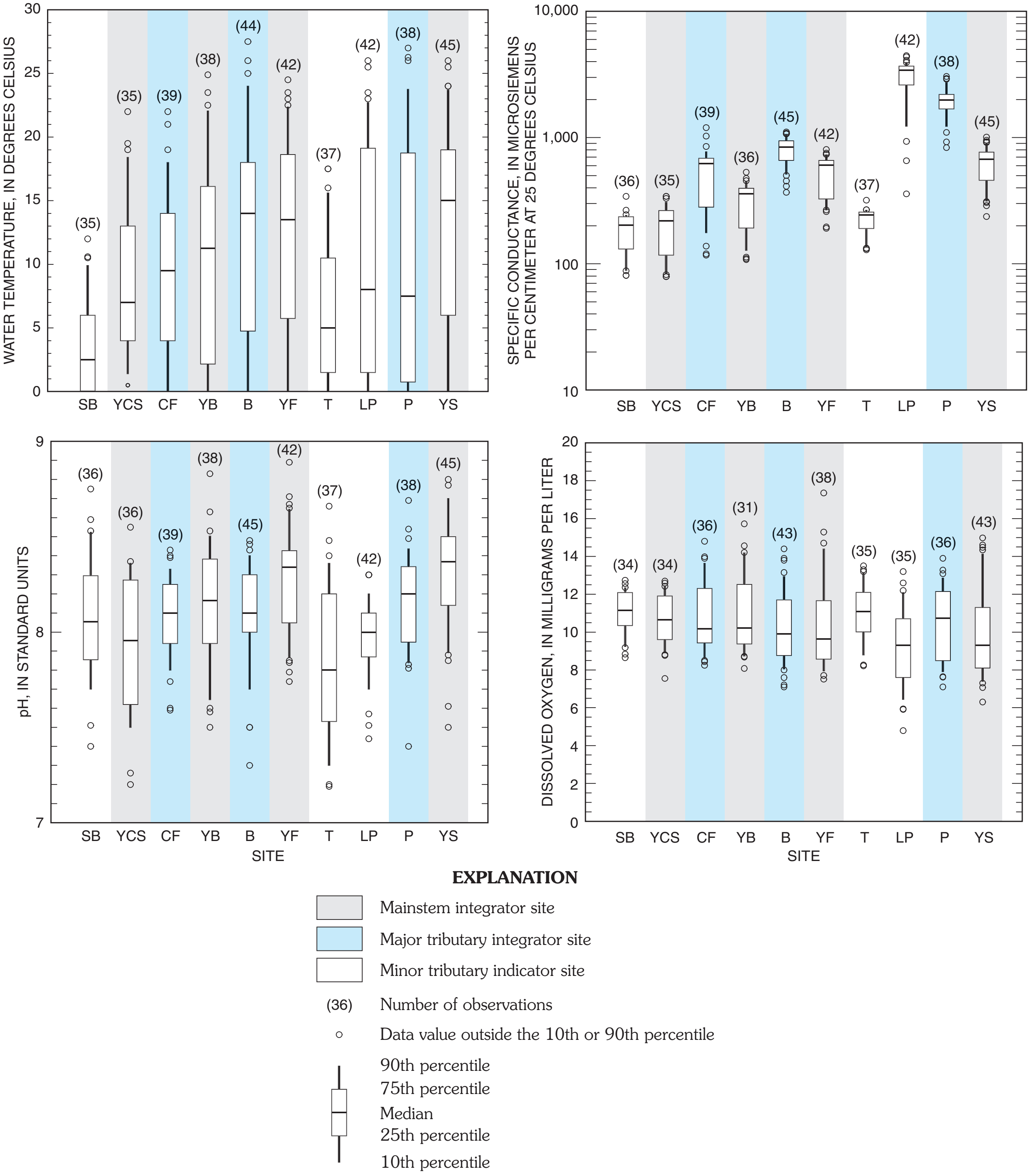


Figure 16. Statistical summary of water temperature, specific conductance, pH, and dissolved-oxygen concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

tions of dissolved oxygen primarily are affected by atmospheric pressure and temperature. Atmospheric pressure and dissolved oxygen are directly proportional to each other, whereas temperature and dissolved oxygen are inversely proportional; so, as pressure increases and temperature decreases, oxygen becomes more soluble in a stream. Concentrations of dissolved oxygen in streams are depleted through respiratory uptake by organisms and by the decaying of organic matter in streams. Oxygen is replenished from the atmosphere and by photosynthesis of aquatic plants. Water-quality criteria for dissolved oxygen that have been determined for the States of Montana and Wyoming are not a single number and depend on aquatic life stages present in a stream (Wyoming Department of Environmental Quality, 2001b, Montana Department of Environmental Quality, 2002a) and, as such, are not used for comparison in this report, except in general terms.

Median dissolved-oxygen concentrations varied slightly among sites and ranged from 9.3 mg/L at site YS to 11.2 mg/L at site SB (fig. 16), which are acceptable concentrations when compared to State criteria for minimum concentrations for all life forms. The median dissolved-oxygen concentrations tended to be larger at sites that are closer to mountainous areas, where stream temperatures also were the lowest; thus, making oxygen more soluble, despite lower atmospheric pressure with elevation. The median dissolved-oxygen concentrations tended to be lower at sites in the basin and plains, like site LP, where stream temperatures generally are warmer, although atmospheric pressure tends to be higher. Dissolved-oxygen conditions for all sites generally were near saturation (100 percent); median values ranged from 94.6 percent of saturation at site LP to 109 percent of saturation at site YCS.

Fecal-Indicator Bacteria

Analyses for fecal-indicator bacteria of fecal coliform and *E. coli* were added to the fixed-site sampling during 2000 and 2001 to assess the sanitary quality at the fixed sites in the YELL, because the presence of these bacteria can be an indication that contamination from fecal material has occurred. Fecal coliform was identified as the primary cause of impairment for streams in Wyoming in the 2002 305(b) report, including several reaches in the Bighorn River and Tongue River Basins (Wyoming Department of Environmental Quality, 2002). Antiquated facilities and shifting ground resulted in nine sewage spills in Yellowstone National Park during 1999-2001 (Associated Press, 2001a, 2001b; Wyoming Department of Environmental Quality, 2002). Stream reaches in Montana that were identified with fecal-coliform impairments by the Montana Department of Environmental Quality were outside of the YELL (Montana Department of Environmental Quality, 2002b). Although fecal-indicator bacteria do not necessarily cause illness themselves, large levels of fecal-indicator bacteria can indicate the possible presence of other pathogens that cause such waterborne diseases as gastroenteritis and bacillary dysentery, typhoid fever, and cholera (Myers and Sylvester, 1997).

The occurrence of fecal coliform in recreational waters is not positive confirmation that fecal contamination has occurred because at least one member of the fecal-coliform group, *Klebsiella*, has non-fecal sources, including pulp and paper mill effluents, textile processing plant effluents, cotton mill wastewaters, and sugar beet wastes (U.S. Environmental Protection Agency, 1986a). The presence of *E. coli*, another member of the fecal-coliform group, is direct evidence that fecal contamination has occurred because the only sources are humans or other warm-blooded animals (Cabelli, 1977; Dufour, 1977). *E. coli* was determined to have a stronger relation to swimming-associated gastrointestinal illness than fecal coliform and, as such, was determined to be a better fecal-indicator bacteria for monitoring recreational waters (Dufour, 1984; U.S. Environmental Protection Agency, 1986a). However, because both the States of Montana and Wyoming were using fecal coliform in their water-quality criteria at the time of this study (Wyoming Department of Environmental Quality, 2001b, Montana Department of Environmental Quality, 2002a), it was important to monitor for both of the fecal-indicator bacteria.

The water-quality criteria for fecal coliform for the States of Montana and Wyoming are not a single number and are based on multiple samples in a 30-day period, the class of water, time of year, or location relative to sewage treatment outfalls (Wyoming Department of Environmental Quality, 2001b, Montana Department of Environmental Quality, 2002a). Because multiple samples were not collected during a 30-day period in most cases, recommended limits for single samples that were proposed by the U.S. Environmental Protection Agency (USEPA) are used in this report for assessing the magnitude of fecal-indicator-bacteria concentrations.

Concentrations

The medians and ranges of fecal-indicator-bacteria concentrations varied among the fixed sites (fig. 17). For all sites, the largest median concentrations for fecal coliform of 135 col/100 mL and *E. coli* of 156 col/100 mL were at site LP, which is the rangeland indicator site. The largest concentration in a single sample from all 156 samples of fecal coliform was 1,400 col/100 mL at site P. For all 145 samples of *E. coli*, the largest concentration in a single sample was 1,500 col/100 mL at site LP. The Little Powder River and Powder River Basins are both dominated by grasslands that are grazed by cattle; however, small towns, rural domestic homes with septic systems, and agricultural return flows also may contribute to bacteria in these basins. For all sites, the smallest median concentrations were 3 col/100 mL of fecal coliform and 3 col/100 mL for *E. coli* at site YCS, which drains a predominantly forested basin of Yellowstone National Park. Concentrations of fecal-indicator bacteria for the mineral resource area (site SB) and the forested (site T) indicator sites, which both drain predominantly forested areas, were small as

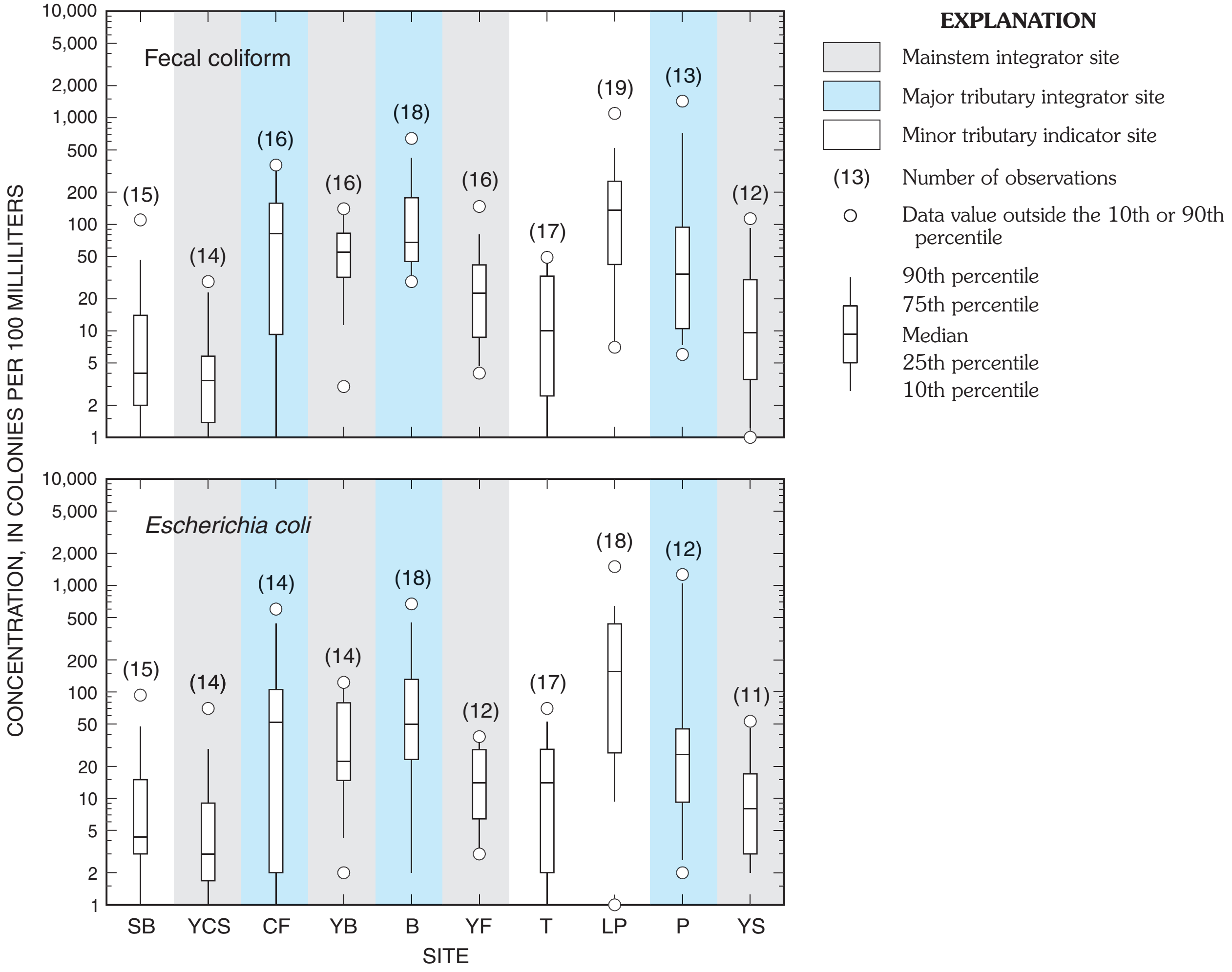


Figure 17. Statistical summary of fecal-indicator-bacteria concentrations for fixed sites in the Yellowstone River Basin, 2000-2001.

well; median concentrations were 14 col/100 mL or less for fecal coliform and *E. coli* at both sites. Fecal-indicator-bacteria concentrations at site SB, site YCS, and site T may be good indicators of wildlife contributions in forested drainage basins in the YELL.

The largest median concentrations of fecal coliform (55 col/100 mL) and *E. coli* (22 col/100 mL) on the mainstem of the Yellowstone River were at site YB, which is downstream from parts of the Billings, Montana urban area. The median fecal-indicator-bacteria concentrations at site YB were smaller than median concentrations of fecal coliform (540 col/100 mL) and *E. coli* (420 col/100 mL) for sites with urban land use during a NAWQA synoptic study of fecal-indicator bacteria in Wyoming (Clark and Gamper, 2003); however, the streams sampled as part of the synoptic study had substantially smaller streamflow than the Yellowstone River.

Comparison to Recommended Limits

Historically, USEPA studies determined that statistically significant swimming-associated gastrointestinal illness may occur when concentrations of fecal coliform for a single sample are larger than 400 col/100 mL (U.S. Environmental Protection Agency, 1976). The USEPA recommends four different limits for *E. coli* concentrations for a single sample, depending on the degree of exposure with the source waters. The recommended limit for *E. coli* for a single sample defined in the USEPA study are: 235 col/100 mL for designated beach areas, 298 col/100 mL for moderate use, full-body contact recreation, 406 col/100 mL for light use, full-body contact recreation, and 576 col/100 mL for infrequent use, full-body contact recreation (U.S. Environmental Protection Agency, 1986a). The recommended limit of 235 col/100 mL was not used for comparison in this report because none of the fixed sites were at designated beaches. Values that exceed recommended limits do not necessarily indicate violations of water-

Table 7. Fecal-indicator bacteria exceeding U.S. Environmental Protection Agency's recommended limits for a single sample for recreational contact with water for fixed sites in the Yellowstone River Basin, 2000-2001.

[col/100 mL, colonies per 100 milliliters; >, greater than]

Site report idenfifier (fig. 2)	Number of fecal-coliform samples	Percent of samples where fecal coliform concentration >400 col/100 mL	Number of *Escherichia coli* concentration samples	Percent of samples where *Escherichia coli* concentration >298 col/100 mL (moderate use, full-body contact)	Percent of samples where *Escherichia coli* concentration >406 col/100 mL (light use, full-body contact)	Percent of samples where *Escherichia coli* concentration >576 col/100 mL (infrequent use, full-body contact)
SB	15	0.0	15	0.0	0.0	0.0
YCS	14	.0	14	.0	.0	.0
CF	16	.0	14	14.3	7.1	7.1
YB	16	.0	14	.0	.0	.0
B	18	5.6	18	11.1	11.1	5.6
YF	16	.0	12	.0	.0	.0
T	17	.0	17	.0	.0	.0
LP	19	10.5	18	27.8	27.8	11.1
P	13	7.7	12	16.7	16.7	16.7
YS	12	.0	11	.0	.0	.0
All sites	156	2.6	145	7.6	6.9	4.1

quality criteria for the State of Montana or Wyoming, but are used for comparative purposes.

Concentrations of fecal-indicator bacteria in some samples exceeded recommended criteria. The USEPA recommended single-sample limit for fecal coliform was exceeded in 2.6 percent of the 156 samples for fecal coliform, and the recommended single-sample limit for moderate use, full-body contact recreation for *E. coli* was exceeded in 7.6 percent of 145 samples (table 7). No concentrations exceeded the recommended limits for fecal coliform and *E. coli* in samples collected from the Yellowstone River (sites YCS, YB, YF and YS). No concentrations exceeded the recommended limits for fecal coliform and *E. coli* in samples collected from the mineral resource area (site SB) and the forested (site T) indicator sites. At least one sample from the three major tributary sites (site CF, site B, and site P) had a fecal-indicator-bacteria concentration that exceeded one of the recommended limits. Site LP, the rangeland indicator site, had the largest percentage of samples (10.5 percent) where fecal coliform exceeded the recommended single-sample limit of 400 col/100 mL. *E. coli* concentrations at site LP exceeded the recommended limits for moderate and light use, full-body contact recreation in 27.8 percent of the samples. Stream reaches in the Bighorn River upstream from Kane, Wyoming and the Little Powder were assessed as being impaired by fecal coliform for contact recreational use in the Wyoming 305(b) water-quality assessment for 2002 (Wyoming Department of Environmental Quality, 2002).

The Spearman's Rho correlation coefficient between fecal coliform and *E. coli* was 0.820 (p-value <0.001) for samples collected from the fixed sites (fig. 18). Fecal coliform and *E. coli* data from the NAWQA synoptic study in Wyoming also were correlated (Spearman's Rho=0.976, p-value <0.001) (Clark and Gamper, 2003). These results indicate that *E. coli* is an important contributor to fecal-coliform concentrations at YELL fixed sites. Because of this relation, historical fecal-coliform data generally will be a useful indicator of *E. coli* presence in these streams as the States of Montana and Wyoming transition to using *E. coli* for recreational water-quality criteria as recommended by USEPA (U.S. Environmental Protection Agency, 2002c).

Temporal Variability

Fecal-coliform (p-value <0.001) and *E. coli* concentrations (p-value <0.001) significantly varied by sampling period. Median concentrations of fecal coliform and *E. coli* have the same general seasonal pattern, where the smallest median concentrations were during January–March and the largest median concentrations were during April–June (fig. 19). Elevated concentrations of fecal-indicator bacteria during the April–June sampling period are probably the result of

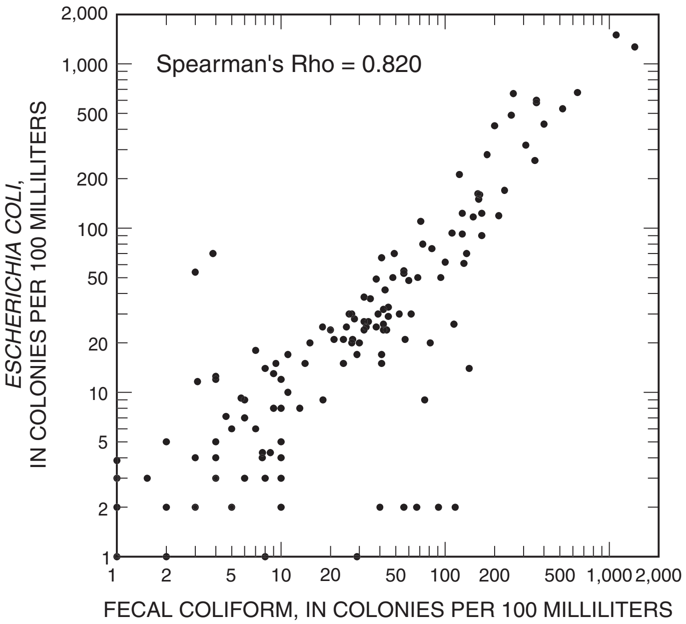


Figure 18. Fecal-coliform and *Escherichia coli* relation for fixed sites in the Yellowstone River Basin, 2000-2001.

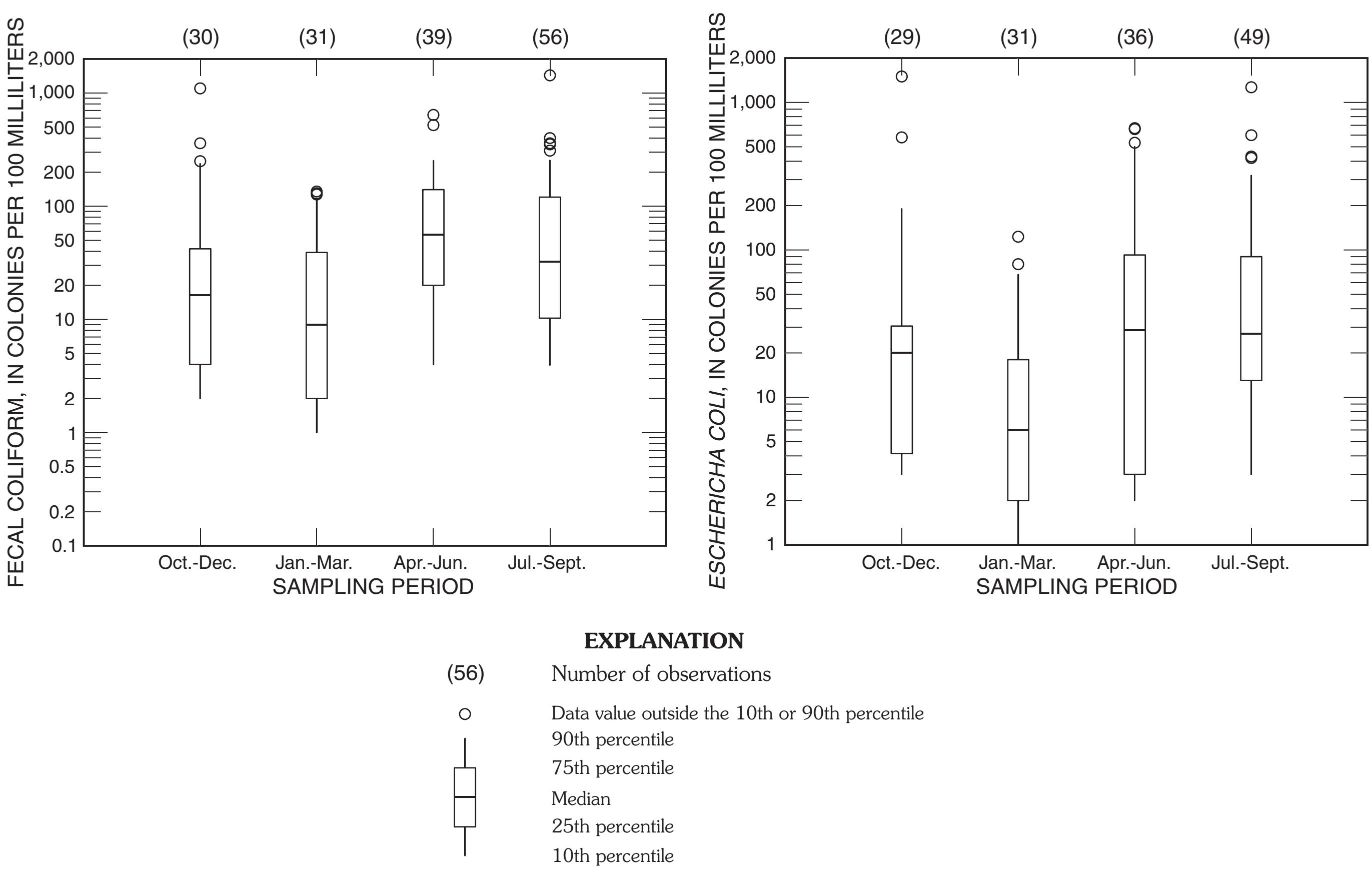


Figure 19. Seasonal variations in fecal-indicator-bacteria concentrations for fixed sites in the Yellowstone River Basin, 2000-2001.

increased streamflow associated with lowland thunderstorms or snowmelt runoff and increased land-use activity. Streamflow has been demonstrated to have a positive relation with bacteria because of overland flow that can carry bacteria-laden sediment to streams or turbulent flows that can resuspend bacteria-laden sediment from the stream bottom (Stephenson and Street, 1978; Elder, 1987; Hunter and others, 1992; Barbe´ and Francis, 1995). Concentrations that exceeded USEPA recommended limits for single samples were observed in samples during the October–December, April–June, and July–September sampling periods. Examination of the sampling event dates indicates that the individual samples that exceeded limits were collected during the months of May to October. Human health risk to exposure is highest during summer months because recreational contact with waters is most likely occurring at that time. The water-quality criteria for recreational contact generally apply to the period from May to September.

Major Ions and Dissolved Solids

The general quality of stream waters often is described on the basis of the major-ion composition and dissolved-solids concentrations. The major-ion composition includes those inorganic ionic constituents commonly present in concentrations exceeding 1.0 mg/L (Hem, 1985). The relative proportions of the major cations (generally calcium, magnesium, potassium, and sodium) and the major anions (generally bicarbonate plus carbonate, chloride, fluoride, sulfate, and nitrate) are used to describe the water type. Although nitrate is used in characterizing water type, general discussion of nitrate is included in the “Nutrients” section of this report. Dissolved-solids concentrations represent the combined sum of all the dissolved constituents in a water sample with the primary contributors being the major cations, major anions, and nonionic silicon that is reported in terms of the equivalent concentration of silica. Dissolved-solids concentrations were determined in the laboratory using a residue-on-evaporation method at 180°C (Fishman and Friedman, 1989). Dissolved solids in stream waters primarily result from the weathering of minerals in rocks and soils near the land surface, but also can result from human activities, such as irrigation and oil and gas development.

Water Type

Variations in water composition at the fixed sites are reflective of the diverse geologic terrain in the YELL. A trilinear diagram, which illustrates the relative percentage of the major cations and anions on two trilinear plots and a diamond-shaped plot that combines the cation and anion information (Piper, 1944), indicates that water composition in the YELL varied among sites, ranging from dilute calcium-bicarbonate type at site SB and site T to concentrated sodium-sulfate type at site LP (fig. 20). Stiff diagrams (Stiff, 1951), which detail the magnitude of concentrations of the major ions in milliequivalents per liter, illustrate how water type changes through the basin (fig. 21). A sample with typical (near the median) dissolved-solids concentration was selected to represent the major-ion composition for the Piper and Stiff diagrams for each site. Concentrations of the dominant ions (calcium, sodium, bicarbonate, and sulfate) varied at the fixed sites (fig. 22).

On the mainstem of the Yellowstone River, the water type changes from a mixed-cation bicarbonate type upstream at site YCS to a mixed-cation sulfate type downstream at site YF and site YS. The water type at site YCS is a dilute sodium-calcium-magnesium bicarbonate type, and is reflective of the Cretaceous-, Tertiary-, and Quaternary-period volcanic rocks that are the dominant rock types in the YELL basin upstream from site YCS. Waters draining areas underlain by igneous rocks typically have small concentrations of dissolved solids with sodium and calcium as the major cations and bicarbonate as the major anion (Drever, 1997). Reaches of the Yellowstone River that drain YNP upstream from site YCS receive inputs of geothermal waters (Knapton and Bahls, 1993), which are highly mineralized and typically contribute sodium, chloride, fluoride, and silica to major-ion chemistry of the area stream waters (Cox, 1973). Concentrations of silica also generally were larger at site YCS compared to the other fixed sites (Swanson and others, 2000, 2001, 2002). Downstream on the Yellowstone River at site YB, in addition to the volcanic rocks, Cretaceous-period sedimentary rocks also underlie a large part of the basin, which results in calcium and magnesium comprising a larger percentage of the cation composition. The major-ion median concentrations in the Yellowstone River are higher at site YF and site YS compared to sites YCS and YB, as the proportion of the area underlain by fine-grained Cretaceous- and Tertiary-period sedimentary rocks increases in the downstream basins. The water type of the Yellowstone River at site YS is a calcium-sodium-magnesium sulfate type.

Different geology in the Clarks Fork Yellowstone River, Bighorn River, and Powder River Basins produces different water types for the major tributaries. Geology of the Clarks Fork Yellowstone River Basin is diverse and includes Precambrian-era crystalline rocks, Paleozoic- and Mesozoic-era sedimentary rocks, and Cretaceous- and Tertiary-period volcanic and sedimentary rocks. The median water type at site CF plots as calcium bicarbonate type (fig. 20). The dominant anion in samples at site CF varied between bicarbonate and sulfate depending on the time of year. Bicarbonate dominates in late spring and early summer when dissolved atmospheric gases in the snow are contributed during snowmelt runoff (Colby and others, 1956). In contrast, sulfate dominates during winter when sulfate-rich ground water that has been in contact with basin materials for a long time is a larger proportion of the stream’s base flow. A study of the lithologic controls of calcium concentrations in the upper reaches of the Clarks Fork Yellowstone River upstream from site CF found the Paleozoic-era sedimentary rocks to be a larger contributor of calcium than the volcanic or crystalline rocks (Horton and others, 1999). The water types at site B and site P are mixed-cation

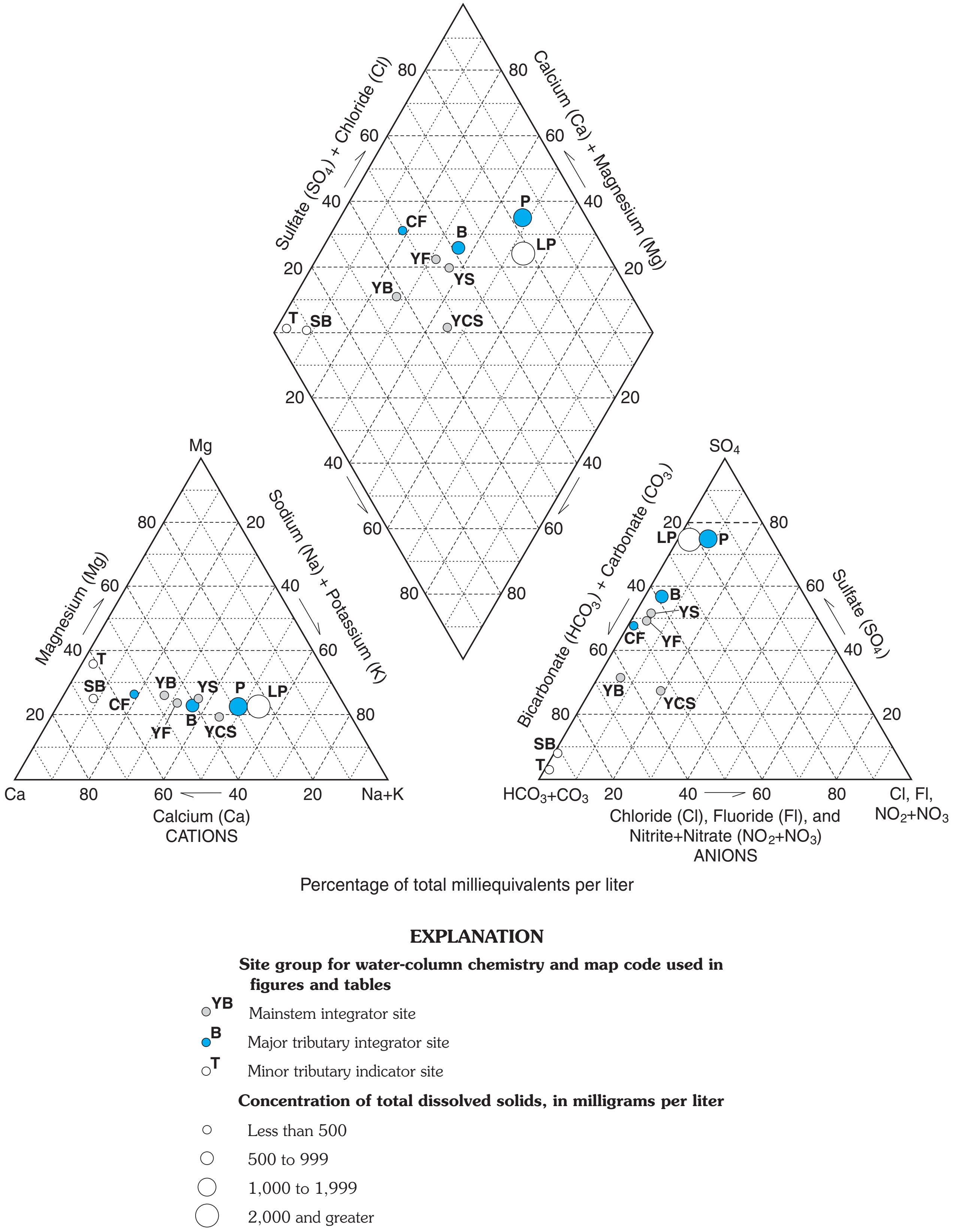


Figure 20. Trilinear diagram showing major-ion composition and dissolved-solids concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

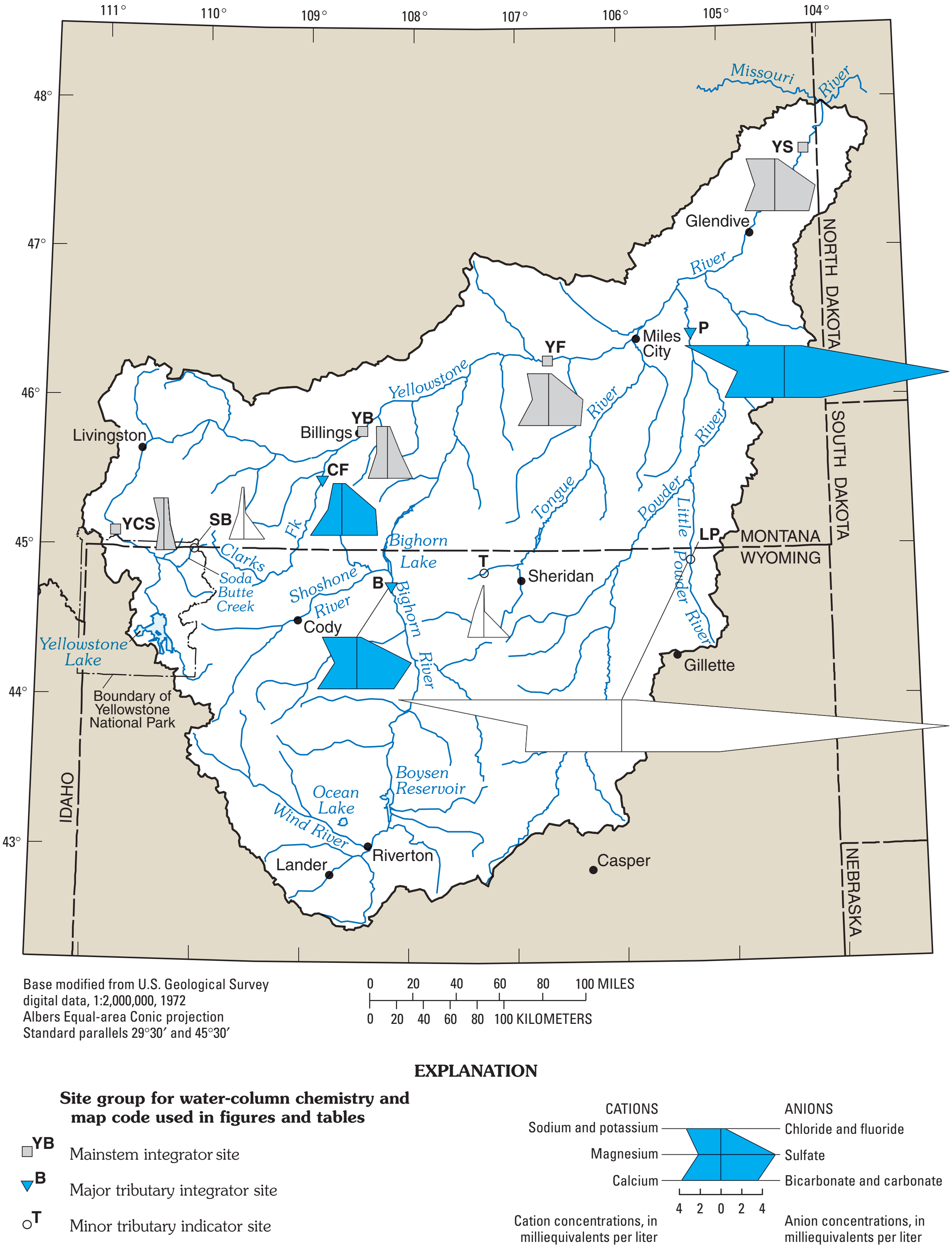


Figure 21. Stiff diagrams showing major-ion composition for fixed sites in the Yellowstone River Basin, 1999-2001.

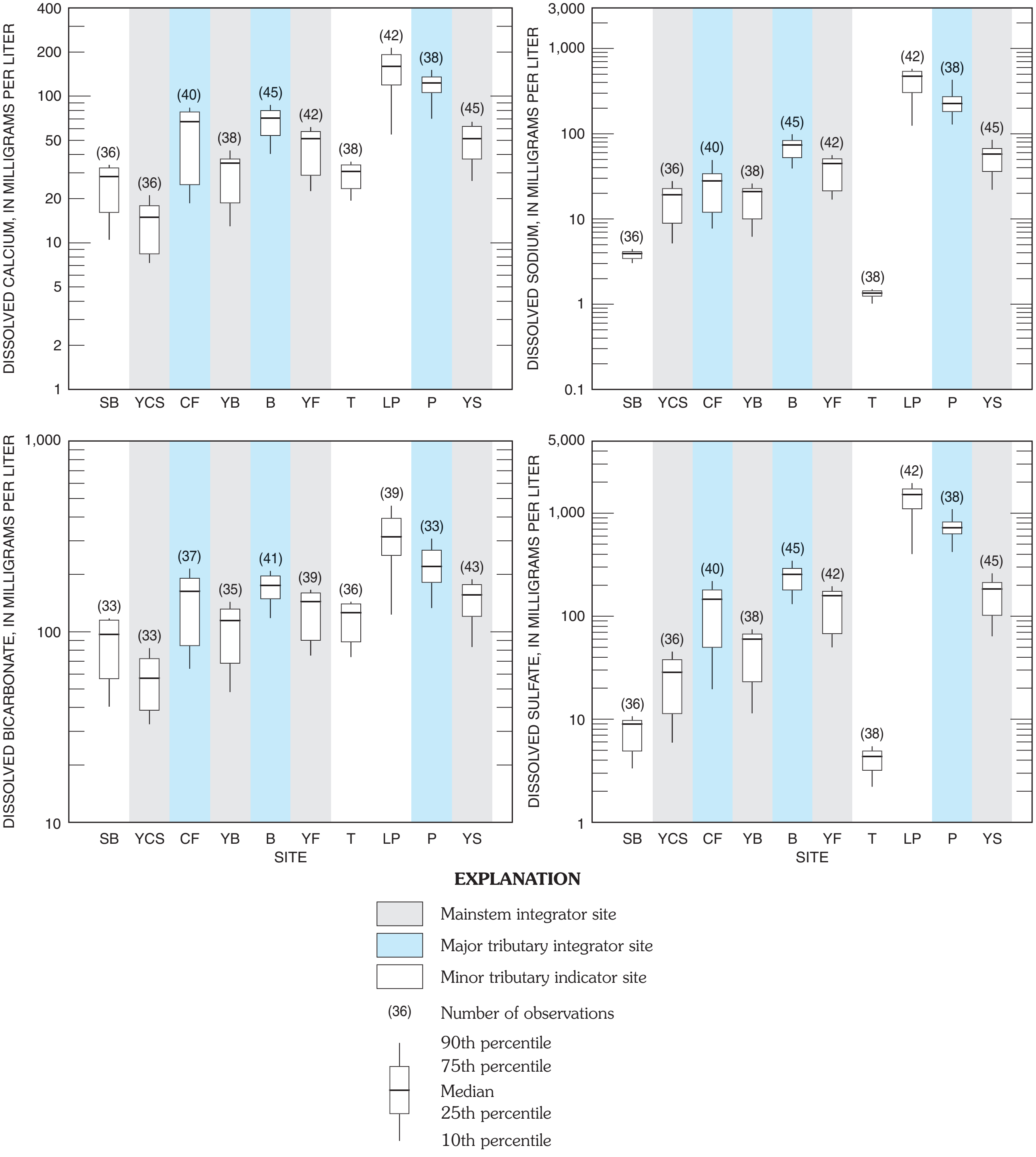


Figure 22. Statistical summary of concentrations of dissolved calcium, sodium, bicarbonate, and sulfate for fixed sites in the Yellowstone River Basin, 1999-2001.

sulfate types owing to weathering of larger percentages of Cretaceous- and Tertiary-period sedimentary rocks underlying the basins compared to the Clarks Fork Yellowstone River Basin. The water type at site B is calcium-sodium-magnesium sulfate compared to site P, which is a sodium-calcium-magnesium sulfate. The predominance of sodium-based salts, which result from evaporation, in the Powder River Basin results in larger sodium adsorption ratios (ranging from 3 to 9) at site P compared to other integrator sites (Swanson and others, 2000, 2001, 2002).

In comparison to the major tributary integrator sites, the drainage areas of the minor tributary indicator sites are small with more homogenous geology underlying the basins. The water types at the indicator sites are dominated by a single cation and single anion as compared to the mixed water types at the integrator sites. The water type for site SB and site T is dilute calcium bicarbonate. Igneous rocks and Paleozoic- and Mesozoic-era sedimentary rocks underlie over 97 percent of the basins upstream from site SB and site T. The water type for site LP is a concentrated sodium sulfate. Tertiary-period sedimentary rocks underlie nearly 100 percent of the Little Powder Basin. Median concentrations of calcium, sodium, bicarbonate, and sulfate were the largest at site LP for all sites in the YELL (fig. 22). In addition, larger sodium adsorption ratios (ranging from 2 to 9) were measured at site LP compared to the other indicator sites (Swanson and others, 2000, 2001, 2002).

Dissolved Solids

In addition to geology, variations in precipitation, evaporation, and contact times affect ranges of dissolved-solids concentrations in samples from the fixed sites in the YELL (fig. 23). Median dissolved-solids concentrations ranged from 118 mg/L in samples from site SB to 2,840 mg/L in samples from site LP. Dissolved-solids concentrations generally were smallest at site YCS, site SB, and site T, where annual precipitation is high and rock types are resistant to weathering. Site YCS and site SB are near YNP, which can receive annual precipitation in excess of 59 inches and mean annual evaporation is low in the cool highlands of the Park (Zelt and others, 1999). Along with the high annual precipitation, the steep gradients in mountain streams produce fast stream velocities, resulting in short contact time between stream waters and basin materials (Colby and others, 1956). In contrast, the largest median dissolved-solids concentrations were at site LP and site P; parts of the plains region, which includes site LP and site P, receive mean annual precipitation of about 14 inches. Annual evaporation also is substantially higher in the plains than in the mountainous areas and may exceed annual precipitation, resulting in the accumulation of soluble salts in or near the surface. Slower stream velocities in flatter areas than in mountainous areas are more favorable for the dissolution of salts (Colby and others, 1956). Median dissolved-solids concentrations for samples from site CF, site B, and the sites downstream from site YCS on the mainstem of the Yellowstone River (site YB, site YF, and site YS) are in between those of the mountains and plains fixed sites (fig. 23). Although these sites are in areas that may receive low annual precipitation, their dissolved-solids concentrations are diluted from basin tributaries that partially drain mountainous areas.

Although the natural factors are important controls on dissolved solids, land-use activities from humans also may contribute dissolved solids to streams. Increased dissolved solids in streams in the YELL have been attributed to irrigation (Knapton and Bahls, 1993; Peterson, 1993; Lindner-Lunsford and others, 1992). Irrigation contributes dissolved solids to streams because as crops consume applied irrigation water, they leave behind salts that can later be transported to streams (Colby and others, 1956). Land use along the Clarks Fork Yellowstone, Bighorn, Little Powder, Powder, and Yellowstone Rivers includes agricultural covers, such as row crops, small grains, and hay that are irrigated and may contribute to increased dissolved solids. The Bighorn, Little Powder, and Powder Rivers also receive inputs of discharge water associated with coal, oil, or gas development that may be high in dissolved solids (Lindner-Lunsford and others, 1992; Peterson, 1993; Clark and others, 2001).

Comparison to Water-Quality Criteria

National Secondary Drinking Water Regulations or Secondary Maximum Contaminant Levels (SMCLs), which are non-enforceable guidelines that regulate contaminants that may cause cosmetic or aesthetic effects in drinking water, are established for chloride, fluoride, sulfate, and dissolved solids (U.S. Environmental Protection Agency, 2002d). SMCLs are useful for assessing the relative magnitude of concentrations of these constituents in samples from the YELL. The SMCLs of 250 mg/L for chloride and 2.0 mg/L for fluoride were not exceeded in any samples from the fixed sites in the YELL. The SMCLs of 250 mg/L for sulfate and 500 mg/L for dissolved solids were exceeded in some samples from fixed sites (table 8). Concentrations of sulfate and dissolved solids exceeded SMCLs in 100 percent of the samples collected at site P and in 95.2 percent of the samples collected at site LP. Concentrations exceeding the sulfate and dissolved-solids SMCLs also were frequent in samples collected at site B.

Temporal Variability

Concentrations of dissolved solids significantly varied by sampling period (fig. 24) for site SB, site YCS, site CF, site YB, site YF, site T, and site YS (*p*-values <0.05). For these sites, median dissolved-solids concentrations were smallest during the April-June sampling period, when the more concentrated base flow is diluted by snowmelt runoff. Because dissolved solids generally are inversely related to streamflow and much of the variation in streamflow is seasonal, variation in dissolved-solids concentrations also can be seasonal. The variance is low and medians are larger for dissolved-solids

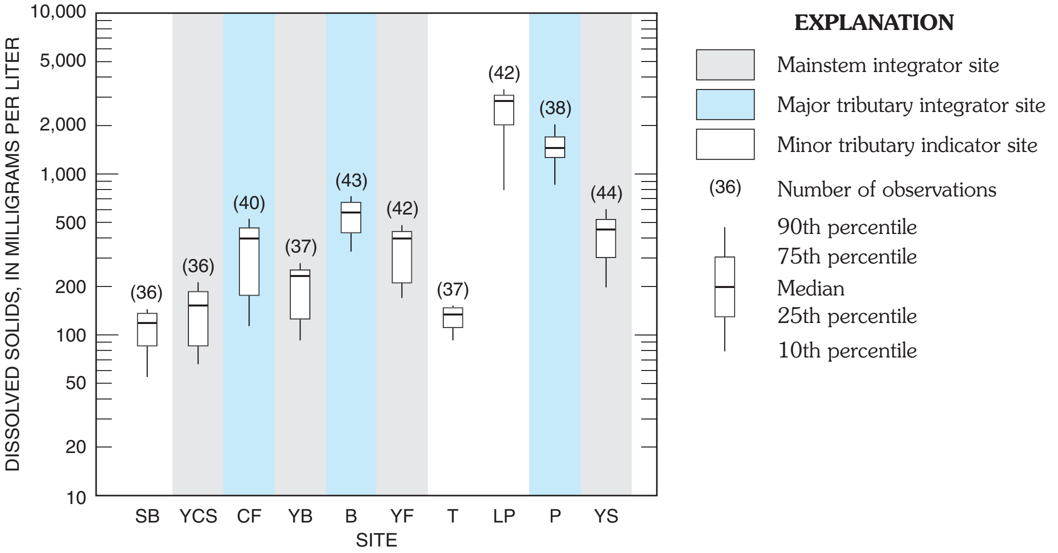


Figure 23. Statistical summary of dissolved-solids concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

Table 8. Sulfate and dissolved-solids concentrations exceeding U.S. Environmental Protection Agency's Secondary Maximum Contaminant Levels for fixed sites in the Yellowstone River Basin, 1999-2001

[mg/L, milligrams per liter; >, greater than]

Site report identifier (fig. 2)	Number of sulfate samples	Percent of samples where sulfate concentration >250 mg/L	Number of dissolved-solids samples	Percent of samples where dissolved-solids concentration >500 mg/L
SB	36	0.0	36	0.0
YCS	36	.0	36	.0
CF	40	5.0	40	12.5
YB	38	.0	37	.0
B	45	53.3	43	65.1
YF	42	.0	42	4.8
T	38	.0	37	.0
LP	42	95.2	42	95.2
P	38	100	38	100
YS	45	8.9	44	29.5
All sites	400	27.0	395	31.9

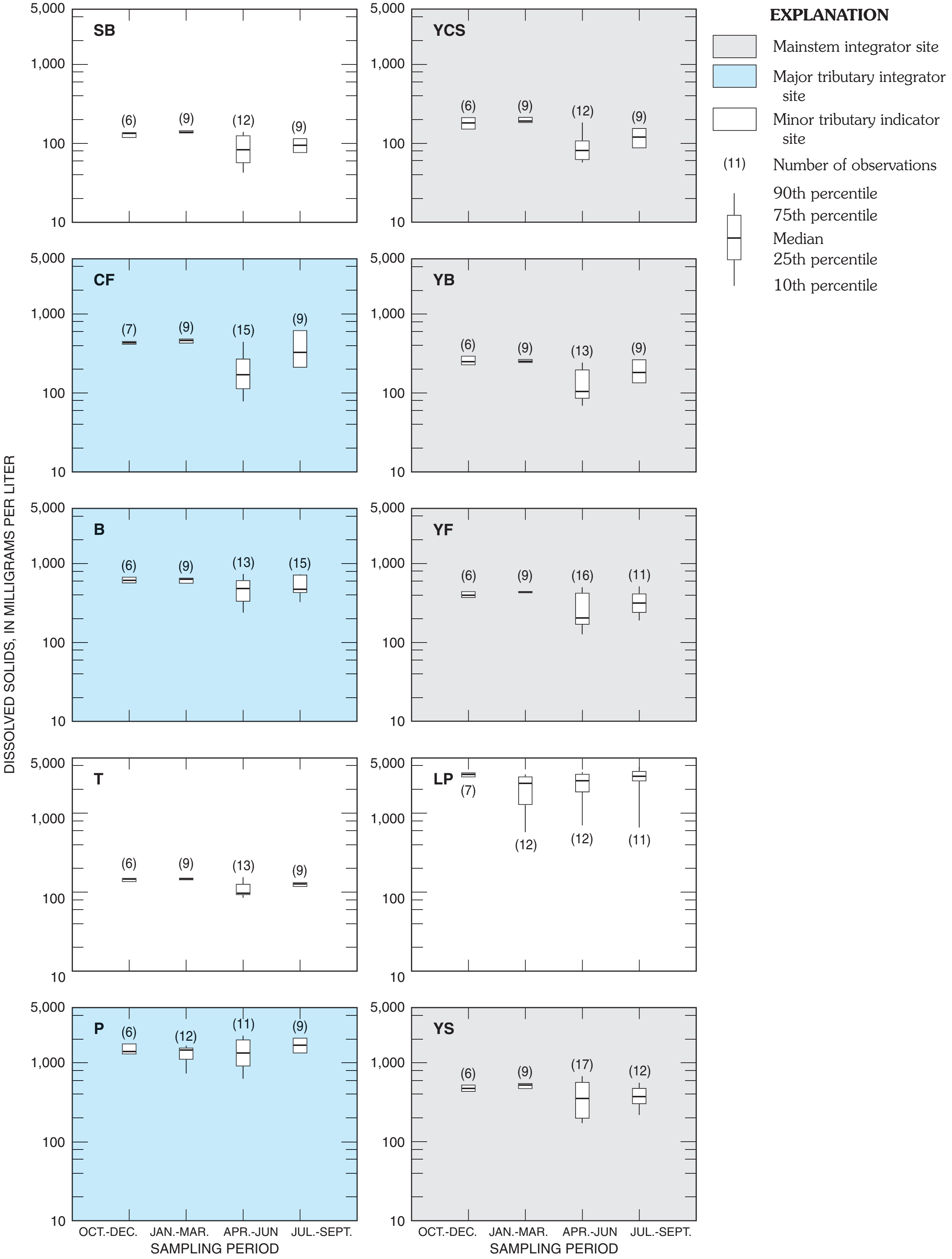


Figure 24. Seasonal variations in dissolved-solids concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

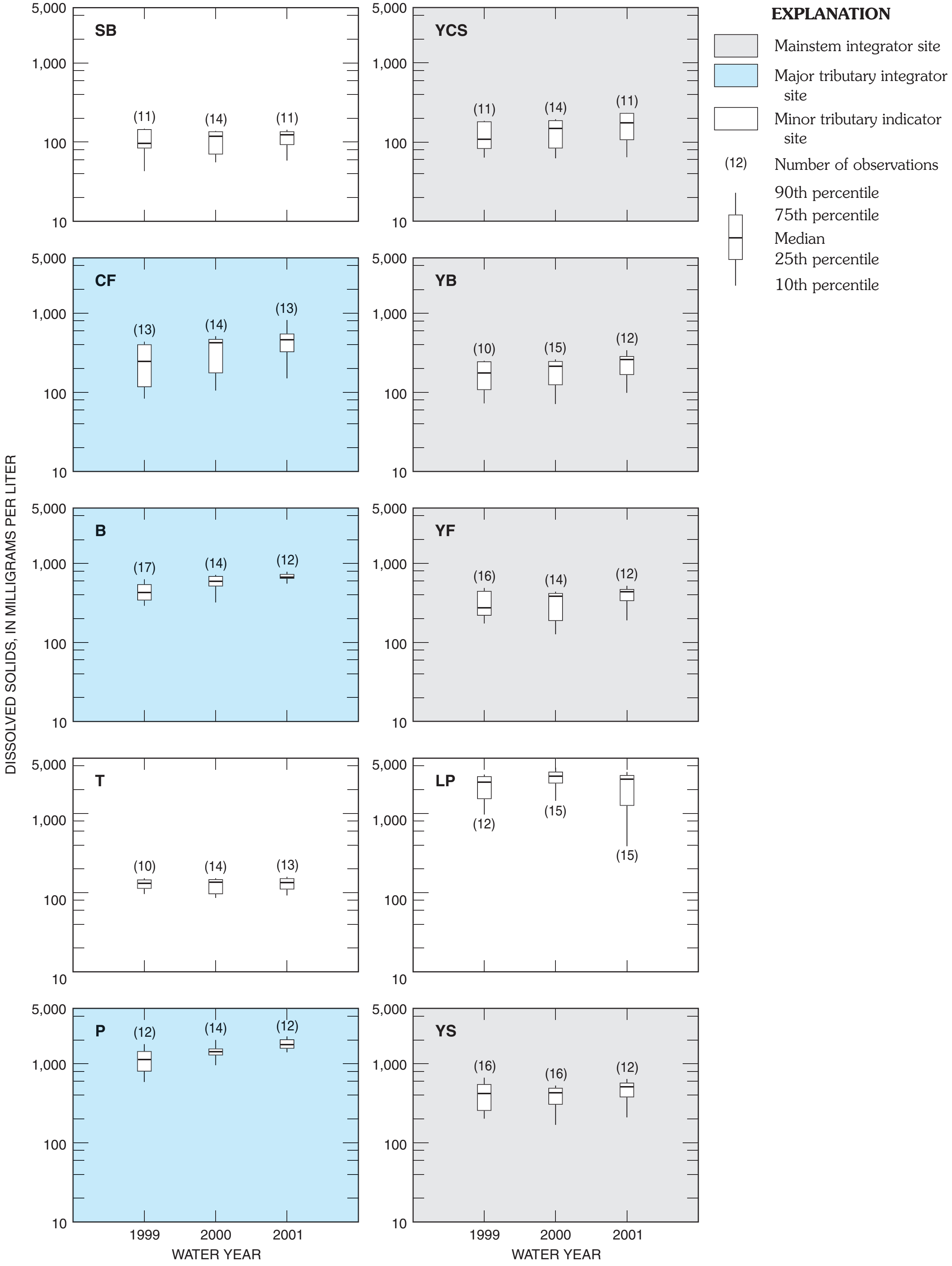


Figure 25. Annual variations in dissolved-solids concentrations for fixed sites in Yellowstone River Basin, 1999-2001.

concentrations at these sites during the October–December and January–March sampling periods when base flow dominates the stream chemistry. A significant difference in concentrations was not determined at site B (*p*-value=0.135), where the smallest median concentration was during the July-September sampling period. A large reservoir, Boysen Reservoir, that captures snowmelt runoff regulates the streamflow on the Bighorn River upstream from site B and releases can dilute flows during the irrigation season. The seasonal pattern of dissolved-solids concentrations at site LP and site P are different from the other fixed sites. Dissolved-solids concentrations are variable throughout most of the year, with the largest median concentrations occurring during the July–September sampling period. Irrigation return flows and decreased streamflow because of low precipitation and high evaporation may contribute dissolved solids during the July–September sampling period.

In addition to seasonal variations in streamflow, annual variations in streamflow affected dissolved-solids concentrations on a longer time scale (fig. 25). Significant differences in annual dissolved-solids concentrations were determined for site CF, site YB, site B, and site P (*p*-values <0.05) during the 3-year study period. The variations in median concentrations are attributed to decreased streamflows associated with drought conditions that occurred during water years 2000 and 2001. In particular, streamflows in the Bighorn River (site B) and Powder River (site P) were substantially smaller in water years 2000 and 2001 compared to water year 1999. The minimum dissolved-solids concentrations at these sites during water year 2001 exceeded the median concentrations of water year 1999, which was a normal to moderately wet year.

Nutrients

Nutrients analyzed as part of the YELL fixed-site sampling include dissolved and total phases of nitrogen, phosphorus, and organic carbon. Nitrogen and phosphorus are essential nutrients for healthy plant and animal populations (Fuhrer and others, 1999). Solutes of organic carbon are nutrients for microbes, which are factors in some chemical processes (Hem, 1985). Excessive nutrient concentrations, however, can degrade or facilitate degradation of water quality. Nutrients are the third leading pollutant in impaired rivers and streams in the United States (U.S. Environmental Protection Agency, 2000a).

Nitrogen analyses during the fixed-site sampling included dissolved ammonia plus organic nitrogen as nitrogen, total ammonia plus organic nitrogen as nitrogen, dissolved ammonia as nitrogen, dissolved nitrite as nitrogen, and dissolved nitrite plus nitrate as nitrogen (referred to as dissolved nitrate in this report). Nitrate, the oxidized form of nitrogen, typically is the most common form of dissolved nitrogen in streams (U.S. Environmental Protection Agency, 1986b). Total nitrogen in this report is the sum of the total ammonia plus organic nitrogen and dissolved nitrate. If the concentration of one form of nitrogen was censored, the total-nitrogen concentration was equal to the concentration of the uncensored form. If concentrations for both forms were censored, the total-nitrogen concentration was censored at the largest reporting level.

Pathways of nitrogen to streams include atmospheric deposition, overland runoff, ground-water discharge, and point discharges. Sources of nitrogen in streams include natural biological and chemical reactions, plant material, as well as anthropogenic activities such as fertilizer application and sewage disposal. Concerns for nitrogen in streams include dissolved-nitrate concentrations larger than ambient conditions resulting in human health issues for drinking water, and eutrophication and subsequent hypoxic conditions (dissolved-oxygen concentrations smaller than 2.0 mg/L) for streams and other receiving waters (Fuhrer and others, 1999). Median flow-weighted mean concentrations for streams in relatively undeveloped basins of the United States (background concentrations) are about 0.020 mg/L for dissolved ammonia, 0.087 mg/L for dissolved nitrate, and 0.26 mg/L for total nitrogen (Clark and others, 2000).

Phosphorus analyses during the fixed-site sampling included dissolved orthophosphate as phosphorus, dissolved phosphorus, and total phosphorus. Dissolved phosphorus primarily is in the form of orthophosphate. Phosphates sorb strongly to soil and sediment particles. For some soils, large soil phosphorus levels result in more phosphorus available in the dissolved form (Fuhrer and others, 1999). Total phosphorus primarily includes phosphates and particulate forms.

Pathways of phosphorus to streams include overland runoff and point discharges. Natural sources of phosphorus in streams in the Western United States include soils and sediments derived from marine sedimentary rocks. Because phosphorus is essential in metabolism, anthropogenic sources of phosphorus include animal and human waste (Hem, 1985). Phosphorus also is a necessary plant nutrient and is sometimes added as a fertilizer. Eutrophication is the primary concern for phosphorus in streams (Fuhrer and others, 1999). Background concentrations are about 0.010 mg/L for orthophosphate and 0.022 mg/L for total phosphorus (Clark and others, 2000).

Organic carbon analyses during the fixed-site sampling included DOC and total organic carbon. Because concentrations of DOC approximated concentrations of total organic carbon in solution for samples in the YELL, only DOC is discussed in this report. Organic solutes are important in weathering processes, diagenesis, photosynthesis, photochemical reactions, and transport of metals (Drever, 1997, p. 107). Complexation of metals by DOC can result in high concentrations of metals in solution (Drever, 1997, p. 35 and p. 188); however, several metals are less toxic to aquatic organisms when complexed with organic solutes (Drever, 1997, p. 179). When water is treated for drinking, organic compounds react with chlorine to form potentially carcinogenic disinfection by-products (U.S. Geological Survey, 1997). Concentrations of DOC in streams of temperate and arid/semiarid zones generally are about 3 mg/L (Hem, 1985).

Concentrations

Concentrations of nitrogen species, phosphorus species, and organic carbon in samples were examined for the fixed sites. In addition, flow-weighted concentrations were determined for dissolved nitrate, total nitrogen, and total phosphorus.

Nitrogen

Dissolved-ammonia concentrations in most samples from the fixed sites were less than laboratory reporting levels (fig. 26). Concentrations generally were largest in samples collected at site YCS (median concentration 0.04 mg/L; maximum concentration 0.23 mg/L) downstream from YNP in comparison with concentrations for other fixed sites. Ammonia occurs naturally in many geothermal waters of YNP; concentrations larger than 600 mg/L (as nitrogen) have been measured in some springs in YNP (Ball and others, 1998, p. 23). A probable source of the relatively large ammonia concentrations is leaching of organic-rich sedimentary rocks at depth by the high-temperature geothermal waters and subsequent surface discharge of those waters (D. Kirk Nordstrom, USGS, written commun., 2000; Love and Good, 1970). Sorey and others (1991) reported a total discharge of about 2.2 cubic feet per second (ft^3/sec) from La Duke Hot Spring upstream from site YCS. Because of the chemical properties of ammonia and the physical characteristics of these surface waters, a substantial fraction of the ammonia in the geothermal waters upstream from site YCS probably becomes oxidized, contributing to nitrate concentrations at that site.

Median dissolved-nitrate concentrations in samples from the fixed sites ranged from 0.04 mg/L to 0.54 mg/L (fig. 26). Dissolved-nitrate concentrations were smallest for the indicator sites SB, T, and LP; concentrations were less than laboratory reporting levels in 67 percent of the samples from site LP. Dissolved-nitrate concentrations were largest for the integrator sites CF and B. On the mainstem Yellowstone River, dissolved-nitrate concentrations increased downstream in the upper part of the basin from site YCS to site YF; however, dissolved-nitrate concentrations were similar at site YF and site YS in the lower part of the basin.

In general, flow-weighted mean dissolved-nitrate concentrations at YELL fixed sites were related to drainage area and land-cover characteristics on alluvial deposits, where anthropogenic sources of nitrate would most commonly be applied. Flow-weighted mean dissolved-nitrate concentrations increased with increasing drainage area (fig. 27A; Kendall's tau (τ) = 0.56; *p*-value = 0.025). Correlations between flow-weighted mean dissolved-nitrate concentrations and drainage area for the tributary and mainstem fixed sites were similar; however, an apparent negative shift was observed from the tributary relation to the mainstem relation, probably due in part to flow dilution on the mainstem. In comparing flow-weighted mean dissolved-nitrate concentrations between sites with similar size drainage areas, annual mean streamflows were about 3 to 12 times greater at the mainstem sites than at the tributary sites.

Flow-weighted mean dissolved-nitrate concentrations were most strongly correlated with increasing agricultural land use on alluvial deposits upstream from the sites (fig. 27D; τ = 0.62; *p*-value = 0.012). For all tributary sites, the largest flow-weighted mean dissolved-nitrate concentrations were determined for sites CF and B, where the percent of agricultural lands on alluvial deposits also were largest. Flow-weighted mean dissolved-nitrate concentrations were smaller at sites with more forested land (fig. 27B; τ = -0.56; *p*-value = 0.025) compared to sites with more rangeland (fig. 27C; τ = 0.56; *p*-value = 0.025) on alluvial deposits. The positive correlation of concentrations with rangeland area and the negative correlation of concentrations with forested land area are characteristics consistent with results from other investigations. Nolan and Hitt (2003, p. 10) reported that background dissolved-nitrate concentrations in samples from shallow aquifers beneath rangelands were significantly (p-value < 0.001) larger than ground-water concentrations beneath forested lands and attributed the larger concentrations to natural sources and processes.

Flow-weighted mean dissolved-nitrate concentrations for the YELL fixed sites in relatively undeveloped basins (site SB, site YCS, site T, and site LP) generally were smaller than or similar to concentrations for streams in relatively undeveloped basins in the United States (background concentrations). For site SB, site YCS, and site T, flow-weighted mean dissolved-nitrate concentrations generally were smaller than or similar to the computed median background concentrations for dissolved nitrate of 0.087 mg/L (Clark and others, 2000). The exception was site LP, where the flow-weighted mean dissolved-nitrate concentration (0.18 mg/L) was larger than the median and smaller than the 75th-percentile (0.21 mg/L) of background concentrations; however, the estimated flow-weighted mean concentration has a large degree of uncertainty because a large percentage of the dissolved-nitrate concentrations in samples from site LP were reported as less than laboratory reporting levels.

Median total-nitrogen concentrations in samples from the fixed sites ranged from 0.13 mg/L to 0.95 mg/L (fig. 26). Concentrations were smaller for the mineral resource area (site SB) and forested (site T) indicator sites compared to the integrator sites on the major tributaries (site CF, site B, and site P). Median total-nitrogen concentrations for mainstem sites (site YCS, site YB, site YF, and site YS) increased downstream. Organic nitrogen composed proportionally more of the total nitrogen in samples for site LP and site P when compared to all other fixed sites.

The flow-weighted mean total-nitrogen concentrations were correlated with land-cover characteristics on alluvial deposits (fig. 28). In general, flow-weighted mean total-nitrogen concentrations were most strongly correlated with increasing rangeland (τ = 0.87; p-value < 0.001) and decreasing forested land (τ = -0.87; p-value < 0.001) on alluvial deposits upstream from the sites. In contrast to comparisons

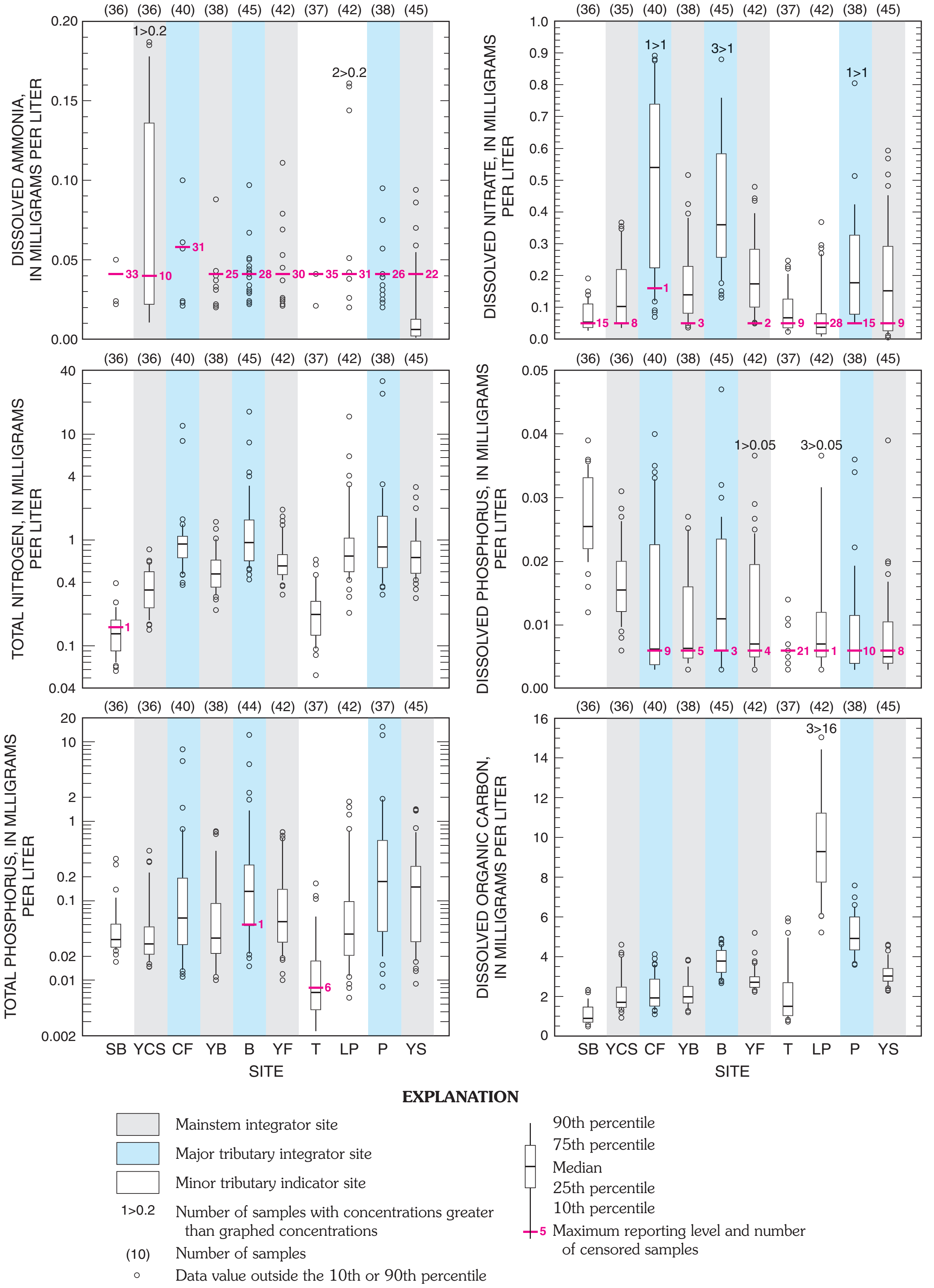


Figure 26. Statistical summary of concentrations of selected nutrients for fixed sites in the Yellowstone River Basin, 1999-2001.

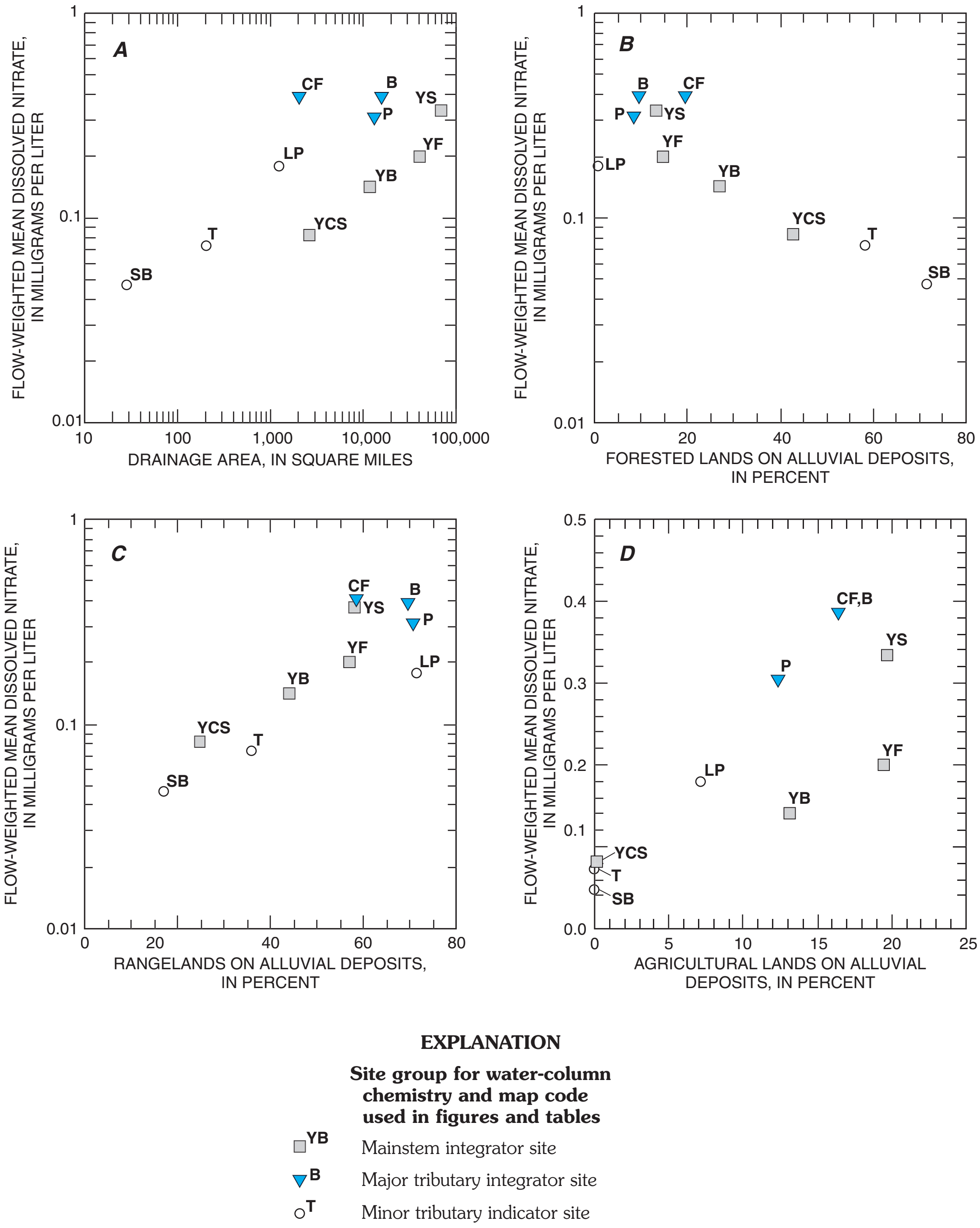


Figure 27. Flow-weighted mean dissolved-nitrate concentrations related to *A*, drainage area; *B*, forested lands; *C*, rangeland; and *D*, agricultural lands on alluvial deposits for fixed sites in the Yellowstone River Basin, 1999-2001.

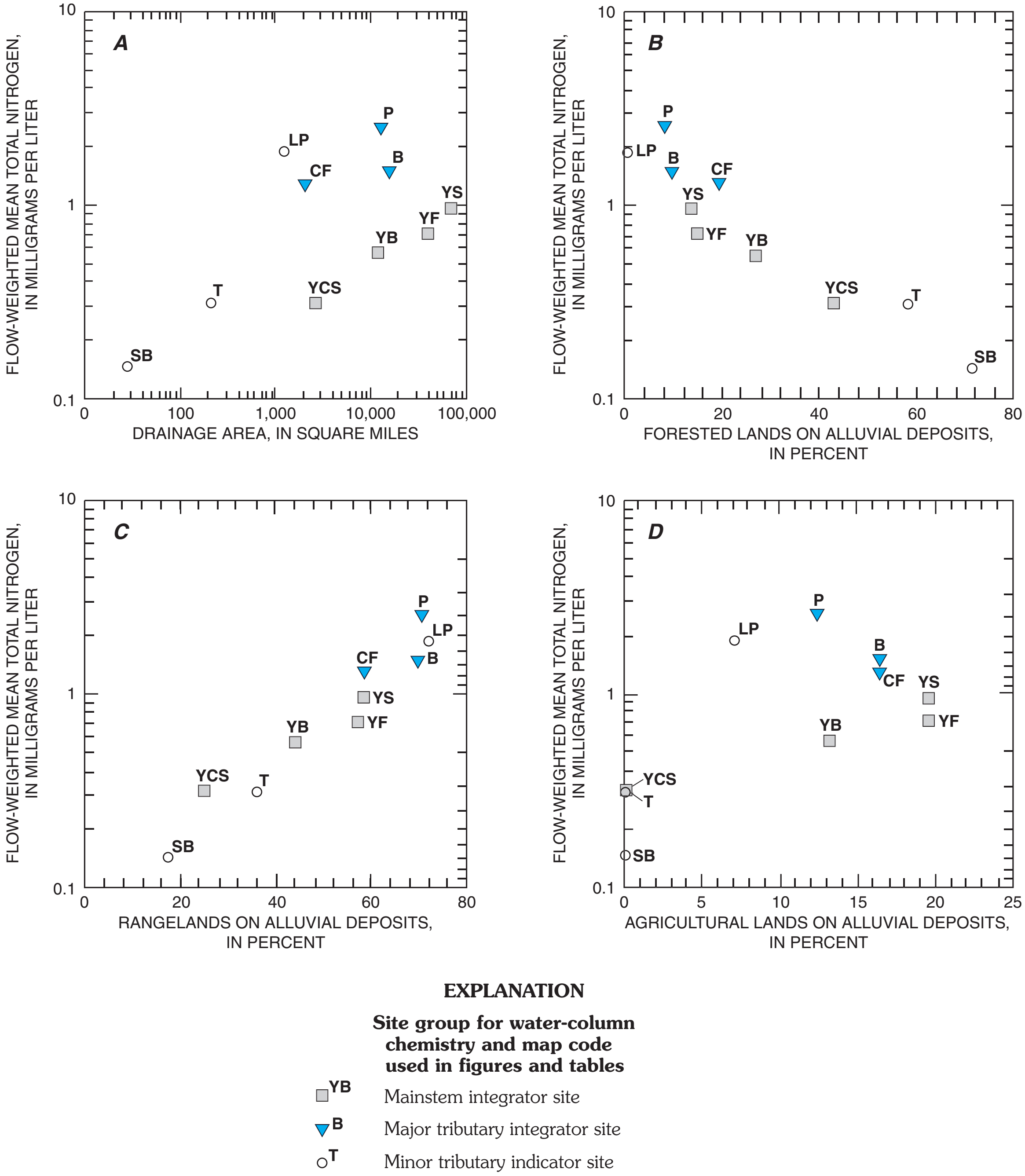


Figure 28. Flow-weighted mean total-nitrogen concentrations related to *A*, drainage area; *B*, forested lands; *C*, rangeland; and *D*, agricultural lands on alluvial deposits for fixed sites in the Yellowstone River Basin, 1999-2001.

of flow-weighted mean dissolved-nitrate concentrations with land-cover characteristics, flow-weighted mean total-nitrogen concentrations were not correlated with agricultural lands on alluvial deposits ($\tau = 0.31$; p-value = 0.209).

Flow-weighted mean total-nitrogen concentrations in samples from fixed sites in relatively undeveloped basins (site SB, site YCS, site T, and site LP), generally were smaller than or similar to concentrations for streams in relatively undeveloped basins in the United States (background concentrations). For site SB, site YCS, and site T, flow-weighted mean total-nitrogen concentrations generally were smaller than or similar to the computed median background concentrations for total nitrogen of 0.26 mg/L (Clark and others, 2000). The flow-weighted mean total-nitrogen concentration at site LP (1.9 mg/L) was larger than the 75th-percentile (0.50 mg/L) background concentration. Physical and hydrologic characteristics of the sites used in the analyses by Clark and others (2000, fig. 3) are very different from those for site LP. The drainage area for site LP is much larger than the drainage areas for most of the background sites used by Clark and others (2000), whereas the mean streamflow and annual runoff are much smaller for site LP in comparison to most of the background sites. Additionally, most of the background sites used in the analyses by Clark and others (2000) were in basins that were not characterized as mostly rangeland. Sources and cycling of nitrogen in rangelands can differ substantially from sources and cycling of nitrogen in other land covers.

Phosphorus

Median dissolved-phosphorus concentrations in samples ranged from less than reporting levels at site T to 0.026 mg/L at site SB (fig. 26). The smallest concentrations were measured at the forested indicator site T; more than 50 percent of the samples analyzed from this site had concentrations less than the maximum reporting level. The largest dissolved-phosphorus concentrations generally were measured at the mineral resource area indicator site SB, where concentrations ranged from 0.012 mg/L to 0.039 mg/L. Potential sources for dissolved phosphorus upstream from site SB probably are both natural and anthropogenic. Phosphorus is a common constituent in marine sedimentary rocks (Hem, 1985); outcrops of formations with these lithologies are upstream from site SB (Elliott, 1979). In addition to the simple dissolution of particulate phosphorus from these outcrops, past mining activities resulting in increased weathering of phosphorus-containing minerals could contribute to dissolved phosphorus concentrations at moderate to high streamflows. In a previous investigation of the hydrogeology of the Soda Butte Creek Basin, Metesh and others (1999, p. 22) noted an increase in dissolved-nitrate concentrations in the downstream direction during March 1997. Considering the observation by Metesh and others (1999) and because phosphorus is found in human and animal waste (Hem, 1985), shallow ground-water discharge from unsewered development along the creek could contribute to dissolved-phosphorus concentrations at site SB at low streamflows.

Median total-phosphorus concentrations in samples from the fixed sites ranged from 0.007 mg/L to 0.18 mg/L (fig. 26). Concentrations were smallest in samples collected from the forested indicator site T and largest in samples collected from site P. Median total-phosphorus concentrations at mainstem sites (site YCS, site YB, site YF, and site YS) increased downstream.

Concentrations of total phosphorus typically increase with increasing suspended-sediment concentrations (fig. 29) because of physical and chemical properties. Because of the erosive nature of the soils in much of the basins and plains areas of the YELL, suspended-sediment concentrations in streams can be large. Thus, total-phosphorus concentrations can be large (for example, site P) and generally increase downstream with increasing suspended-sediment concentrations (for example, site YCS, site YB, site YF, and site YS). Ordinary least squares and robust linear-regression relations (Helsel and Hirsch, 1992; Insightful Corp., 2002) were developed for each site using base-10 logarithms of total-phosphorus and suspended-sediment concentrations. Correlation coefficients (Pearson's r) ranged from 0.68 (site T) and 0.79 (site YB) to 0.97 (site YS) and 0.98 (site YCS and site YF). When compared to concentrations measured at other YELL fixed sites, dissolved phosphorus at site SB composed a larger fraction of the total phosphorus at lower suspended-sediment concentrations and streamflows, probably because of natural and anthropogenic sources in the basin (see previous discussion in this section).

Potential sources of phosphorus in samples from YELL fixed sites most likely are natural. Anthropogenic inputs of phosphorus in the YELL are low relative to other parts of the United States (David Mueller, U.S. Geological Survey, written commun., 2002). Natural sources of particulate phosphorus in the YELL, however, are more common relative to sources in other parts of the Nation. Outcrops of Permian-period marine phosphorites occur throughout western Wyoming and southwestern Montana (McKelvey and others, 1953). Soil phosphorus content in the upper Missouri River Basin is relatively high compared to other parts of the United States (Parker, 1953). Shacklette and Boerngen (1984) noted that mean phosphorus concentrations in soils and other surficial materials generally are naturally larger in the western United States (320 micrograms per gram (μg/g)) than in the eastern United States (200 μg/g). Phosphorus concentrations in bed sediments also are naturally larger in western U.S. streams than eastern U.S. streams (Jeffrey Grossman, U.S. Geological Survey, written commun., 2003).

Flow-weighted mean total-phosphorus concentrations ranged from 0.04 mg/L to 2.1 mg/L. As with sample median concentrations, flow-weighted concentrations in samples from the fixed sites were smallest at site T, largest at site P, and increased downstream at mainstem sites (sites YCS, YB, YF, and YS). Flow-weighted mean total-phosphorus concentrations at sites in relatively undeveloped basins in the YELL (site SB, site YCS, site T, and site LP) were larger than the computed 75th-percentile background concentration of 0.022 mg/L by Clark and others (2000, table 1). The flow-weighted mean total-phosphorus concentration at site LP (0.46 mg/L) was larger than the maximum background concentration reported by Clark and others (2000). The relatively large total phosphorus-concentrations at YELL fixed sites probably result from natural sources. Additionally, physical and hydrologic characteristics of the sites used in the analyses by Clark and others (2000) are very different from those for site LP.

Organic Carbon

Median DOC concentrations in samples from the fixed sites ranged from 0.89 mg/L to 9.3 mg/L (fig. 26). Concentrations generally were smaller than 3 mg/L, which is typical for streams of temperate and arid/semiarid zones (Hem, 1985). The largest DOC concentrations were measured at the rangeland indicator site, site LP, where DOC concentrations ranged from 5.2 mg/L to 38 mg/L. Carbon fractionation analyses were completed for a single sample collected at site LP. Fractionation results indicated a relatively large component of aliphatic (straight or branched chain) carbon (George Aiken, USGS, written commun., 2000). These results might be expected if the DOC concentrations at site LP were derived from a relatively large source of weathered carbon. Ground-water discharge from coal aquifers probably is not the source of DOC at site LP, because DOC concentrations in samples at site LP do not have a negative correlation with streamflow and DOC concentrations in samples from coal aquifers in the region generally are small. However, possible sources of weathered carbon upstream from site LP are washoff from coal outcrops and (or) springs and seeps that discharge in response to rainfall or snowmelt from clinker in the basin, where waters in contact with residuum from the burned coal over adequate residence times could contribute to larger DOC concentrations at larger streamflows.

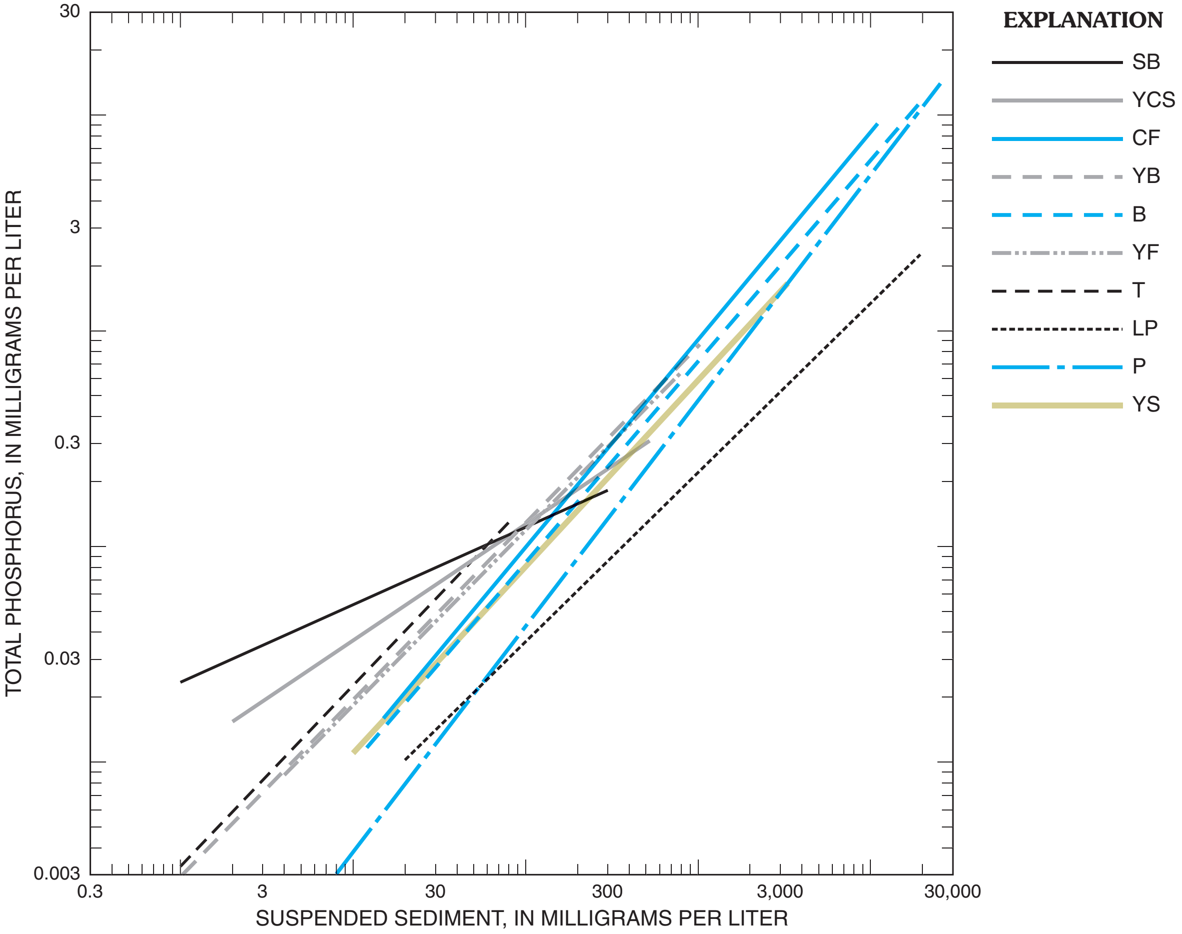


Figure 29. Relations of total-phosphorus and suspended-sediment concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

Comparison to Water-Quality Criteria

Nutrient concentrations in samples from YELL fixed sites generally were smaller than water-quality criteria. Dissolved-nitrate concentrations in all samples from YELL fixed sites were smaller than the Maximum Contaminant Level (MCL) of 10 mg/L for human health (U.S. Environmental Protection Agency, 2002d). Aquatic-life criteria pertaining to ammonia concentrations are water temperature- and pH-dependent and further classified by fish life stage (U.S. Environmental Protection Agency, 1999). Ammonia concentrations in all samples from fixed sites did not exceed any of the aquatic-life criteria. Total-phosphorus concentrations in some samples from some YELL fixed sites were larger than the desired goal of 0.10 mg/L for preventing nuisance plant growth in streams (U.S. Environmental Protection Agency, 1986b). Median total-phosphorus concentrations exceeded the recommended goal in samples from site B, site P, and site YS. Total-phosphorus concentrations in samples from these sites likely are naturally occurring.

Total-nutrient concentrations for YELL fixed sites were larger than concentrations for USEPA nutrient ecoregion reference conditions. For preventing adverse effects of excess human-caused nutrient inputs in the Middle Rockies, Wyoming Basin, and Northwestern Great Plains Ecoregions, USEPA developed unique nutrient criteria from monitoring data for each ecoregion (U.S. Environmental Protection Agency, 2000b, 2000c, 2001). Because data for reference sites are few, the criteria were based on the lower quartile of sample concentrations from all monitoring data. The ecoregion criteria for total nitrogen (0.090 mg/L, Middle Rockies; 0.25 mg/L, Wyoming Basin; 0.38 mg/L, Northwestern Great Plains) were exceeded by the sample 10th-percentile concentrations for all fixed sites except site SB. For site SB, the sample median concentration exceeded the ecoregion criterion. The ecoregion criteria for total phosphorus (0.015 mg/L, Middle Rockies; 0.022 mg/L, Wyoming Basin; 0.029 mg/L, Northwestern Great Plains) were exceeded by the sample 25th-percentile concentrations for most fixed sites. The exceptions were site SB and site YCS (10th-percentile exceeded criterion), site LP (median exceeded criterion), and site T (75th-percentile exceeded criterion).

Temporal Variability

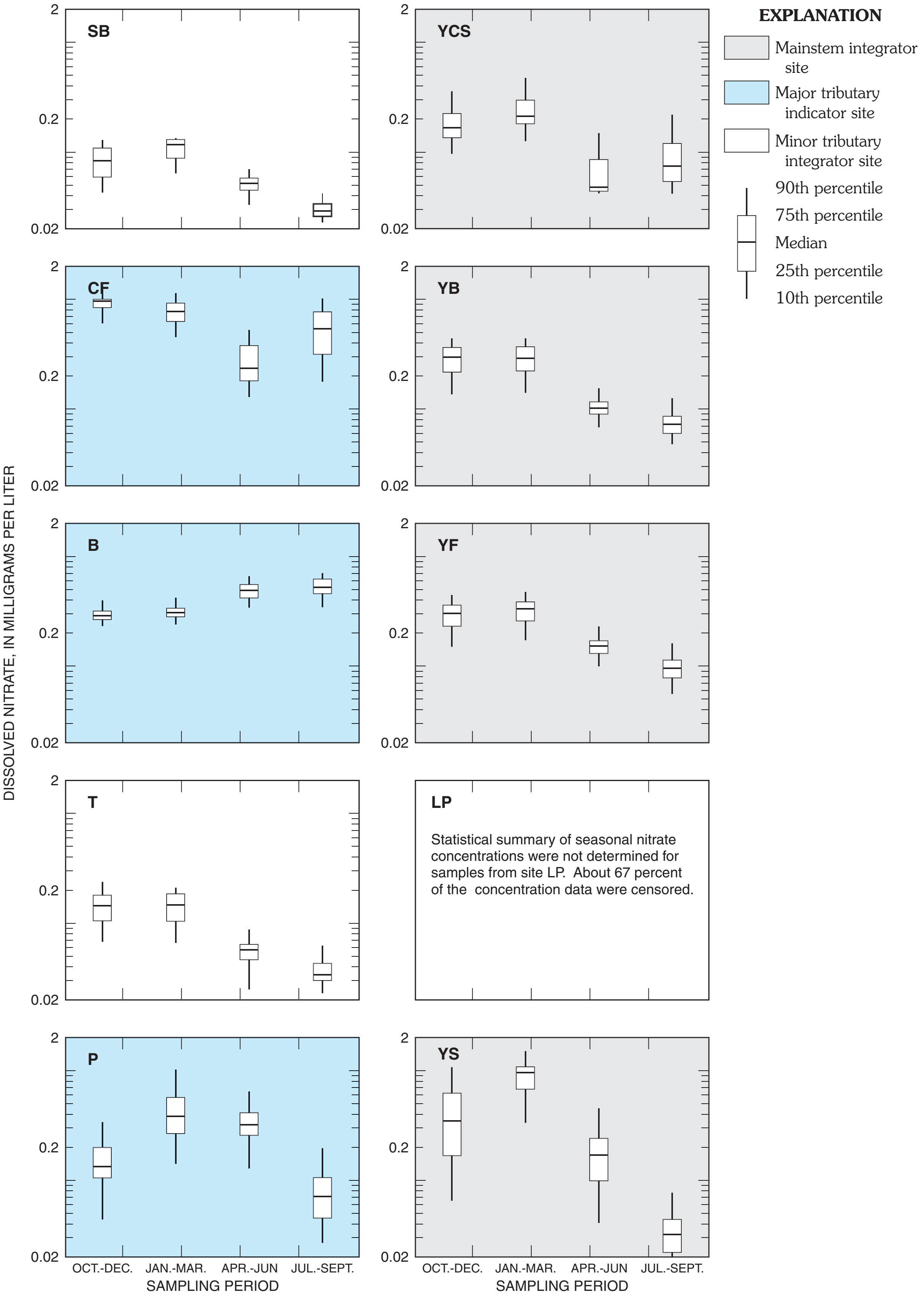
Nutrients for YELL fixed sites were evaluated by season to assess temporal variations in concentrations as related to environmental factors. Daily concentrations of dissolved nitrate, total nitrogen, and total phosphorus were estimated using the rating-curve method (Cohn and others, 1989) and the computer program LOADEST (Crawford, 1991). Daily concentrations estimated using this method are subject to large errors. To minimize the effects of potential errors, statistical summaries of the estimated values for October–December, January–March, April–June, and July–September are used to assess seasonal variations.

Nitrogen

Median dissolved-nitrate concentrations generally were larger during October–December and January–March for the mainstem fixed sites (fig. 30). Sources of nitrate (for example, oxidation of ammonia in geothermal waters or discharge from alluvial aquifers) are less dilute during winter months when streamflows are lower than during other months. Uptake of nitrate by algae—an important process that reduces concentrations in streams during summer—also is minimal during winter months when solar inputs are smaller than during other months and stream temperatures are near freezing. For samples from the mainstem sites, the largest differences in seasonal nitrate concentrations were at site YS where concentrations during January–March were much larger than those during July–September. At site YS, the larger nitrate concentrations during January–March probably are a result of discharges from shallow ground-water sources. During July–September, the smaller nitrate concentrations probably are caused in part by increased uptake during July and August when algae are most active (Peterson and others, 2004).

Dissolved-nitrate concentrations varied by sampling period for samples from major tributary integrator sites and minor tributary indicator sites (fig. 30). Because concentrations generally increase when flows decrease, ground water that is discharged from alluvial deposits is a probable source of nitrate in stream samples at the tributary sites. For site SB, median dissolved-nitrate concentrations were largest during January–March when biological uptake is diminished and dilution by streamflow is lowest. For site CF, median dissolved-nitrate concentrations were largest during October–December. Dissolved-nitrate concentrations, however, also were large during July–September for site CF as well as for site B. The large dissolved-nitrate concentrations during July–September when algal uptake is greatest probably are the result of nitrogen-enriched irrigation return flows and shallow ground-water discharge.

Total-nitrogen concentrations in samples from YELL fixed sites varied by sampling period (fig. 31). For samples from the mainstem sites, the largest concentrations shifted from January–March at site YCS to April–June at site YS. From upstream to downstream at the mainstem sites, relatively less of the total nitrogen present is composed of dissolved-inorganic nitrogen (for example, ammonia and nitrate), which is present in larger concentrations during January–March and relatively more is composed of organic nitrogen, which is present in larger concentrations during April–June. For site B, site T, site LP, and site P, median total-nitrogen concentrations were largest during April–June. Because streamflows are largest during April–June and result in large suspended-sediment concentrations, the large total-nitrogen concentrations likely are related to suspended particulate organic matter. For site SB, median total-nitrogen concentrations were largest during January–March, similar to dissolved-nitrate concentrations. For site CF, median total-nitrogen concentrations were similar during all seasons.



Statistical summary of seasonal nitrate concentrations were not determined for samples from site LP. About 67 percent of the concentration data were censored.

Figure 30. Seasonal statistical summary of LOADEST estimated daily dissolved-nitrate concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

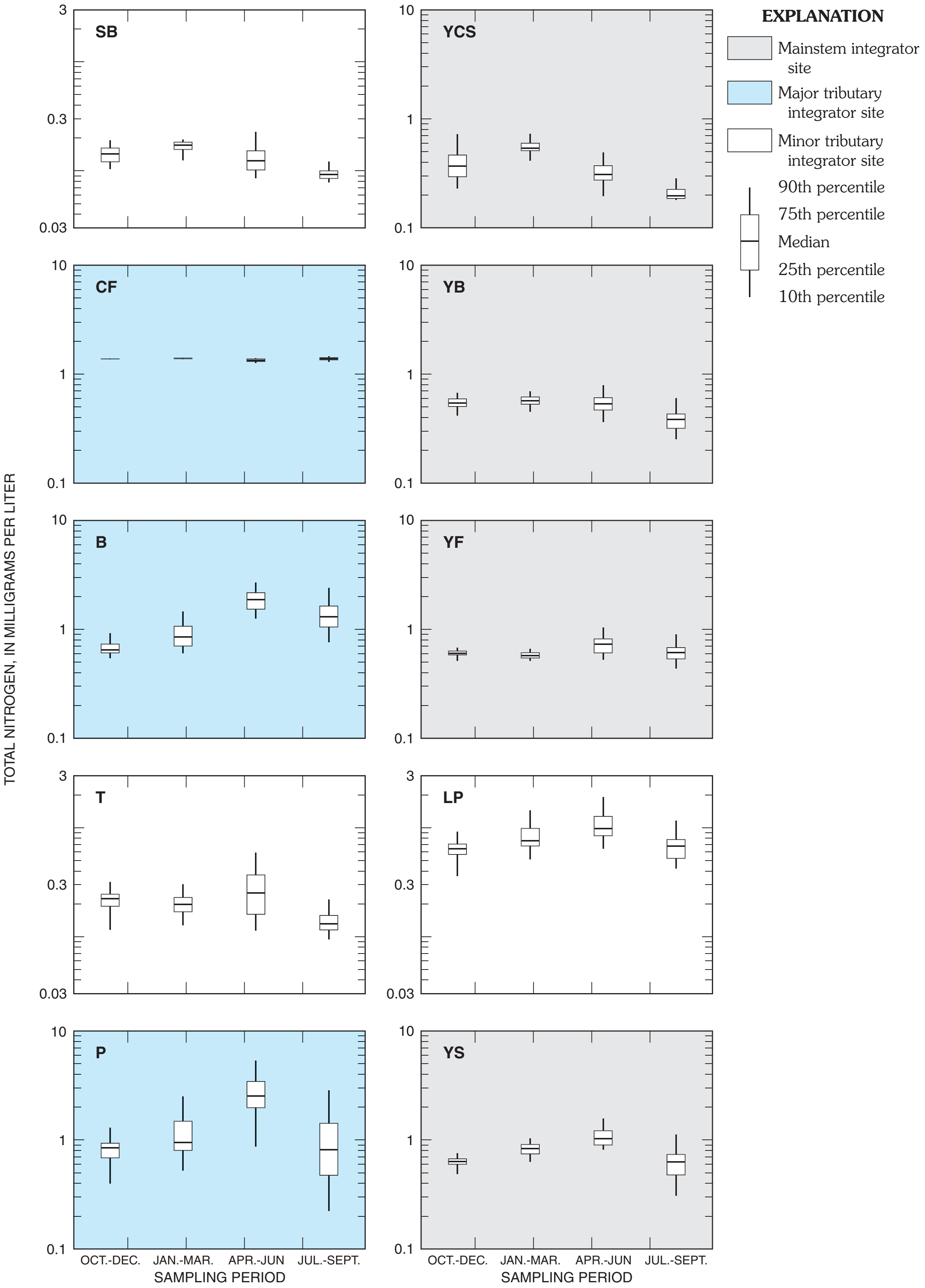


Figure 31. Seasonal statistical summary of LOADEST estimated daily total-nitrogen concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

Phosphorus

Total-phosphorus concentrations in samples from mainstem and tributary YELL fixed sites were largest during April–June (fig. 32). Streamflows at all fixed sites generally are largest during this period as a result of runoff from snowmelt events and rainfall events. Because suspended-sediment concentrations are largest when streamflows are largest and because phosphorus sorbs to sediment particles, the large total-phosphorus concentrations during April–June are expected.

Trace Elements

The dissolved trace elements of iron and manganese routinely were analyzed as part of the YELL fixed-site sampling and are discussed in this section of the report. In addition, targeted sampling of selected trace elements was added to address regional issues. Specifically:

- Selected dissolved trace elements were analyzed for sites in the Powder River Basin (site LP and site P) and on the lower mainstem Yellowstone River (site YF and site YS) to augment baseline water-quality data for the lower Yellowstone River Basin;
- Dissolved arsenic was analyzed for sites on the mainstem Yellowstone River (site YCS, site YB, site YF, and site YS) to document the flux of arsenic from YNP; and
- A comprehensive schedule of trace elements was analyzed for site SB where mineralized rocks and past mining activities characterize about one-third of the drainage area upstream from the site.

Concentrations of arsenic, copper, selenium, and zinc are discussed in this report because of their importance to regulatory interests and/or regional issues. Results of trace-element analyses are summarized using descriptive statistics of sample concentrations. Some trace-element concentrations were less than laboratory reporting levels, so statistics of sample concentrations were estimated using robust methods (see “Data-Analysis Methods” section of this report).

Iron and Manganese

Median concentrations of dissolved iron varied among sites (fig. 33). Concentrations of dissolved iron generally were small for the tributary sites, including site SB, site CF, site B, and site T. A large number of samples from site LP and site P were diluted during analysis owing to large dissolved-solids concentrations and, as a result, iron concentrations were reported at a higher reporting level than for samples from the other fixed sites. Median dissolved-iron concentrations generally were low for samples from site YB, site YF, and site YS on the mainstem. For all fixed sites, the median dissolved-iron concentration was largest for samples collected at site YCS (median concentration of 35.4 μg/L, fig. 33). One probable source for the dissolved iron is geothermal water. Ball and others (1998, p. 23) reported concentrations of dissolved iron (Fe(II)) as large as 65,000 μg/L from acidic thermal springs in the basin. Concentrations of dissolved iron in samples from site YCS generally were largest during the months of January–March when streamflows were small and the influence of geothermal waters on stream-water quality would be most substantial. Concentrations of dissolved iron of about 40 μg/L, however, occurred in samples from site YCS collected over a range of streamflows, including the largest streamflows (greater than 15,000 ft^3/sec). Other factors probably contribute to these observed concentrations. For example, at least some of the iron in many of these samples probably is in a colloidal form. Dissolved constituents are defined operationally by the nominal pore size of the filter of 0.45 μm. Some iron colloids are small enough to pass through the filter and be analyzed as part of the dissolved fraction. Also, the bed-sediment iron concentration of a sieved (62 μm) composite sample from site YCS was the largest of the fixed sites sampled during 1998 (Peterson and Boughton, 2000). Large streamflows can suspend bed sediments including colloids, thereby contributing to increased dissolved concentrations.

Concentrations of dissolved manganese range from less than 1 to 350 μg/L for all samples from the fixed sites (fig. 33). The median concentration of dissolved manganese was substantially larger at site LP than at the other fixed sites. Dissolved manganese in samples from site LP tended to be large when streamflows were small, indicating that ground water probably is the source of the manganese. Other streams in northeastern Wyoming have elevated concentrations of dissolved manganese (Swanson and others, 2002), and manganese has been cited as a cause of stream impairment for the area (Wyoming Department of Environmental Quality, 2002). Samples from site CF had the largest median concentration of dissolved manganese of samples from the integrator sites. For samples from the mainstem sites, the median concentration of dissolved manganese, like iron, was largest at site YCS.

Arsenic

The sampling frequency for dissolved arsenic was variable at the fixed sites. Dissolved-arsenic concentrations in stream samples were as large as 41.6 μg/L at site YCS (fig. 33). Median concentrations in samples from the Yellowstone River were 21.0 μg/L at site YCS and 10.5 μg/L at site YB. Although few in number, samples from tributary fixed sites (sites SB, LP, and P) indicate that arsenic concentrations were small or less than reporting levels.

Concentrations of trace elements in natural waters not affected by anthropogenic activities generally are very small (Drever, 1997); however, elevated concentrations of arsenic are common in many geothermal waters (Hem, 1985). In YNP, there are over 10,000 thermal features including more than 300 geysers (Yellowstone National Park, 2001). Concentrations of dissolved arsenic in samples collected at selected sites in the YELL Study Unit indicate that the geothermal waters

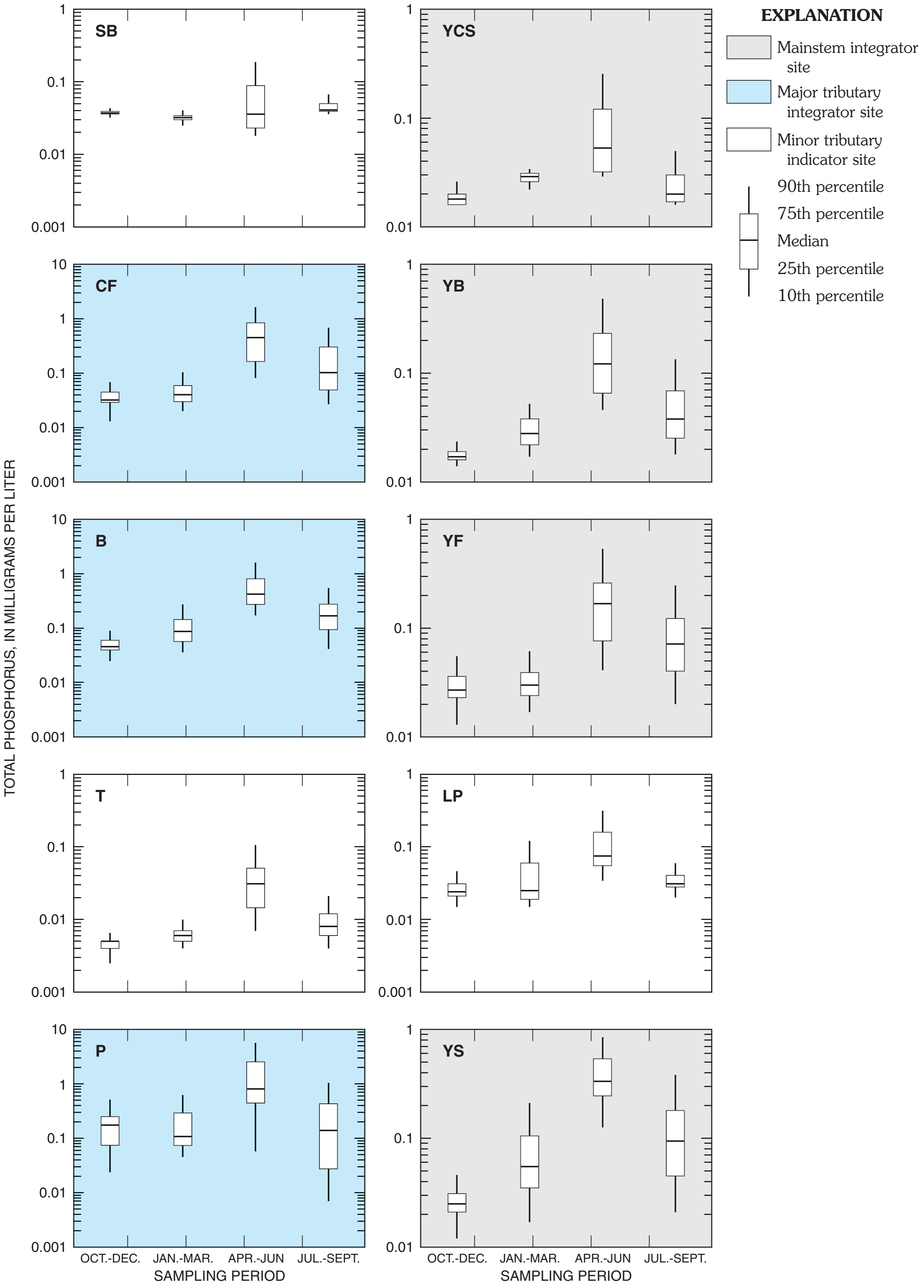


Figure 32. Seasonal statistical summary of LOADEST estimated daily total-phosphorus concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

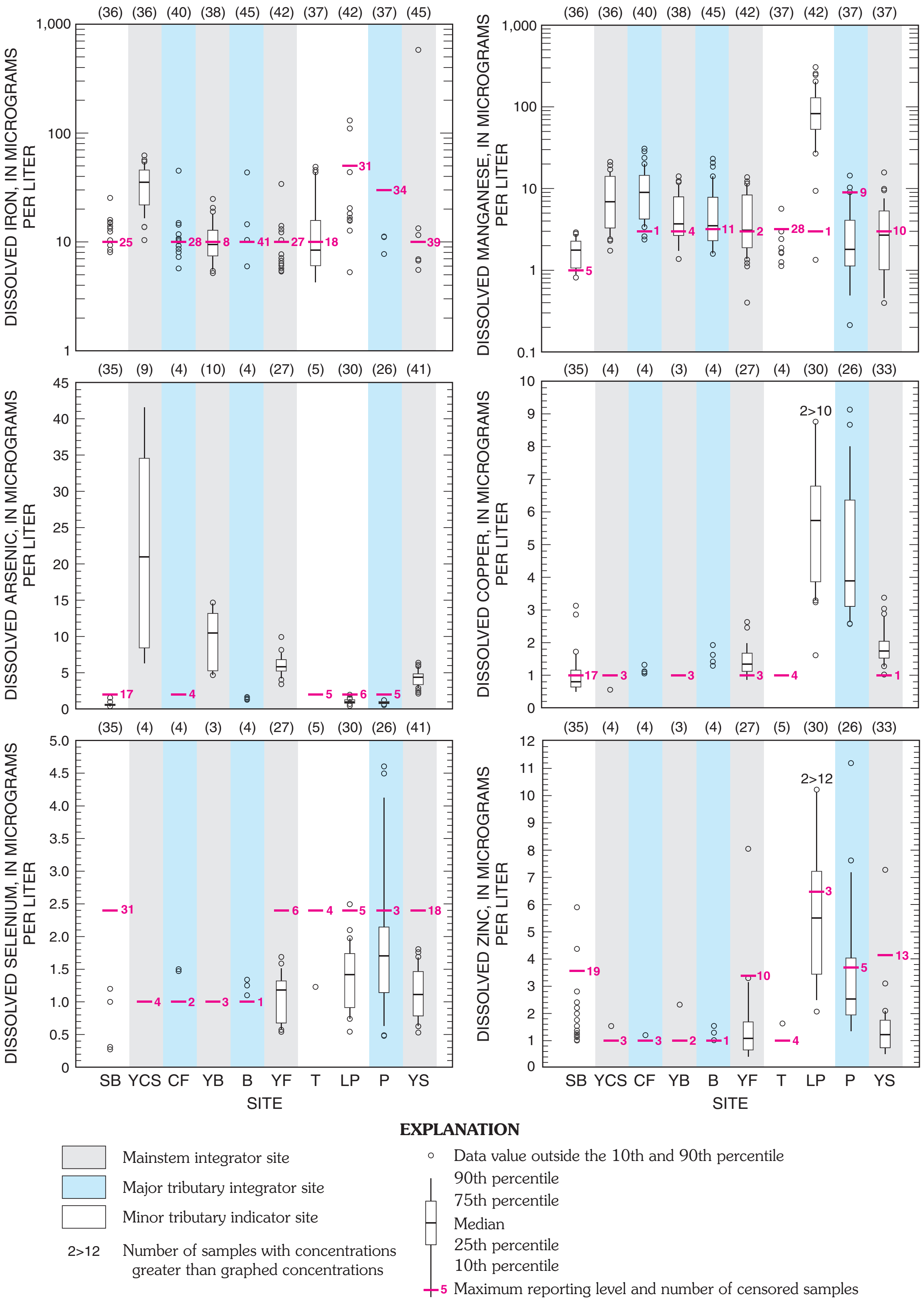


Figure 33. Statistical summary of selected trace-element concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

of YNP are a substantial source of arsenic in the Yellowstone River (fig. 34, site YCS). The largest dissolved-arsenic concentrations in samples from site YCS were observed during low streamflows; small concentrations are the result of dilution from large streamflows. In the oxidizing environment of streams in and around YNP, arsenic—as arsenate—has been shown to be relatively conservative (Stauffer and others, 1980; Nimick and others, 1998). Analyses of arsenic in fine sediments (less than 62 µm) of bed materials for the mainstem indicated a decrease in arsenic concentrations from site YCS to site YS (Peterson and Boughton, 2000, table 8) similar to the decrease observed in stream samples (fig. 33; fig. 34). Because concentrations of arsenic in samples from tributary fixed sites were small or less than reporting levels, downstream decreases in arsenic concentration for the mainstem Yellowstone River probably are a result of dilution from tributary inflows downstream from site YCS.

Copper

Sampling frequency for dissolved copper was variable at the fixed sites. Concentrations of dissolved copper generally were small for samples collected at fixed sites in the YELL (fig. 33). The median concentration of dissolved copper was largest at site LP, the rangeland indicator site. Copper, however, is the most strongly complexed transition element and is often complexed by organic solutes (Drever, 1997, p. 189). Complexation of copper by organic solutes can increase the dissolved concentrations in solution. Large concentrations of DOC at site LP may contribute to dissolved-copper concentrations at that site. Large dissolved-solids and DOC concentrations in samples from site LP indicate that part of the dissolved copper at site LP probably is complexed, which decreases the toxicity of copper to aquatic life.

Elevated concentrations of copper commonly are associated with acid mine drainage (Hem, 1985, p. 141). Mineralized rocks and past mining activities characterize one-third of the drainage area upstream from site SB, and mine tailings were disposed of in-channel upstream from site SB. Earlier studies in and near the Soda Butte Creek drainage basin reported some trace elements, including copper, at concentrations of concern in bed sediment, tissue, and stream samples (Nimmo and Willox, 1996; Peterson and Boughton, 2000; Boughton, 2001). However, large concentrations of dissolved copper were not observed during the fixed-site sampling at site SB. The large concentrations described by some previous investigators were from samples collected at or near obvious sources of trace elements, such as seeps from mine tailings. Copper concentrations in bed sediment and tissue were largest at site SB when compared to concentrations measured at the other nine fixed sites (Peterson and Boughton, 2000).

Selenium

Sampling frequency for dissolved selenium was variable at the fixed sites. Concentrations of dissolved selenium in samples from these sites ranged from less than laboratory reporting levels to 4.6 µg/L (fig. 33). Comparison of discrete concentrations between sites is complicated by multiple laboratory reporting levels. Concentrations of dissolved selenium

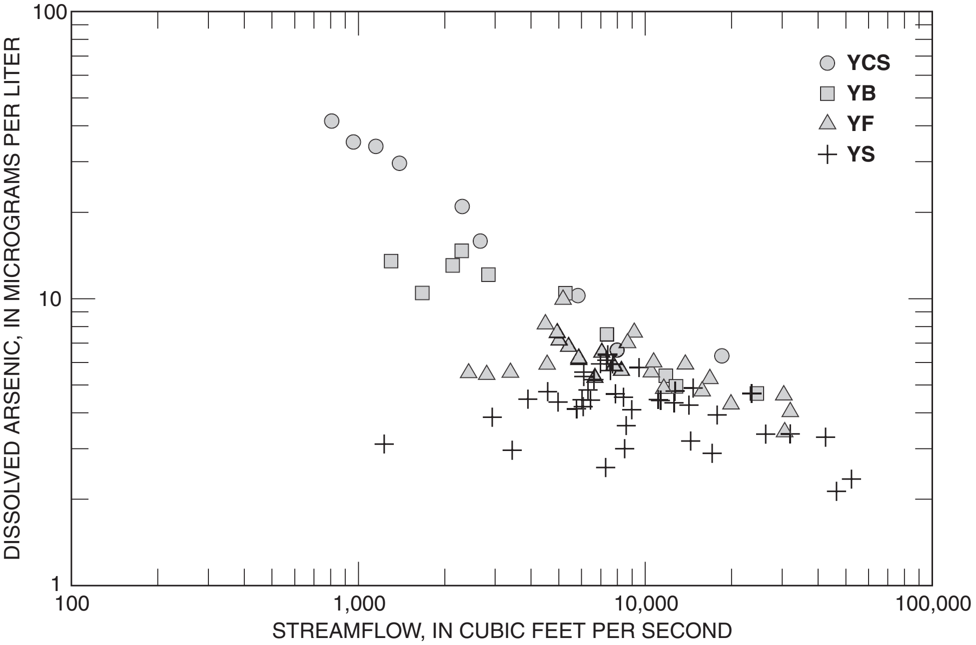


Figure 34. Relation of dissolved-arsenic concentrations and streamflow for fixed sites on the Yellowstone River in the Yellowstone River Basin, 1999-2001.

generally were largest in samples collected at site P, ranging from 0.48 µg/L to 4.6 µg/L. Elevated selenium concentrations are associated with areas underlain by Cretaceous-period rocks, such as parts of the Powder River Basin (U.S. Department of Interior, 1998). Selenium naturally occurs in Cretaceous-period sedimentary rocks of marine origin and the sediment, soils, and other geologic units derived from those rocks. Previous investigations have shown selenium to be very mobile in alkaline soils in the arid regions of the Western United States, and dissolved concentrations may become concentrated in streams draining irrigated lands with those characteristics (U.S. Department of Interior, 1998).

Zinc

Sampling frequency for dissolved zinc was variable at the fixed sites. The median concentration of dissolved zinc was largest in samples collected at site LP. Large DOC concentrations are an important factor in the complexation of zinc by organic solutes (Drever, 1997, p. 110, 188-189). Large concentrations of DOC at site LP may contribute to the dissolved-zinc concentrations at that site. Elevated concentrations of zinc commonly are associated with acid mine drainage (Hem, 1985, pg. 142). Historical mining in the Soda Butte Creek Basin, resulted in exposed mine tailings upstream from the mineral resource area indicator site, site SB; however, large concentrations of dissolved zinc were not observed during the fixed-site sampling at site SB.

Comparison to Water-Quality Criteria

To assess the magnitude of trace-element concentrations for the fixed sites in the YELL, concentrations of iron, manganese, arsenic, copper, selenium, and zinc were compared to water-quality criteria. SMCLs are established for dissolved iron and manganese (U.S. Environmental Protection Agency, 2002d). All of the dissolved-iron concentrations analyzed in samples from the fixed sites were smaller than the SMCL of 300 µg/L, except for one sample from site YS. Concentrations of dissolved manganese in samples from all of the sites, except site LP, were smaller than the SMCL of 50 µg/L. Dissolved-manganese concentrations exceeded the SMCL in about 76 percent of the samples from site LP; however, the Little Powder River is not used for domestic drinking water. The USEPA MCL for dissolved arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2002b). Ingestion of arsenic in water can cause damage to the skin and circulatory systems and may result in increased risk of bladder and lung cancer. Concentrations of arsenic from the Yellowstone River were larger than the MCL in about 75 percent of the samples at site YCS and in more than 50 percent of the samples from site YB. The Yellowstone River is used as a municipal drinking-water supply in this reach, including by the city of Billings, Montana.

Aquatic-life criteria for some trace elements, including copper and zinc, often are expressed as a function of hardness, which is a measure of the amount of calcium and magnesium in water, and are not a single number. Hardness is used as a surrogate for several water-quality characteristics that affect the toxicity of those metals; toxicity of certain metals decreases with increasing hardness (U.S. Environmental Protection Agency, 2002a). Dissolved copper and zinc concentrations in all samples collected at fixed sites were smaller than the chronic aquatic-life criteria. Dissolved-selenium concentrations in all of the samples were smaller than the chronic aquatic-life criterion of 5 µg/L (U.S. Environmental Protection Agency, 2002a); however, concentrations were larger than 2 µg/L in about 31 percent of the samples at site P. Concentrations of total selenium greater than 2 µg/L in water appear to produce adverse effects on some fish and wildlife species (U.S. Department of Interior, 1998, table 32).

Pesticides

Pesticides are used on a regular basis in a variety of agricultural and non-agricultural areas to control nuisance plants and organisms. National pesticide use has increased substantially during the last several decades and, with their increased use, an increase in crop production and control of public health hazards has occurred (Larson and others, 1997). Correspondingly, because of their widespread use, pesticides commonly are detected in streams, raising concerns about the potential adverse effects on human health and aquatic life (Larson and others, 1999). The NAWQA Program has collected thousands of samples to describe the distribution, trends, and governing factors of pesticide occurrence in streams in the United States.

To assess the occurrence of pesticides in the YELL, water samples were collected and analyzed for selected pesticides at five of the fixed sites (site CF, site YB, site B, site YF, and site YS) that have mixed land use. Pesticide samples were collected from January to December 1999 at site CF, site YB, and site B. Samples at site YF and site YS were collected from January 1999 to September 2001. For all sites, at least one sample was collected during each month of the year to address temporal variation in pesticide occurrence.

A GCMS method (Zaugg and others, 1995) was used to analyze for 47 commonly used pesticides, including 26 herbicides, 17 insecticides, and 4 breakdown products, in samples collected from the YELL (table 9). A second analytical method was used to detect additional pesticides in streams but only results for the samples analyzed using the GCMS method are presented in this report because the other analytical method was still under development during the collection of most of the samples. The GCMS method measures pesticides at very small concentrations, often 10 to 1,000 times smaller than the USEPA drinking-water standards and method reporting levels commonly used at other analytical laboratories. The low-level methods are used to detect and evaluate emerging issues, as well as to track contaminant concentrations over time.

Table 9. Trade names, type, reporting levels, drinking-water criteria, and aquatic-life criteria for pesticide compounds analyzed by gas chromatography/mass spectrometry method.

[NWIS, National Water Information System; µg/L, micrograms per liter; --, not available]

NWIS parameter code	Pesticide compound	Trade name	Type	Method reporting level, in µg/L	Other reporting levels used, in µg/L	Drinking-water criteria, in µg/L	Aquatic-life criteria, in µg/L
82660	2,6-Diethylanaline	--	Breakdown product	0.002	0.003	--	--
49260	Acetochlor	Guardian, Relay	Herbicide	.002	.004	--	--
46342	Alachlor	Alanex, Lasso	Herbicide	.002	.004	[1]2	--
34253	*alpha*-HCH	--	Breakdown product	.002	.005	[2]0.06	--
39632	Atrazine	AAtrex	Herbicide	.001	.003, .005, .006	[1]3	[4]1.8
82673	Benfluralin	Balan, Benefin	Herbicide	.002	.01	--	--
04028	Butylate	Sutan+, Genate Plus	Herbicide	.002		[3]400	--
82680	Carbaryl	Carbatox, Sevin	Insecticide	.003	.041	[3]700	[4]0.20
82674	Carbofuran	Furadan	Insecticide	.003	.01, .013, .02, .03	[1]40	[4]1.8
38933	Chlorpyrifos	Dursban, Lorsban	Insecticide	.004	.005	[3]20	[5].041
04041	Cyanazine	Bladex	Herbicide	.004	.018	[3]1	[4]2.0 (interim)
82682	DCPA	Dacthal	Herbicide	.002	.003, .004	[3]70	--
04040	Deethylatrazine	--	Breakdown product	.002	.004, .007	--	--
39572	Diazinon	Basudin, Spectracide	Insecticide	.002	.005	[3].6	[6].08
39381	Dieldrin	Panoram D-31, Octalox	Insecticide	.001	.005	[7].02	[5].056
82677	Disulfoton	Di-Syston	Insecticide	.017	.021	[3].3	--
82668	EPTC	Eptam, Eradicane	Herbicide	.002	.005, .007, .008	--	--
82663	Ethalfluralin	Sonalan	Herbicide	.004	.009	--	--
82672	Ethoprop	Mocap, Prophos	Insecticide	.003	.005	--	--
04095	Fonofos	Dyfonate	Insecticide	.003	--	[3]10	--

Table 9. Trade names, type, reporting levels, drinking-water criteria, and aquatic-life criteria for pesticide compounds analyzed by gas chromatography/mass spectrometry method.—Continued.

NWIS parameter code	Pesticide compound	Trade name	Type	Method reporting level, in µg/L	Other reporting levels used, in µg/L	Drinking-water criteria, in µg/L	Aquatic-life criteria, in µg/L
39341	*gamma*-HCH	Lindane, Isotox	Insecticide	.004		[1].2	[4].01
82666	Linuron	Linurex, Lorox	Herbicide	.002	.035	--	[4]7.0 (interim)
39532	Malathion	Cythion, Malaspray	Insecticide	.005	.027	[3]100	[5].1
82686	Methyl azinphos	Guthion	Insecticide	.001	.050	--	[5].01
82667	Methyl parathion	Penncap-M	Insecticide	.006	.030, .050	[3]2	--
39415	Metolachlor	Bicep, Dual	Herbicide	.002	.004, .005, .013	[3]100	[4]7.8
82630	Metribuzin	Lexone, Sencor	Herbicide	.004	.006	[3]200	[4]1.0 (interim)
82671	Molinate	Hydram, Ordram	Herbicide	0.002	0.004	--	--
82684	Napropamide	Devrinol	Herbicide	.003	.007, .020	--	--
34653	*p,p'*-DDE	--	Breakdown product	.003	.006	[7]1	[5]0.001 (total DDT)
39542	Parathion	Alkron, Bladan	Insecticide	.004	.007	--	[5].013
82669	Pebulate	Tillam	Herbicide	.002	.004, .030	--	--
82683	Pendimethalin	Prowl, Stomp	Herbicide	.004	.010	--	--
82687	*cis*-Permethrin	Ambush	Insecticide	.005	.006	--	--
82664	Phorate	Thimet, Rampart	Insecticide	.002	.011	--	--
04037	Prometon	Pramitol, Gesafram	Herbicide	.02		[3]100	--
82676	Pronamide	Kerb	Herbicide	.003	.004	[3]50	--
04024	Propachlor	Bexton, Ramrod	Herbicide	.007	.010	[3]90	--
82679	Propanil	Stampede	Herbicide	.004	.011	--	--
82685	Propargite	Comite, Omite	Insecticide	.013	.023, .030	--	--
04035	Simazine	Aquazine, Princep	Herbicide	.005	.011	[1]4	[4]10

Table 9. Trade names, type, reporting levels, drinking-water criteria, and aquatic-life criteria for pesticide compounds analyzed by gas chromatography/mass spectrometry method.—Continued.

NWIS parameter code	Pesticide compound	Trade name	Type	Method reporting level, in µg/L	Other reporting levels used, in µg/L	Drinking-water criteria, in µg/L	Aquatic-life criteria, in µg/L
82670	Tebuthiuron	Graslan, Spike	Herbicide	.01	.02, .08	[3]500	[4]1.6 (interim)
82665	Terbacil	Sinbar, Herbicide 732	Herbicide	.007	.034	[3]90	--
82675	Terbufos	Counter, Contraven	Insecticide	.01	.02	[3].9	--
82681	Thiobencarb	Bolero, Saturn	Herbicide	.002	.005	--	--
82678	Triallate	Far-Go, Avadex BW	Herbicide	.001	.002, .003, .005	--	[4].24 (interim)
82661	Trifluralin	Treflan, Trim	Herbicide	.002	.009	[3]5	[4].20

[1] Maximum Contaminant Level, U.S. Environmental Protection Agency (2002d)

[2] Risk-specific dose at 10^{-5} cancer risk, U.S. Environmental Protection Agency (2002f)

[3] Health Advisory level, U.S. Environmental Protection Agency (2002d)

[4] Canadian Council of Ministers of the Environment, 2002

[5] Continuous chronic criteria, U.S. Environmental Protection Agency (2002a)

[6] International Joint Commission United States and Canada (1978)

[7] Risk-specific dose at 10^{-4} cancer risk, U.S. Environmental Protection Agency (2002f)

The method reporting level for each pesticide is included in table 9. For some samples, other reporting levels were used for the analysis because of matrix effects in the sample, instrument performance, or changes in the method reporting level through time. The USEPA MCLs, health advisory levels, risk specific dose at 10^{-4} cancer risk (RSD4) and risk specific dose at 10^{-5} cancer risk (RSD5) for human health, and guidelines for the protection of aquatic life issued by USEPA, Canadian water-quality guidelines, and the International Joint Commission of Canada and the United States, were compiled for the pesticides. These criteria values are presented for assessing the magnitude of a sample concentration for a pesticide but do not necessarily correspond to the water-quality criteria that would be applicable at a site (table 9).

Pesticide Use

The occurrence of pesticides in streams are dependent on many factors, such as the land use and land cover, timing of the application, amount of the pesticide that is applied, soil properties, and the physical and chemical characteristics of each pesticide—such as, the water solubility, persistence, and sorption properties (Larson and others, 1997). The agricultural land covers (including row crops, small grains, pasture or hay, and fallow) and urban land covers (including urban grasses, residential areas, and transportation) combined composed less than 10 percent of the basins of the five fixed sites that were sampled for pesticides in the YELL. However, these agricultural and urban land covers frequently are adjacent to stream corridors in the basins and compose a large percentage of the area on alluvial deposits. Crop types typically grown in the YELL include hay, alfalfa, wheat, oats, barley, sugar beets, beans, and corn (National Agricultural Statistics Service, 2003). The amount of active ingredient applied in the entire YELL for 20 of the 47 pesticides analyzed by the GCMS method used for samples collected in this study (fig. 35) was compiled from crop acreage data from the 1992 Census of Agriculture (U.S. Department of Commerce, 1995).

Frequency of Detections

At least one pesticide was detected in 87 percent of the 136 samples that were collected. The frequency of pesticide detections in samples varied among the sites—about 54 percent of the samples from site YB had a pesticide detection compared to about 95 percent of the samples at site YS. Of the pesticides that were analyzed with the GCMS method, 14 of the 26 herbicides were detected; 5 of the 17 insecticides were detected; and 1 of the 4 breakdown products was detected in the samples (table 10). The number of different pesticides

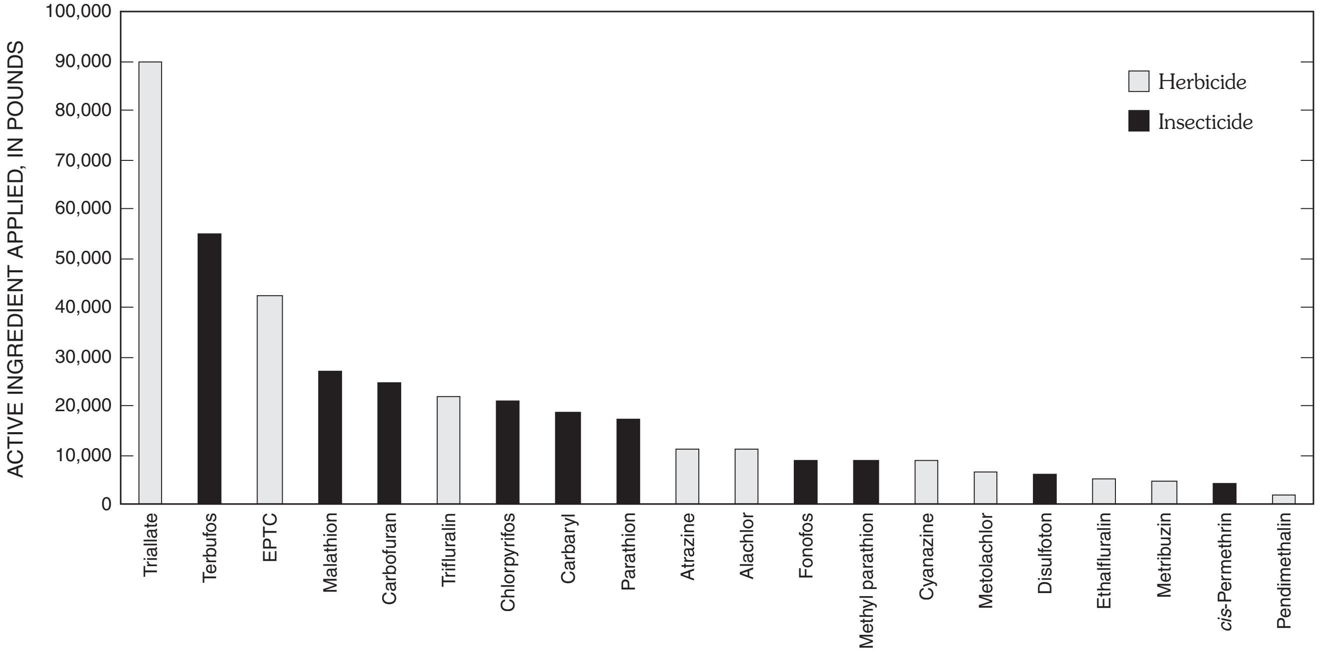


Figure 35. Pesticide use in the Yellowstone River Basin during 1992 (U.S. Department of Commerce, 1995).

detected in samples varied among sites—site YB had the least with 7 different pesticide compounds identified, compared to site B and site YS that had 16 different pesticide compounds detected. Site YS had the highest number of different herbicides detected (11), and site B had the highest number of different insecticides detected (5).

Herbicides frequently were detected in stream samples in the YELL (fig. 36). Atrazine, a selective herbicide generally used in agricultural settings, was the most frequently detected herbicide at each of the fixed sites and was present in 74.8 percent of all samples. Although atrazine was not one of the most frequently applied pesticides in the YELL, it has high potential to move in the hydrologic system because of moderate to high mobility in soils and lengthy half-life (more than 90 days) (Larson and others, 1997). Atrazine also has been determined to move long distances through atmospheric transport processes (Goolsby and others, 1995). The second most frequently detected herbicide was a breakdown product of atrazine, deethylatrazine, which was present in 39.7 percent of all samples. Metolachlor (38.2 percent) and triallate (37.5 percent), which are selective herbicides generally used in agricultural settings (Meister Publishing Company, 2001), also were frequently detected. Like atrazine, metolachlor is commonly detected in streams owing to its large runoff potential (Larson and others, 1997). In contrast, triallate is not readily dissolved in water; however, it is persistent in soil and may become desorbed and leach into water under certain environmental conditions (Cornell University, 2002). The frequent detection of triallate probably is a result of its frequent use in the YELL (fig. 35). Prometon, a nonselective herbicide, was detected in 23.5 percent of the samples (table 10) and is commonly used and detected in urban settings (Barbash and Resek, 1996).

Insecticides were less frequently detected than herbicides in pesticide samples from the five sites in the YELL (fig. 36). Chlorpyrifos was the most commonly detected insecticide and was detected in 5.1 percent of all samples (table 10). The most frequently detected insecticide in samples varied among sites and included carbaryl (6.2 percent) at site CF, carbofuran (7.7 percent) at site YB, malathion (24 percent) at site B, carbofuran (2.4 percent) and chlorpyrifos (2.4 percent) at site YF, and chlorpyrifos (6.8 percent) at site YS (table 10). The occurrences of carbaryl, chlorpyrifos, and malathion in streams have been associated with their use in urban areas (Larson and others, 1999). The frequency of detection of malathion at site B is higher than might be expected from its chemical properties because malathion is known to degrade quickly in soil thereby having a small runoff potential (Larson and others, 1997). The most frequently applied insecticide, terbufos, was detected in less than 1 percent of all samples. The low detection frequency of terbufos is probably due to several factors, including its rapid conversion to its metabolites, low water solubility (Cor-

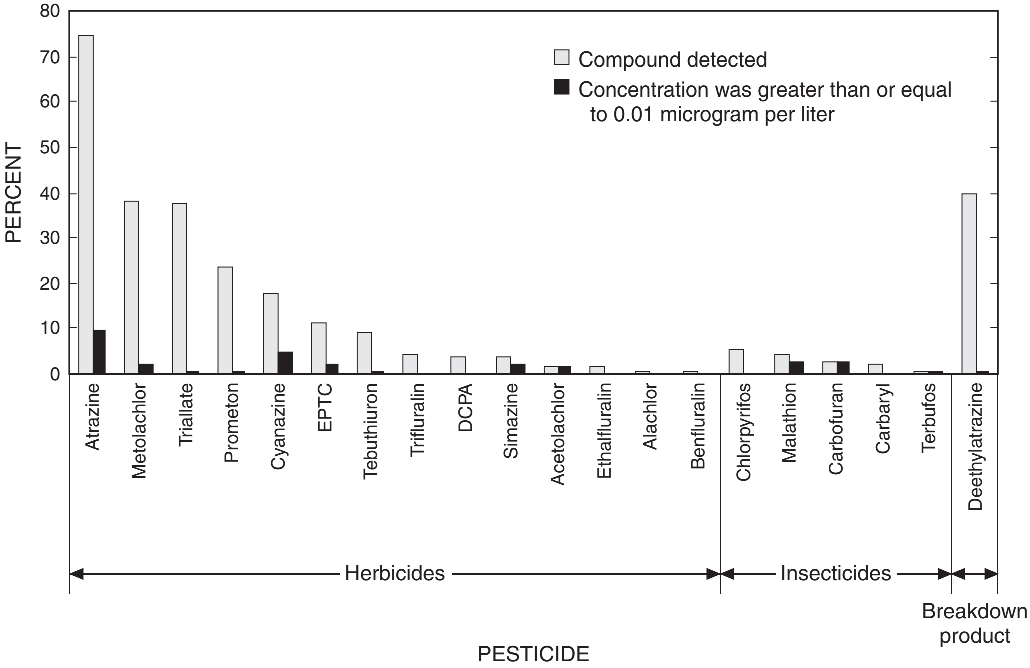


Figure 36. Frequency of pesticide detections for fixed sites in the Yellowstone River Basin, 1999-2001.

nell University, 2002), and a relatively high method reporting level (0.01 µg/L) compared to the other pesticides.

Mixtures of two or more pesticides were detected in 75 percent of the samples. The frequency of occurrence of mixtures of two or more pesticides in samples varied by site. About 38 percent of the samples at site CF had two or more pesticides compared to site YS where over 86 percent of the samples had two or more pesticides detected. Samples containing mixtures of four or more pesticides accounted for about 33 percent of all the samples, including 50 percent of the samples collected at site YS, which integrates all the waters in the basin. One sample from site B contained a mixture of 10 different pesticides, including 8 herbicides, 1 insecticide, and 1 breakdown product.

Although pesticide detections were frequent in stream samples from the YELL, the concentrations of pesticides generally were small. Method reporting levels varied among pesticides, and previous studies have indicated an inverse relation between the method reporting level and pesticide detection frequencies (Barbash and Resek, 1996; Larson and others, 1997). The frequency of detections substantially decreased when an adjusted reporting level of 0.01 µg/L was used (fig. 36, table 10). The reporting level of 0.01 µg/L was selected because this is a reporting level commonly used by other laboratories and other studies for pesticide analyses (Larson and others, 1997). Atrazine was still the most commonly detected herbicide; however, the frequency of detection decreased from 74.8 percent to about 9.6 percent using the adjusted reporting level of 0.01 µg/L. The detection frequency of 9.6 percent for atrazine in samples in the YELL was less than the detection frequency of about 26 percent for atrazine in stream samples from undeveloped sites in the United States compiled for NAWQA with the adjusted reporting level of 0.01 µg/L (U.S. Geological Survey, 2003a). Carbofuran and malathion were the most commonly detected insecticides, with a frequency of detection of about 2.9 percent using the adjusted reporting level. Many of the pesticides that were detected using the lower reporting levels had concentrations less than the adjusted reporting level of 0.01 µg/L, including alachlor, benfluralin, carbaryl, chlorpyrifos, DCPA, ethalfluralin, and trifluralin.

Comparison to Water-Quality Criteria

Drinking-water criteria and aquatic-life criteria are toxicologically derived values that are useful for assessing the magnitude and risk associated with pesticide concentrations in streams. Drinking-water criteria have been established by the USEPA for 27 of the 47 pesticides analyzed by the GCMS method. Concentrations of pesticides were substantially (generally an order of magnitude or more) smaller than drinking-water criteria for human health in all samples collected at fixed sites in the YELL. Aquatic-life criteria, including interim criteria that have been developed by the USEPA, Canada, and the International Joint Commission exist for 19 of the 47 pesticides. Concentrations of pesticides were smaller than aquatic-life criteria in all 136 samples.

Possible risks to humans and aquatic life implied by the NAWQA findings for the 47 pesticides in the YELL remain

Table 10. Statistical summary of detections and concentrations of pesticides for fixed sites in the Yellowstone River Basin, 1999-2001.

[Herbicides are in plain text, insecticides are in bold text, and breakdown products are in italicized text. µg/L, micrograms per liter; --, not applicable; E, estmated; M, compound was identified, but not quantified

Pesticide Compound	Number of samples	Percent of samples, compound identified (number of detections)	Percent of samples, concentration greater than or equal to 0.01 µg/L (number of detections)	Statistical summary of detections		
				Minimum, in µg/L	Median, in µg/L	Maximum, in µg/L
Site CF						
Atrazine	15	40.0(6)	6.7(1)	E0.002	E0.003	0.159
Carbaryl	16	6.2(1)	--	--	--	E.008
DCPA	16	6.2(1)	--	--	--	E.001
Deethylatrazine	16	12.5(2)	6.2(1)	E.005	--	E.019
Ethalfluralin	16	6.2(1)	--	--	--	E.003
Simazine	16	6.2(1)	6.2(1)	--	--	.014
Tebuthiuron	16	6.2(1)	--	--	--	E.01
Triallate	16	25.0(4)	--	E.002	E.003	.004
Trifluralin	16	25.0(4)	--	E.001	E.002	.005
Site YB						
Atrazine	13	38.5(5)	--	E.003	E.003	.008
Carbofuran	13	7.7(1)	7.7(1)	--	--	E.013
Deethylatrazine	13	23.1(3)	--	E.003	E.003	E.004
Metolachlor	13	7.7(1)	--	--	--	E.004
Prometon	13	7.7(1)	--	--	--	M
Simazine	13	7.7(1)	--	--	--	E.003
Triallate	13	23.1(3)	--	E.002	.004	.004
Site B						
Atrazine	21	81.0(17)	--	E.002	.005	.009
Carbaryl	21	4.8(1)	--	--	--	E.004
Carbofuran	21	4.8(1)	4.8(1)	--	--	E.020
Chlorpyrifos	21	14.0(3)	--	E.001	E.003	E.004
Cyanazine	21	19.0(4)	9.5(2)	.006	.009	.14
DCPA	21	9.5(2)	--	E.002	--	E.002
Deethylatrazine	21	43.0(9)	--	E.003	E.004	E.006
EPTC	21	14.0(3)	4.8(1)	E.001	.006	.021
Ethalfluralin	21	4.8(1)	--	--	--	E.002

Table 10. Statistical summary of detections and concentrations of pesticides for fixed sites in the Yellowstone River Basin, 1999-2001.—Continued.

Pesticide Compound	Number of samples	Percent of samples, compound identified (number of detections)	Percent of samples, concentration greater than or equal to 0.01 µg/L (number of detections)	Statistical summary of detections		
				Minimum, in µg/L	Median, in µg/L	Maximum, in µg/L
Site B—Continued						
Malathion	21	24.0(5)	19.0(4)	.006	.012	.025
Metolachlor	21	38.0(8)	4.8(1)	E.002	.004	.019
Prometon	21	29.0(6)	--	M	M	E.01
Tebuthiuron	21	24.0(5)	--	M	E.01	E.01
Terbufos	21	4.8(1)	4.8(1)	--	--	.03
Triallate	21	33.0(7)	--	.001	E.003	.007
Trifluralin	21	4.8(1)	--	--	--	E.002
Site YF						
Atrazine	42	85.7(36)	11.9(5)	E.003	.006	.328
Benfluralin	42	2.4(1)	--	--	--	E.003
Carbofuran	42	2.4(1)	2.4(1)	--	--	E.034
Chlorpyrifos	42	2.4(1)	--	--	--	E.002
Cyanazine	42	23.8(10)	7.1(3)	E.003	E.008	.018
Deethylatrazine	42	40.5(17)	--	M	E0.004	E0.005
EPTC	42	14.3(6)	2.4(1)	E0.001	E.002	.016
Metolachlor	42	40.5(17)	--	E.002	E.004	E.009
Prometon	42	28.6(12)	--	M	M	E.01
Simazine	42	2.4(1)	--	--	--	E.003
Tebuthiuron	42	4.8(2)	--	M	--	E.01
Triallate	42	47.6(20)	2.4(1)	E.001	E.003	.010
Trifluralin	42	2.4(1)	--	--	--	E.002
Site YS						
Acetochlor	44	4.5(2)	4.5(2)	.015	--	.016
Alachlor	44	2.3(1)	--	--	--	E.003
Atrazine	44	84.1(37)	15.9(7)	E.002	.006	.055
Carbaryl	44	2.3(1)	--	--	--	E.005
Carbofuran	44	2.3(1)	2.3(1)	--	--	E.021
Chlorpyrifos	44	6.8(3)	--	E.002	E.002	E.002
Cyanazine	44	22.7(10)	4.5(2)	E.003	E.006	.021

Table 10. Statistical summary of detections and concentrations of pesticides for fixed sites in the Yellowstone River Basin, 1999-2001.—Continued.

Pesticide Compound	Number of samples	Percent of samples, compound identified (number of detections)	Percent of samples, concentration greater than or equal to 0.01 µg/L (number of detections)	Statistical summary of detections		
				Minimum, in µg/L	Median, in µg/L	Maximum, in µg/L
Site YS—Continued						
DCPA	44	4.5(2)	--	E.001	--	E.002
Deethylatrazine	44	52.3(23)	--	E.001	E.004	E.006
EPTC	44	13.6(6)	2.3(1)	E.001	E.004	.010
Malathion	44	2.3(1)	--	--	--	.006
Metolachlor	44	59.1(26)	4.5(2)	M	.005	.017
Prometon	44	29.5(13)	2.3(1)	M	E.01	E.01
Simazine	44	4.5(2)	4.5(2)	.013	--	.014
Tebuthiuron	43	9.3(4)	2.3(1)	M	E.01	.02
Triallate	44	38.6(17)	--	E.001	E.002	.008
All samples						
Acetochlor	136	1.5(2)	1.5(2)	.015	--	.016
Alachlor	136	0.7(1)	--	--	--	E.003
Atrazine	135	74.8(101)	9.6(13)	E.002	E.006	.328
Benfluralin	136	.7(1)	--	--	--	E.003
Carbaryl	136	2.2(3)	--	E.004	E.005	E.008
Carbofuran	136	2.9(4)	2.9(4)	E.013	E.020	E.034
Chlorpyrifos	136	5.1(7)	--	E.001	E.002	E.004
Cyanazine	136	17.6(24)	5.1(7)	E.003	E.007	.021
DCPA	136	3.7(5)	--	E.001	E.002	E.002
Deethylatrazine	136	39.7(54)	0.7(1)	M	E.004	E.019
EPTC	136	11.0(15)	2.2(3)	E.001	E.003	.021
Ethalfluralin	136	1.5(2)	--	E.002	--	E.003
Malathion	136	4.4(6)	2.9(4)	.006	.011	.025
Metolachlor	136	38.2(52)	2.2(3)	M	E.004	.019
Prometon	136	23.5(32)	.7(1)	E.001	E.004	E.011
Simazine	136	3.7(5)	2.2(3)	E.003	.013	.014
Tebuthiuron	135	8.9(12)	.7(1)	M	E.01	.02
Terbufos	136	.7(1)	.7(1)	--	--	.031
Triallate	136	37.5(51)	.7(1)	E.001	E.003	.01
Trifluralin	136	4.4(6)	--	E.001	E.002	.005

unclear, however, because criteria have limitations in their use in evaluating potential risks of pesticides in streams. Criteria have not been established for 20 of the pesticides and breakdown products analyzed for this study, including 5 pesticides (acetochlor, benfluralin, deethylatrazine, EPTC, ethalfluralin) that were detected in stream samples in the YELL. In addition, human-health and aquatic-life criteria generally are established based on toxicity tests conducted for a single compound; however, most of the YELL samples contained two or more compounds. In addition, the aquatic-life criteria do not account for the potential combined effects of pesticides and other stressors, such as temperature fluctuations (Larson and others, 1999).

Temporal Variability

The occurrence of pesticides in streams is related to the time of pesticide application and precipitation or irrigation events. Most pesticides, particularly herbicides, are applied during short seasonal periods; for example, preemergent herbicides are applied just before planting or an insecticide may be applied during a certain period to control a specific pest. The seasonal application of pesticides, followed by the first runoff event from rain or irrigation, is the primary source for pesticide transport to streams (Larson and others, 1997).

The temporal variations of pesticide concentrations were examined using atrazine, the most commonly detected pesticide, in relation to streamflow for site YF and site YS, which were the sites with the most continuous sampling for pesticides (fig. 37). Atrazine generally is applied for early, preplant surface treatments because of operational use limitations for Wyoming and Montana. Atrazine also may be applied to stubble ground after wheat harvest in wheat-corn-fallow crop rotations in the Wyoming part of the basins (U.S. Environmental Protection Agency, 2002e). The largest atrazine concentration (0.328 µg/L) in a single sample occurred during April 1999 at site YF, which may reflect runoff after preplant treatment. Small concentrations during late spring at both sites during 1999 and 2000 probably are caused by dilution during snowmelt runoff. Samples with concentrations larger than 0.01 µg/L generally occurred during April to August, which typically coincides with the growing season. The low-level, but persistent, presence of atrazine during fall and winter months indicates that ground water probably is contributing to concentrations in streams because irrigation has ceased and rainfall runoff events are infrequent. The presence of atrazine in ground water has been reported for the YELL (Eddy-Miller, 1998; Eddy-Miller and Norris, 2001; Peterson and others, 2004).

Suspended Sediment

Suspended-sediment concentrations in streams were analyzed as part of the YELL fixed-site network. Sediments in streams are part of the natural fluvial processes of erosion, transport, and deposition (siltation). As with chemical constituents in streams, however, excessive concentrations of sediment can be cause for concern. These concerns include degradation of water quality and aquatic habitat, and reduction of reservoir capacity. For example, siltation is the leading pollutant in impaired rivers and streams in the United States (U.S. Environmental Protection Agency, 2000a). In addition to siltation, sediment in streams can facilitate the transport of other water-quality degradates, including nutrients, trace elements, and pesticides. Conversely, decreased sediment delivery also can affect aquatic habitat. Diminished sediment transport—either through removal of the sediment source or through reduction of the streamflows transporting the sediment—can result in channel changes including increased aggradation or degradation and changes in particle-size distribution. Decreased suspended sediment can be detrimental to endemic fish; for example, turbid water is believed to be essential habitat for the endangered pallid sturgeon, a species endemic to the YELL (Duffy and others, 1995).

Results of suspended-sediment analyses are summarized in this report using descriptive statistics of sample concentrations. Flow-weighted mean concentrations and estimated total annual loads and yields also are summarized. Yield is the load per unit drainage area upstream from a site. Large reservoirs are sediment sinks where decreased velocities result in settling of particulates and removal of nearly all suspended sediment (Meade and others, 1990, p. 267). Thus, after construction of a large reservoir, that part of the basin upstream from the reservoir does not contribute to the suspended-sediment flux at a site downstream. In this report, yields for the fixed sites were computed using only that part of the basin drainage areas downstream from large reservoirs and reported as reservoir-adjusted yields.

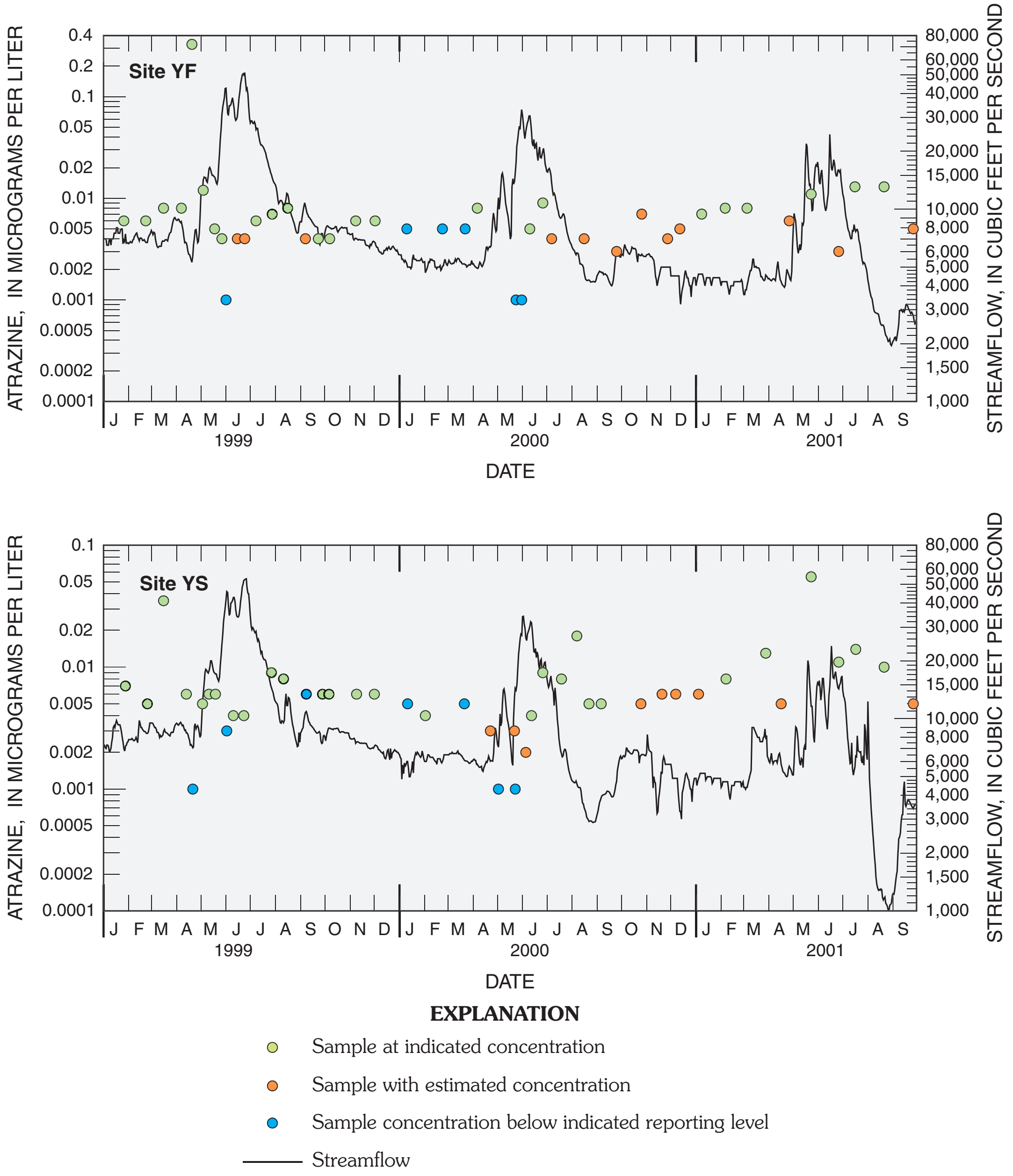


Figure 37. Relation between atrazine concentrations and streamflow for site YF and site YS in the Yellowstone River Basin, 1999-2001.

Concentrations

Median suspended-sediment concentrations in samples from the fixed sites ranged from 2.0 mg/L to 421 mg/L (fig. 38). Suspended-sediment concentrations generally were smallest for the indicator sites in mountainous areas with resistant geology, site SB and site T, and largest for the major tributary integrator site P. On the mainstem Yellowstone River, suspended-sediment concentrations generally increased downstream from site YCS to site YS. The range of suspended-sediment concentrations varied substantially among the fixed sites. The interquartile range (IQR) of concentrations varied from 4 mg/L for site T to 1,490 mg/L for site P.

Flow-weighted mean suspended-sediment concentrations at YELL fixed sites generally increased with increasing drainage area. Base-10 logarithms of flow-weighted mean concentrations and reservoir-adjusted drainage areas (in mi^2) were well correlated (Pearson's r = 0.88, *p*-value = 0.022) for the tributary sites (fig. 39A). Different relations between flow-weighted mean suspended-sediment concentrations and drainage area were observed for the tributary and mainstem sites. Flow-weighted mean suspended-sediment concentrations also increased downstream from site YCS to site YS.

Flow-weighted mean suspended-sediment concentrations were correlated with geologic and soil characteristics. Base-10 logarithms of flow-weighted mean concentrations and the adjusted area of Tertiary-period sedimentary rocks (in mi^2) were well correlated (Pearson's r = 0.94, *p*-value = 0.0048) for the tributary sites (fig. 39B). For the mainstem sites, flow-weighted mean suspended-sediment concentrations generally increased with increasing area of Tertiary-period sedimentary rocks.

Suspended-sediment concentrations also were correlated to soil characteristics. Specifically, soil erodibility is the susceptibility of soil particles to detachment and movement by water. The soil erodibility factor K is used in empirical relations to calculate soil loss by water (U.S. Department of Agriculture, 2000). Basin soil erodibility was determined for the fixed sites using data compiled by Schwarz and Alexander (1995). Base-10 logarithms of flow-weighted mean suspended-sediment concentrations were correlated (all sites: τ = 0.61, *p*-value = 0.02; tributary sites: τ = 0.80, *p*-value = 0.05) with reservoir-adjusted area-weighted mean soil erodibility factor (in percent) (fig. 39C).

Flow-weighted mean suspended-sediment concentrations also were correlated to land-cover characteristics. In general, base-10 logarithms of flow-weighted mean suspended-sediment concentrations were most strongly correlated with increasing reservoir-adjusted rangeland (in percent) (fig. 39D; Pearson's r = 0.88, *p*-value = 0.0008). Geologic characteristics probably are a factor in the positive correlation of suspended-sediment concentrations and rangeland area. Base-10 logarithms of reservoir-adjusted, Tertiary-period sedimentary rocks (in percent) were strongly correlated with reservoir-adjusted rangeland (in percent) (Pearson's r = 0.92, *p*-value = 0.0004).

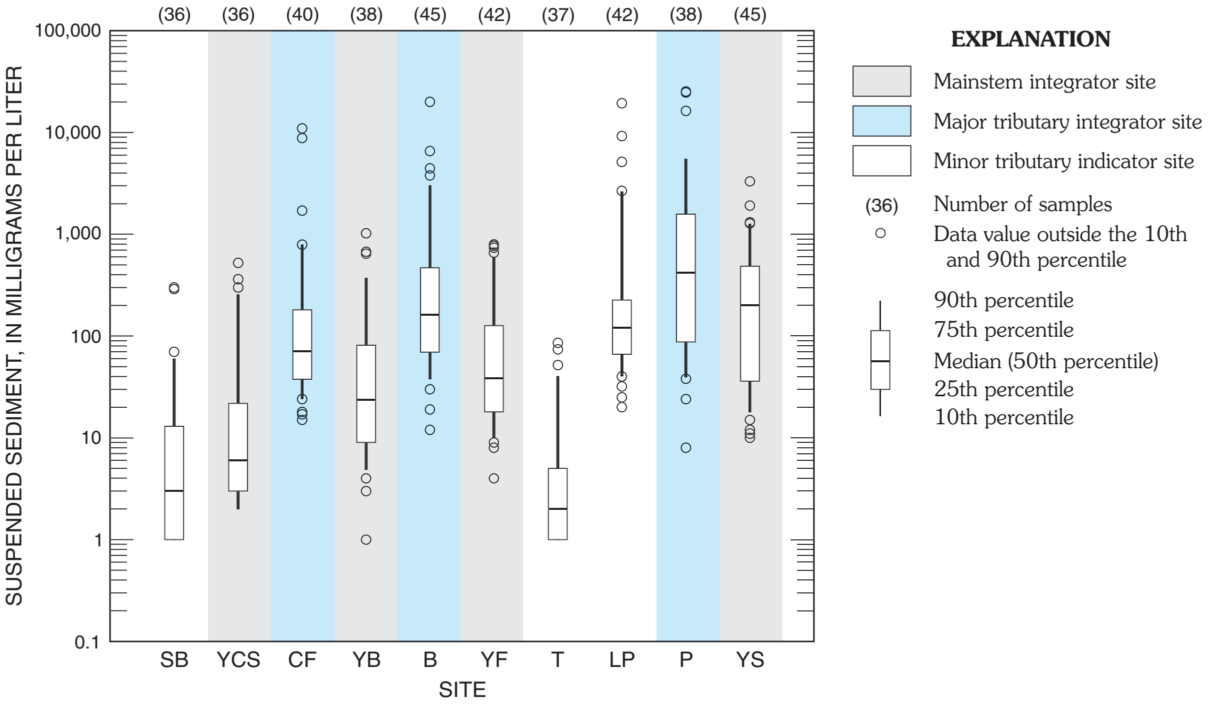


Figure 38. Statistical summary of suspended-sediment concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

Temporal Variability

Estimated daily suspended-sediment concentrations using LOADEST were evaluated by season to assess temporal variations in concentrations for YELL fixed sites. Suspended-sediment concentrations generally were largest during April–June for all fixed sites (fig. 40). Suspended-sediment concentrations were correlated with streamflow. Correlation coefficients (Pearson's r) for base-10 logarithms ranged from 0.62 (site LP) to 0.90 (site YCS) (p-value < 0.0001 all correlations). On average, the largest streamflows of the year occur during April–June, resulting from mountain snowmelt runoff. Similarly, suspended-sediment concentrations were smallest during October–December and January–March when streamflows and sediment inputs are small. During the winter, some of the streams are ice covered, fewer rainstorms result in less overland runoff, and surface irrigation return flows are small to nonexistent. For fixed sites with substantial portions of their drainage area in the plains or basins of the YELL, rainstorms during July–September can result in large streamflows with large suspended-sediment concentrations. During 2000 and 2001, however, precipitation was much lower than normal, resulting in much lower than normal streamflows and possibly lower suspended-sediment concentrations during July–September.

Estimated Loads and Yields

Estimated suspended-sediment loads and yields at YELL fixed sites were computed to describe the sediment flux for streams in the YELL (table 11). Because suspended-sediment load is a function of streamflow and differences in streamflows between the fixed sites are large, differences in suspended-sediment loads between the same fixed sites also are large. For example, average annual suspended-sediment loads for minor tributary indicator sites (site SB, site T, and site LP) are at least an order of magnitude smaller than average annual suspended-sediment loads for major tributary integrator sites (site CF, site B, and site P) and the mainstem integrator sites (site YCS, site YB, site YF, and site YS). Average annual streamflows at site SB, site T, and site LP also are proportionally smaller than streamflows at the other fixed sites. Similarly, on the mainstem Yellowstone River, average annual loads increased downstream with increasing streamflows from site YCS to site YS. For the tributary integrator sites, average annual suspended-sediment loads were similar to the mainstem sites; however, mean annual streamflows were smaller when compared as a group with the mainstem sites (table 2).

Estimated mean annual suspended-sediment yields (table 11) generally decreased with increasing drainage area (table 1) within site groups for the indicator sites and major

Table 11. Estimated water year and average total annual suspended-sediment loads and reservoir-adjusted yields for fixed sites in the Yellowstone River Basin, 1999-2001.

[--, insufficient data.]

Site report identifier (fig. 2)	Estimated total annual load (tons)				Estimated total annual yield (tons per square mile)			
	1999	2000	2001	Average	1999	2000	2001	Average
SB	--	3,600	1,500	[1]2,600	--	130	52	[2]90
YCS	600,000	220,000	62,000	290,000	230	85	24	110
CF	1,400,000	780,000	390,000	840,000	670	380	190	420
YB	1,700,000	870,000	350,000	990,000	150	74	30	84
B	6,500,000	500,000	220,000	2,400,000	810	63	28	300
YF	2,900,000	1,100,000	510,000	1,500,000	140	54	25	73
T	5,500	3,400	470	3,100	27	17	2	15
LP	47,000	2,000	13,000	21,000	38	2	10	17
P	9,100,000	670,000	730,000	3,500,000	690	51	55	270
YS	7,600,000	3,500,000	2,000,000	4,400,000	150	71	40	88

[1] Load is average of water years 2000 and 2001 only.

[2] Yield is average of water years 2000 and 2001 only.

tributary integrator sites. Reservoir-adjusted mean annual suspended-sediment yields were largest for site CF, site B, and site P on major tributaries, which have large drainage areas with mixed geology that includes Tertiary-period sedimentary rocks. Langbein and Schumm (1958) developed an empirical relation between suspended-sediment yield and mean annual precipitation. The result was a relation where sediment yield is a maximum for basins where annual precipitation is between about 10 and 14 inches. For basins receiving less than about 10 inches of precipitation a year, sediment yield is less because of a deficiency of streamflow runoff. For basins receiving more than about 14 inches per year, increased vegetation density limits sediment availability. Estimated mean annual suspended-sediment yields for the YELL fixed sites for the period 1999-2001 were less than would be estimated by the Langbein-Schumm relation (fig. 41A); only site CF was within about one standard deviation (reported as about 30 percent, Langbein and Schumm, 1958, p. 1077) of the relation. Streamflows during water years 2000 and 2001 were smaller than average; thus, estimated annual mean suspended-sediment yields for the period 1999-2001 probably are smaller than average. A comparison of sediment yields for water year 1999 indicated good correlation for site CF, site B, and site P with the Langbein-Schumm relation (fig. 41B).

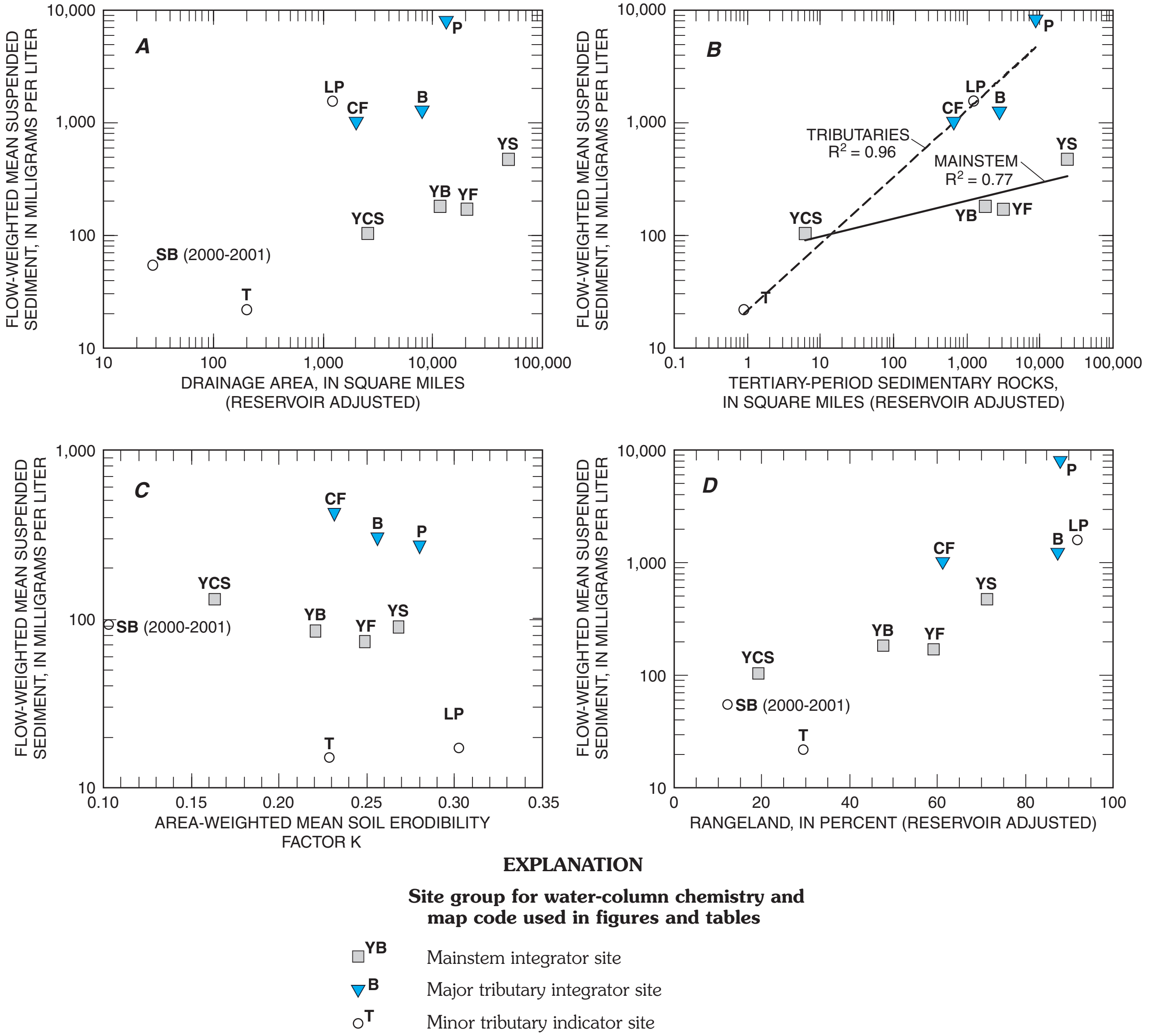


Figure 39. Flow-weighted mean suspended-sediment concentration relation to reservoir-adjusted *A*, drainage area; *B*, Tertiary-period sedimentary rocks; *C*, soil-erodibility factor; and *D*, rangeland for fixed sites in the Yellowstone River Basin, 1999-2001.

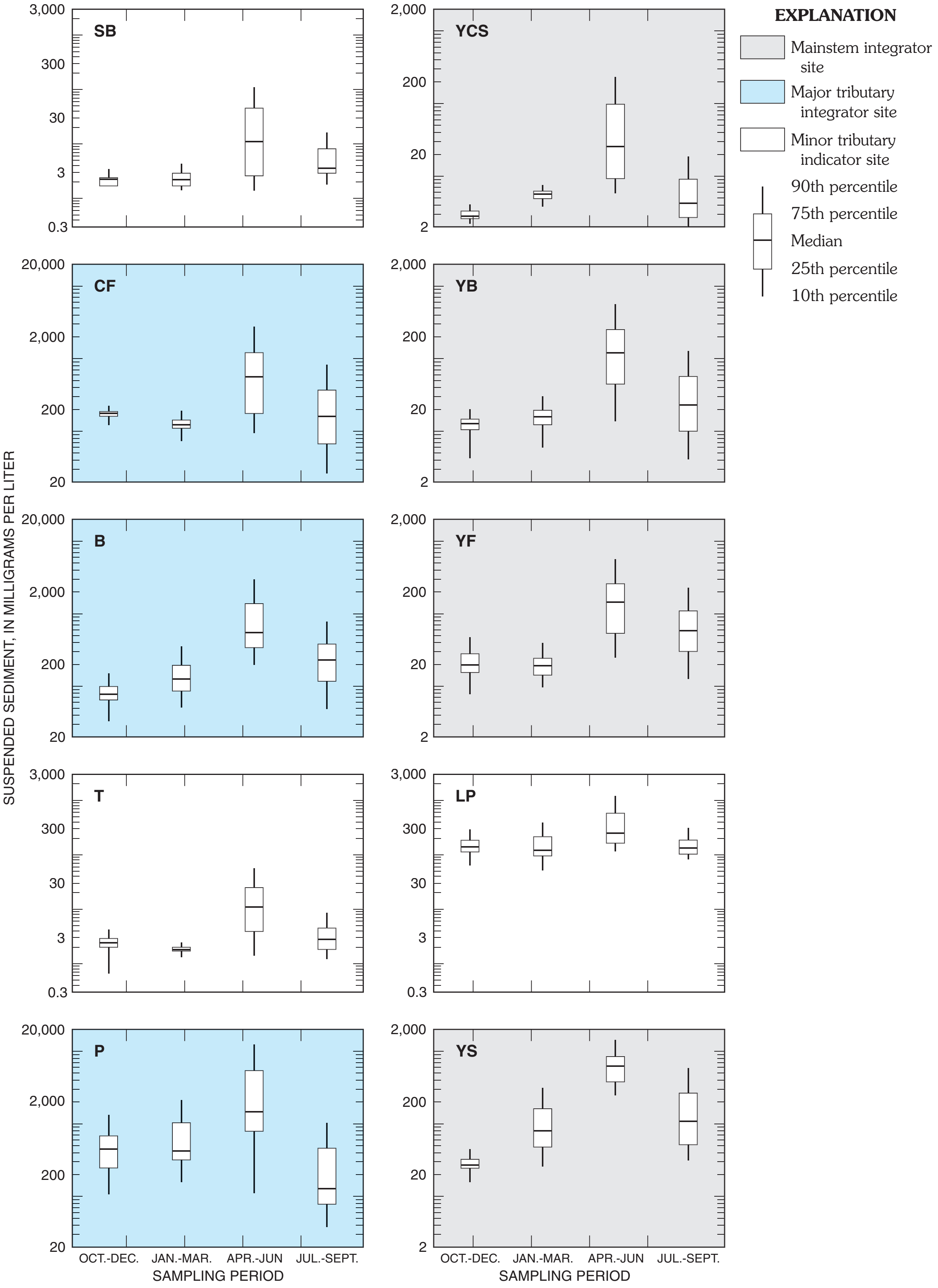


Figure 40. Seasonal statistical summary of LOADEST estimated daily suspended-sediment concentrations for fixed sites in the Yellowstone River Basin, 1999-2001.

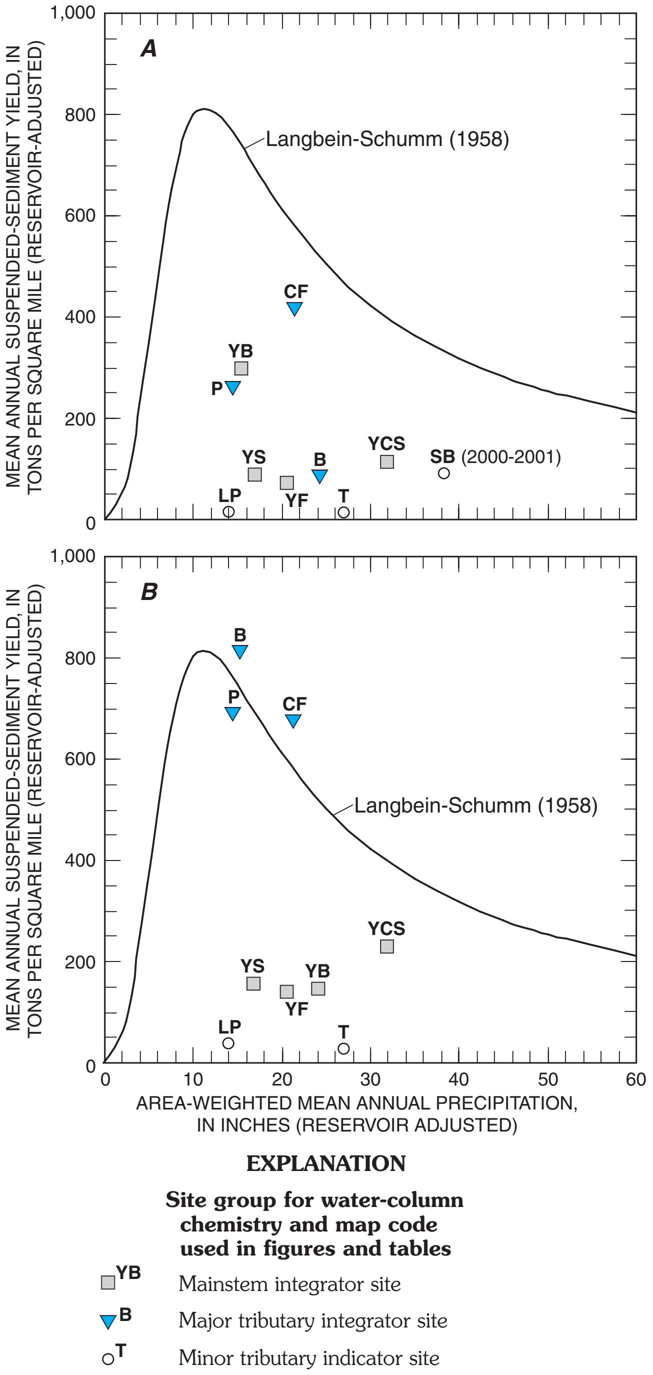


Figure 41. Suspended-sediment yield related to mean annual precipitation for *A*, 1999-2001; and *B*, 1999 for fixed sites in theYellowstone River Basin.

Summary

The National Water-Quality Assessment Program of the U.S. Geological Survey initiated an assessment in 1997 of the quality of water resources in the Yellowstone River Basin. The Yellowstone River Basin has a drainage area of 70,100 square miles and extends from central Wyoming north to include most of southeastern Montana and a small part of western North Dakota. The basin is largely undeveloped; rangelands, which consist of herbaceous grasslands and shrublands, compose about 74 percent of the basin and forested land compose about 14 percent. Agricultural and urban areas compose less than 10 percent of the basin.

Water-quality samples regularly were collected during 1999-2001 at 10 fixed sites on streams representing the major environmental settings of the basin. Integrator sites, which are heterogeneous in land use and geology, were established on the mainstem of the Yellowstone River from Corwin Springs, Montana to Sidney, Montana (4 sites) and on three major tributaries—Clarks Fork Yellowstone River (1 site), the Bighorn River (1 site), and the Powder River (1 site). Indicator sites, which are more homogeneous in land use and geology than the integrator sites, were located on minor tributaries with important environmental settings—Soda Butte Creek in a mineral resource area (1 site), the Tongue River in a forested area (1 site), and the Little Powder River in a rangeland area (1 site). Water-quality sampling frequency generally was at least monthly and sampling included field measurements and laboratory analyses of fecal-indicator bacteria, major ions, dissolved solids, nutrients, trace elements, pesticides, and suspended sediment.

Annual streamflows at all of the sites, except the Little Powder River, are dominated by a snowmelt peak or peaks during late spring through early summer with generally low variability throughout the rest of the year. Streamflows for the Little Powder River are more variable in response to precipitation events. The hydrologic conditions varied during the study period from above average streamflow during water year 1999 to substantially less than average streamflow in response to drought conditions during water years 2000 and 2001.

Median concentrations of fecal coliform and *Escherichia coli* were largest for basins that were predominantly rangeland and smallest for basins that were predominantly forested. Fecal-coliform concentrations exceeded the U.S. Environmental Protection Agency recommended limit for a single sample of 400 colonies per 100 milliliters in 2.6 percent of all samples. *Escherichia coli* concentrations exceeded the U.S. Environmental Protection Agency recommended limit for a single sample of 298 colonies per 100 milliliters for moderate use, full-body contact recreation in 7.6 percent of all samples. *Escherichia coli* concentrations for the rangeland indicator site on the Little Powder River exceeded the U.S. Environmental Protection Agency recommended limit of 298 colonies per 100 milliliters in 27.8 percent of the samples. Concentrations of fecal coliform and *Escherichia coli* significantly varied by season (*p*-value <0.001); the smallest median concentrations were during January–March and the largest median concentrations were during April–June.

Variations in water type in the basin are reflective of the diverse geologic terrain in the Yellowstone River Basin. Water type of the Yellowstone River changed from a mixed-cation bicarbonate type upstream to a mixed-cation sulfate type downstream, where proportionally more of the geology is Tertiary-period sedimentary rocks. The water type of Soda Butte Creek and the Tongue River was calcium bicarbonate. These two sites are in forested and mountainous areas where igneous rocks and Paleozoic-era and Mesozoic-era sedimentary rocks are the dominant geologic groups. The water type of the Little Powder River was sodium sulfate. The Little Powder River originates in the plains and geology of the basin is nearly homogenous with Tertiary-period sedimentary rocks.

Dissolved-solids concentrations ranged from fairly dilute in Soda Butte Creek, which had a median concentration of 118 milligrams per liter, to concentrated in the Little Powder River, which had a median concentration of 2,840 milligrams per liter. Dissolved-solids concentrations at some sites varied by sampling period and annually in response to variations in streamflow. Significant differences in dissolved-solids concentrations by sampling period were determined for sites on Soda Butte Creek, the Yellowstone River (four sites), the Clarks Fork Yellowstone River, and the Tongue River (*p*-values <0.05) as a result of snowmelt runoff. Significant differences in annual dissolved-solids concentrations were determined for sites on the Clarks Fork Yellowstone River; Yellowstone River at Billings, Montana; Bighorn River; and the Powder River (*p*-values <0.05) as a result of annual variations in streamflow.

Nutrient concentrations generally were small and reflect the relatively undeveloped conditions in the basin. Ammonia concentrations generally were largest in samples collected from the Yellowstone River at Corwin Springs, Montana, which is downstream from Yellowstone National Park and receives discharge from geothermal waters that are high in ammonia. Some correlations were made with anthropogenic factors. Median dissolved-nitrate concentrations in all samples from the fixed sites ranged from 0.04 milligram per liter to 0.54 milligram per liter. Flow-weighted mean dissolved-nitrate concentrations were positively correlated with increasing agricultural land use and rangeland on alluvial deposits upstream from the sites and negatively correlated with increasing forested land. Median total-phosphorus concentrations ranged from 0.007 to 0.18 milligram per liter. Median total-phosphorus concentrations exceeded the U.S. Environmental Protection Agency's recommended goal of 0.10 milligram per liter for preventing nuisance plant growth for samples collected from the Bighorn River, Powder River, and Yellowstone River. Total-phosphorus concentrations were positively correlated with sediment concentrations. Sediment derived from sedimentary rocks that are of marine origin probably is the source of the phosphorus.

Seasonal variations were observed in nutrient concentrations. Dissolved-nitrate concentrations generally were largest during October to March when plant uptake of nitrate is lowest. In contrast, total-phosphorus concentrations were largest during April–June when sediment concentrations, which contribute to the total-phosphorus concentrations, are largest.

Concentrations of trace elements generally were small in samples for sites in the Yellowstone River Basin. Soda Butte Creek, which is in a mineral resource area with historical mining in the basin upstream from the sampling site, did not have elevated concentrations of trace elements compared to other sites. On the Yellowstone River, median concentrations of dissolved arsenic of 21 micrograms per liter at Corwin Springs, Montana, and 10.5 micrograms per liter at Billings, Montana, exceeded the drinking-water Maximum Contaminant Level of 10 micrograms per liter. Geothermal waters from Yellowstone National Park are a significant source of arsenic in the Yellowstone River; dissolved-arsenic concentrations decreased in the downstream direction. Concentrations of dissolved selenium were largest in the Powder River, ranging from 0.48 microgram per liter to 4.6 micrograms per liter. Concentrations were smaller than the chronic aquatic-life criterion of 5 micrograms per liter; however, other studies have shown that concentrations of total selenium larger than 2 micrograms per liter may produce adverse effects on some fish and wildlife species.

Pesticide concentrations generally were small for three sites on the Yellowstone River, one site on the Clarks Fork Yellowstone River, and one site on the Bighorn River. Herbicides were more frequently detected than insecticides. Atrazine was the most commonly detected herbicide and was detected in 74.8 percent of all samples. The second most frequently detected herbicide was a breakdown product of atrazine, deethylatrazine, which was present in 39.7 percent of all samples. Chlorpyrifos was the most commonly detected insecticide and was detected in 5.1 percent of all samples. Concentrations of all compounds generally were smaller than 0.01 microgram per liter and substantially smaller than aquatic-life or human-health criteria. Mixtures of two or more pesticides were detected in 75 percent of the samples.

Suspended-sediment concentrations were seasonally variable and were largest during April–June during snowmelt runoff. Suspended-sediment concentrations were smallest for the fixed sites on Soda Butte Creek and the Tongue River because of the resistant geology in the mountainous settings. Reservoir-adjusted yields were largest for the Clarks Fork Yellowstone River, Bighorn River, and the Powder River, which have large drainage areas with mixed geology that includes Tertiary-period sedimentary rocks. On the Yellowstone River, suspended-sediment loads increased in the downstream direction.

References

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Associated Press, 2001a, Yellowstone Park reports sewage spill: Billings Gazette, June 7, 2001, accessed Mar. 15, 2003, at URL *http://www.billingsgazette.com/index.php?display=rednews/2001/06/07/build/wyoming/sewage.inc*

Associated Press, 2001b, Yellowstone suffers new sewage spill: Billings Gazette, November 27, 2001, accessed Mar. 15, 2003, at URL *http://www.billingsgazette.com/index.php?display=rednews/2001/11/27/build/wyoming/10sewage.inc*

Ball, J.W., Nordstrom, D.K., Cunningham, K.M., Schoonen, M.A.A., Xu, Yong., and DeMonge, J.M., 1998 (revised and reprinted, April 2001), Water-chemistry and on-site sulfur-speciation data for selected springs in Yellowstone National Park, Wyoming, 1994-1995: U.S. Geological Survey Open-File Report 98-574, 35 p. (also accessible on the World Wide Web at URL *http://wwwbrr.cr.usgs.gov/projects/GWC_chemtherm/pubs/ofr%2098-574.pdf*).

Barbash, J.E., and Resek, E.A., 1996, Pesticides in ground water—Distribution, trends, and governing factors: Chelsea, Mich., Ann Arbor Press, Pesticides in the Hydrologic System series, v. 2, 588 p.

Barbe´, D.E. and Francis, J.C., 1995, An analysis of seasonal fecal coliform levels in the Tchefuncte River: Water Resources Bulletin, v. 31 no. 1, p. 141-146.

Bartos, T.T., and Ogle, K.M., 2002, Water quality and environmental isotopic analyses of ground-water samples collected from the Wasatch and Fort Union Formations in areas of coalbed methane development—Implications to recharge and ground-water flow, eastern Powder River Basin, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 02-4045, 88 p.

Boughton, G.K., 2001, Metal loading in Soda Butte Creek upstream of Yellowstone National Park, Montana and Wyoming—A retrospective analysis of previous research; and quantification of metal loading, August 1999: U.S. Geological Survey Water-Resources Investigations Report 01-4170, 68 p.

Bryan, Michelle, and Kakuk, Michael, 1997, A guide to Montana water quality regulation: Environmental Quality Council, Legislative Environmental Policy Office, and Montana State University, Montana University System Water Center, April 18, 1997, 35 p.

Cabelli, V.J., 1977, Indicators of recreational water quality, in Hoadley, A.W., and Dutka, B.J., eds., Bacterial indicators/health hazards associated with water, 1977: American Society for Testing and Materials, ASTM STP 635, p. 222-238.

Canadian Council of Ministers of the Environment, 2002, Canadian Environmental Quality Guidelines, Summary Table, 2002, accessed Jan. 16, 2003, at URL h*ttp://www.ccme.ca/assets/pdf/e1_06.pdf*

Clark, G.M., Mueller, D.K., and Mast, M.A., 2000, Nutrient concentrations and yields in undeveloped stream basins of the United States: Journal of the American Water Resources Association, v. 35, no. 4, p. 849-860.

Clark, M.L., Miller, K.A., and Brooks, M.H., 2001, U.S. Geological Survey monitoring of Powder River Basin stream-water quantity and quality: U.S. Geological Survey Water-Resources Investigations Report 01-4279, 8 p. (also available on the World Wide Web at URL *http://water.usgs.gov/pubs/wri/wri014279/*).

Clark, M.L., and Gamper, M.E., 2003, A synoptic study of fecal-indicator bacteria in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000: U.S. Geological Survey Water-Resources Investigations Report 03-4055, 43 p.

Cohn, T.A., Delong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937-942.

Colby, B.R., Hembree, C.H., and Rainwater, F.H., 1956, Sedimentation and chemical quality of surface waters in the Wind River Basin, Wyoming: U.S. Geological Survey Water-Supply Paper 1373, 336 p.

Cornell University, 2002: Pesticide Management Education Program, digital data: accessed Dec. 5, 2002, at URL *http://pmep.cce.cornell.edu/profiles/index.html*

Cox, E.R., 1973, Water resources of Yellowstone National Park, Wyoming, Montana, and Idaho: U.S. Geological Survey Open-File Report, 161 p.

Crawford, C.G., 1991, Estimation of suspended-sediment rating curves and mean suspended-sediment loads: Journal of Hydrology, v. 129, p. 331-348.

Daly, C., Neilson, R.P., and Phillips, D.L., 1994, A statistical-topographic model for mapping climatological precipitation over mountainous terrain: Journal of Applied Meteorology, v. 33, p. 140-158.

Drever, J.I., 1997, The geochemistry of natural waters—surface and groundwater environments (3d ed.): Prentice Hall, Upper Saddle River, N.J., 436 p.

Duffy, W.G., Berry, C.R., and Keenlyne, K.D., 1995, The pallid sturgeon—Biology and annotated bibliography through 1994, Technical Bulletin 5, South Dakota Cooperative Fish and Wildlife Research Unit, South Dakota State University, Brookings, South Dakota, 32 p., accessed Aug. 22, 2003, at URL *http://infolink.cr.usgs.gov/Science/Pallid_Sturgeon/Pallid%20Sturgeon.pdf*

Dufour, A.P., 1977, *Escherichia coli*—the fecal coliform, in Hoadley, A.W. and Dutka, B.J., eds., Bacterial indicators/health hazards associated with water, 1977: American Society for Testing and Materials, ASTM STP 635, p. 48-58.

Dufour, A.P., 1984, Health effects criteria for fresh recreational waters: Cincinnati, Ohio, U.S. Environmental Protection Agency, Toxicology and Microbiology Division, EPA 600/1-84-044, 33 p.

Eddy-Miller, C.A., 1998, Pesticides in ground water —Park County, Wyoming, 1997: U.S. Geological Survey Fact Sheet 097-98, 4 p.

Eddy-Miller, C.A., and Norris, J.R., 2001, Pesticides in ground water —Sheridan County, Wyoming, 1999-2000: U.S. Geological Survey Fact Sheet 123-01, 4 p.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 188 p.

Elder, J. F., 1987, Indicator bacteria concentrations as affected by hydrologic variables in the Apalachicola River, Florida: Water, Air, and Soil Pollution, v. 32, p. 407-416.

Elliott, J.E., 1979, Geologic map of the southwest part of the Cooke City quadrangle, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigation Map I-1084, 1 sheet, scale 1:24,000.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

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

Fuhrer, G.J., Gilliom, R.J., Hamilton, P.A., Morace, J.L., Nowell, L.H., Rinella, J.F., Stoner, J.D., and Wentz, D.A., 1999, The quality of our Nation's waters—Nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Goolsby, D.A., Scribner, E.A., Thurman, E.M., Pomes, M.L., and Meyer, M.T., 1995, Data on selected herbicides and two triazine metabolites in precipitation of the Midwestern and Northeastern United States, 1990-91: U.S. Geological Survey Open-File Report 95-469, 341 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Heffern, E.L., and Coates, D.A., 1997, Clinker—its occurrence, uses, and effects on coal mining in the Powder River Basin, in Jones, R.W. and Harris, R.E., eds., Proceedings of the 32nd Annual Forum on the Geology of Industrial Minerals: Wyoming State Geological Survey Public Information Circular No. 38, p. 151-165.

Heffern, E.L., and Coates, D.A., 1999, Hydrogeology and ecology of clinker in the Powder River Basin, Wyoming and Montana, in Miller, W.R., ed., Coalbed methane and Tertiary geology of the Powder River Basin: Wyoming Geological Association Guidebook, 50th Annual Field Conference, 1999, p. 231-252.

Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: Water Resources Research, v. 24, p. 1997-2004.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier Science Publishers, 522 p.

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

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Horowitz, A.J., Demas C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94-539, 57 p.

Horton, T.W., Chamberlain, C.P., Fantle, Matt, and Blum, J.D., 1999, Chemical weathering and lithologic controls of water chemistry in a high-elevation river system: Clark's Fork of the Yellowstone River, Wyoming and Montana: Water Resources Research, v. 35, no. 5, p. 1643-1655.

Hunter, Colin, McDonald, Adrian, and Beven, Keith, 1992, Input of fecal coliform bacteria to an upland stream channel in the Yorkshire Dales: Water Resources Research, v. 28, no. 7, p. 1869-1876.

Insightful Corp., 2002, S-PLUS 6 for Windows, Guide to Statistics, Volume 1: Seattle, Wash., 712 p.

Interagency Coordinating Council, 2003, National Wild and Scenic Rivers System: accessed Apr. 15, 2003, at URL *http://www.nps.gov/rivers/*

International Joint Commission United States and Canada, 1978, Great Lakes Water Quality Agreement of 1978, as amended by Protocol signed November 18, 1987, Annex Ió Specific objectives: International Joint Commission United States and Canada, accessed Nov. 18, 2002 at URL *http://www.ijc.org/rel/agree/quality.html*

Jones, S.R., and Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of arsenic and selenium in water and sediment by graphite furnace-atomic absorption spectrometry: U.S. Geological Survey Open-File Report 98-639, 39 p.

Knapton, J.R., and Bahls, L.L., 1993, Montana stream water quality, in Paulson, R.W., Chase, E.B., Williams, J.S., and Moody, D.W., comp., National water summary 1990-91, Hydrologic events and stream water quality: U.S. Geological Survey Water-Supply Paper 2400, p. 361-370.

Lambing, J.H., and Dodge, K.A., 1993, Quality assurance for laboratory analysis of suspended-sediment analysis samples by the U.S. Geological Survey in Montana: U.S. Geological Survey Open File Report 93-131, 34 p.

Langbein, W.B., and Schumm, S.A., 1958, Yield of sediment in relation to mean annual precipitation: Transactions, American Geophysical Union, v. 39, p. 1076-1084.

Larson, S.J., Capel, P.D., and Majewski, M.S., 1997, Pesticides in surface waters-distribution, trends, and governing factors: Chelsea, Mich., Ann Arbor Press, Pesticides in the Hydrologic System series, v. 3, 373 p.

Larson, S.J., Gilliom, R.J., and Capel, P.D., 1999, Pesticides in streams of the United States—initial results from the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98-4222, 91 p.

Lindner-Lunsford, J.B., Parrett, Charles, Wilson, J.F. Jr., and Eddy-Miller, C.A., 1992, Chemical quality of surface water and mathematical simulation of the surface-water system, Powder River drainage basin, northeastern Wyoming and southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 91-4199, 85 p.

Love, J.D., and Good, J.M., 1970, Hydrocarbons in thermal areas, northwestern Wyoming: U.S. Geological Survey Professional Paper 644-B, 23 p.

Lowry, M.E., and Rankl, J.G., 1987, Hydrology of the White Tail Butte area, northern Campbell County, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 82-4117, 47 p.

McKelvey, V.E., Cathcart, J.B., Altschuler, Z.S., Swanson, R.W., and Buck, K.L., 1953, Domestic phosphate desposits, in Pierre, W.H., and Norman, A.G., eds., Agronomy—A series of monographs, Volume IV—Soil and fertilizer phosphorus in crop nutrition: New York, Academic Press, Inc., p. 347-376.

McLain, Betty, 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of chromium in water by graphite furnace atomic absorption spectrophotometry: U.S. Geological Survey Open-File Report 93-449, 16 p.

Meade, R.H., Yuzyk, R.T., and Day, T.J., 1990, Movement and storage of sediment in rivers of the United States and Canada, in Wolman, M.G., and Riggs, H.C., eds., Surface water hydrology, The Geology of North America, v. O-1: Boulder, Colo., Geological Society of America, p. 255-280.

Meister Publishing Company, 2001, Farm chemicals handbook 2002: Willoughby, Ohio, Meister Publishing Company, v. 88 [variously paged].

Metesh, John, English, Alan, Lonn, Jeff, Kendy, Eloise, and Parrett, Charles, 1999, Hydrogeology of the upper Sode Butte Creek Basin, Montana: Billings, Mont., Montana Bureau of Mines and Geology, 66 p., 1 sheet.

Miller, K.A., 1999, Surface water, in Zelt, R.B., and others, Environmental setting of the Yellowstone River basin, Montana, North Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 98-4269, p. 31-46 (also available on the World Wide Web at URL *http://water.usgs.gov/pubs/wri/wri984269/surwater.html*).

Miller, Kirk, and Quinn, Tom, 1997, National water-quality assessment program—Yellowstone River Basin: U.S. Geological Survey Fact Sheet 149-97, 4 p. (also available on the World Wide Web at URL *http://water.usgs.gov/pubs/FS/FS-149-97/*).

Montana Department of Environmental Quality, 2002a, Administrative rules of Montana—Title 17, chapter 30, water quality, sub-chapter 6, surface-water quality standards and procedures, September 30, 2002, 52 p. accessed Mar. 16, 2003, at URL *http://www.deq.state.mt.us/dir/Legal/Chapters/CH30-06.pdf*

Montana Department of Environmental Quality, 2002b, 2002 303(d) list: accessed Mar. 16, 2003, at URL *http://nris.state.mt.us/wis/environet/2002_303dhome.html*

Mueller, D.K., Martin, J.D., and Lopes, T.J., 1997, Quality-control design for surface-water sampling in the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-223, 17 p.

Myers, D.M., and Sylvester, M.A., 1997, Biological indicators, fecal indicator bacteria, national field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7.1 [variously paged].

Myers, D.N., and Wilde F.D., 1997, Biological indicators, national field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water Resources Investigations, book 9, chap A7, 38 p.

National Agricultural Statistics Service, 2003: digital data, accessed Apr. 2, 2002, at URL *http://www.nass.usda.gov/*

Nimick, D.A., Moore, J.N., Dalby, C.E., and Savka, M.W., 1998, The fate of geothermal arsenic in the Madison and Missouri Rivers, Montana and Wyoming: Water Resources Research, v. 34, no. 11, p. 3051-3067.

Nimmo, D.R., and Willox, M.J., 1996, Seasonal liabilities from the McLaren tailings on aquatic resources in Soda Butte Creek and Yellowstone National Park, *in* Nelson, J.D., and others, eds., Proceedings of the Third Interagency Conference on Tailings and Mine Waste, Fort Collins, Colorado: Rotterdam, The Netherlands, Balkema Publishing, p. 415-420.

Nolan, B.T., and Hitt, K.J., 2003, Nutrients in shallow ground waters beneath relatively undeveloped areas in the conterminous United States: U.S. Geological Survey Water-Resources Investigations Report 02-4289, 17 p.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118-125, scale 1:7,500,000.

Oregon Climate Service, 1998, Western U.S. average monthly precipitation, 1961-90: Corvallis, Oregon State University, Oregon Climate Service, digital data, accessed Nov. 25, 2001, at URL *http://www.ocs.orst.edu/prism/state_products/west_maps.html*

Parker, F.W., 1953, Phosphorus status and requirements of soils in the United States, in Pierre, W.H., and Norman, A.G., eds., Agronomy—A series of monographs, Volume IV—Soil and fertilizer phosphorus in crop nutrition: New York, Academic Press, Inc., p. 401-426.

Patton, C.J., and Truitt, E.P., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion: U.S. Geological Survey Open-File Report 00-170, 31 p.

Peterson, D.A., 1993, Wyoming stream water quality, in Paulson, R.W., Chase, E.B., Williams, J.S., and Moody, D.W., comp., National water summary 1990-91, Hydrologic events and stream water quality: U.S. Geological Survey Water-Supply Paper 2400, p. 569-576.

Peterson, D.A., and Boughton, G.K., 2000, Organic compounds and trace elements in fish tissue and bed sediment from streams in the Yellowstone River Basin, Montana and Wyoming, 1998: U.S. Geological Survey Water-Resources Investigations Report 00-4190, 39 p.

Peterson, D.A., Miller, K.A., Bartos, T.T., Clark, M.L., Porter, S.D., and Quinn, T.L., 2004, Water-quality in the Yellowstone River Basin, Montana, Wyoming, and North Dakota, 1999-2001: U.S. Geological Survey Circular 1234, 34 p.

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water analyses: American Geophysical Union Transactions, v. 25, p. 914-923.

Schwarz, G.E., and Alexander, R.B, 1995, State Soil Geographic (STATSGO) Data Base for the Conterminous United States: U.S. Geological Survey Open-File Report 95-449, digital map, scale 1:250,000, accessed Nov. 25, 2001, at URL *http://water.usgs.gov/lookup/getspatial?ussoils*

Shacklette, H.T., and Boerngen, J.G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Shelton, L.R., 1997, Field guide for collecting samples for analysis of volatile organic compounds in stream water for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-401, 14 p.

Shields, R.R., White, M.K., Ladd, P.B., Chambers, C.L., and Dodge, K.A., 2001, Water resources data, Montana, water year 2001: U.S. Geological Survey Water-Data Report MT-01-1, 672 p.

Sorey, M.L., Colvard, E.M., Nimick, D.A., Shields, R.R., Thordsen, J.J., and Ambats, G., 1991, Hydrologic investigations in the Corwin Springs Known Geothermal Resources Area and adjacent parts of Yellowstone National Park, *in* Sorey, M.L., ed., Effects of potential geothermal development in the Corwin Springs Known Geothermal Resources Area, Montana, on the thermal features of Yellowstone National Park: U.S. Geological Survey Water-Resources Investigations Report 91-4052, chap. G, 41 p.

Stauffer, R.E., Jenne, E.A., and Ball, J.W., 1980, Chemical studies of selected trace elements in hot-spring drainages of Yellowstone National Park—Geohydrology of geothermal systems: U.S. Geological Survey Professional Paper 1044-F, 20 p.

Stednick, J.D., 1991, Wildland Water Quality Sampling and Analysis: San Diego, Academic Press, Inc., Harcourt Brace Jovanovich, Publishers, 217 p.

Stephenson, G.R., and Street, L.V., 1978, Bacterial variations in streams from a southwest Idaho rangeland watershed: Journal of Environmental Quality, v. 7, no. 1, p 150-157.

Stevens, H.H. Jr, and Ficke, J.F., and Smoot, G.F., 1975, Water temperature—influential factors, field measurement, and data presentation: U.S Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D1, 65 p.

Stiff, H.A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

Swanson, R.B., Smalley, M.L., Woodruff, R.E., and Clark, M.L., 2000, Water resources data, Wyoming, water year 1999, Volume 1—Surface-water data: U.S. Geological Survey Water Data Report WY-99-1, 484 p.

Swanson, R.B., Smalley, M.L., Woodruff, R.E., and Clark, M.L., 2001, Water resources data, Wyoming, water year 2000, Volume 1—Surface-water data: U.S. Geological Survey Water Data Report WY-00-1, 525 p.

Swanson, R.B., Woodruff, R.E., Laidlaw, G.A., Watson, K.R., and Clark, M.L., 2002, Water resources data, Wyoming, water year 2001, Volume 1—Surface-water data: U.S. Geological Survey Water Data Report WY-01-1, 518 p.

U.S. Bureau of Land Management, 2002, Surface and mineral status (ownership) for Wyoming: U.S. Bureau of Land Management, Wyoming State Office, accessed Mar. 7, 2003, at URL *http://www.wy.blm.gov/gis/plssgis.html*

U.S. Census Bureau, 2000, Census 2000 redistricting data (Public Law 94-171) summary file: U.S. Census Bureau, accessed Mar. 3, 2003 at URL *http://quickfacts.census.gov/cgi-bin/state_QuickLinks?30000*

U.S. Department of Agriculture, 2000, Summary Report, 1997 National Resources Inventory (revised December 2000): Natural Resources Conservation Service, Washington, D.C., and Statistical Laboratory, Iowa State University, Ames, Iowa, 89 p., accessed Sept. 2, 2003, at URL *http://www.nrcs.usda.gov/technical/nri/1997/summary_report/glossary.html*

U.S. Department of Commerce, 1995, 1992 Census of agriculture, Geographic area series 1A, U.S. summary state data file, and cross-tab data file: U.S. Department of Commerce, Bureau of the Census, Data User Services Division, CD-AG-92-1C [CD-ROM, dBase format].

U.S. Department of the Interior, 1998, Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment—Selenium: U.S. Department of Interior, National Irrigation Water Quality Program, Information Report no. 3, p. 139-184, accessed Jan. 3, 2003, at URL *http://www.usbr.gov/niwqp/guidelines/Selenium.pdf*

U.S. Environmental Protection Agency, 1976, Quality criteria for water: Washington, D.C., U.S. Environmental Protection Agency, Office of Water Planning and Standards, EPA 440/9-76/023, 537 p.

U.S. Environmental Protection Agency, 1986a, Ambient water quality criteria for bacteria—1986: Washington, D.C., U.S. Environmental Protection Agency, Office of Water Regulations and Standards Division, EPA 440/5-84-002, 18 p.

U.S. Environmental Protection Agency, 1986b, Quality criteria for water—1986: Washington, D.C., U.S. Environmental Protection Agency, EPA 440/5-86-001, unnumbered pages.

U.S. Environmental Protection Agency, 1996, Level III ecoregions of the continental United States (revision of Omernik, 1987): Corvallis, Oreg., U.S. Environmental Protection Agency, digital map, scale 1:250,000.

U.S. Environmental Protection Agency, 1999, 1999 update of ambient water quality criteria for ammonia: U.S. Environmental Protection Agency, Office of Water, EPA-822-R-99-014, 147 p., accessed Apr. 1, 2003, at URL *http://www.epa.gov/waterscience/standards/ammonia/99update.pdf*

U.S. Environmental Protection Agency, 2000a, National water-quality inventory—1998 report to Congress: U.S. Environmental Protection Agency, Office of Water, EPA841-F-00-006, accessed Mar. 7, 2003, at URL *http://www.epa.gov/305b/98report/*

U.S. Environmental Protection Agency, 2000b, Ambient water quality recommendations—Information supporting the development of State and Tribal nutrient criteria, rivers and streams in Nutrient Ecoregion II: U.S. Environmental Protection Agency, Office of Water, EPA 822-B-00-015, December 2000, 39 p., 3 appendix, accessed May 2, 2003, at URL *http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_2.pdf*

U.S. Environmental Protection Agency, 2000c, Ambient water quality recommendations—Information supporting the development of State and Tribal nutrient criteria, rivers and streams in Nutrient Ecoregion III: U.S. Environmental Protection Agency, Office of Water, EPA 822-B-00-016, December 2000, 33 p., 3 appendix, accessed May 2, 2003, at URL *http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_3.pdf*

U.S. Environmental Protection Agency, 2001, Ambient water quality recommendations—Information supporting the development of State and Tribal nutrient criteria, rivers and streams in Nutrient Ecoregion IV: U.S. Environmental Protection Agency, Office of Water, EPA 822-B-00-013, December 2001, 31 p., 3 appendix, accessed May 2, 2003, at URL *http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_4.pdf*

U.S. Environmental Protection Agency, 2002a, National recommended water quality criteria, 2002: Washington, D.C., U.S. Environmental Protection Agency, Office of Water and Office of Science and Technology, EPA-822-R-02-047, 36 p., accessed Jan. 3, 2003, at URL *http://www.epa.gov/waterscience/pc/revcom.pdf*

U.S. Environmental Protection Agency, 2002b, Implementation guidance for the Arsenic Rule—Drinking water regulations for arsenic and clarifications to compliance and new source contaminants monitoring: U.S. Environmental Protection Agency, Office of Water, EPA-816-K-02-018, Final Guidance, August 2002 [variously paged], accessed May 3, 2003, at URL *http://www.epa.gov/safewater/ars/pdfs/regguide/ars_final_!mainguide_9-13.pdf*

U.S. Environmental Protection Agency, 2002c, Implementation guidance for ambient water quality criteria for bacteria, May 2002 draft: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 823-B-02-003, 90 p.

U.S. Environmental Protection Agency, 2002d, 2002 Edition of the Drinking Water Standards and Health Advisories: U.S. Environmental Protection Agency, Office of Water, EPA-822-R-02-038, Summer 2002, accessed Jan. 16, 2003, at URL *http://www.epa.gov/ost/drinking/standards/* and URL *http://www.epa.gov/waterscience/drinking/standards/dwstandards.pdf*

U.S. Environmental Protection Agency, 2002e, digital data: accessed Dec. 18,2002, at URL *http://www.epa.gov/pesticides/reregistration/atrazine/chem_chap.pdf*

U.S. Environmental Protection Agency, 2002f, Integrated Risk Information System (IRIS) database: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, accessed March 2002, at URL *http://www.epa.gov/iris*

U.S. Forest Service, 2003, New World Mining District Response and Restoration Project: U.S. Department of Agriculture, U.S. Forest Service, Gallatin National Forest, accessed Mar. 7, 2003, at URL *http://www.maximtechnologies.com/newworld/index.htm*

U.S. Geological Survey, 1992, National Land Cover Dataset (NLCD): Sioux Falls, South Dakota, U.S. Geological Survey digital data, accessed Mar. 14, 2003, at URL *http://landcover.usgs.gov/natllandcover.asp*

U.S. Geological Survey, 1997, USGS drinking water initiative: U.S. Geological Survey Fact Sheet FS-047-97, 2 p. (also available on the World Wide Web at URL *http://water.usgs.gov/pubs/FS/FS-047-97/index.html*).

U.S. Geological Survey, 1997 to 2004, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, 2 v.[variously paged], (also available on the World Wide Web at URL *http://pubs.water.usgs.gov/twri9A*. Chapters originally were published from 1997-1999; updates and revisions are ongoing and are summarized at URL *http://water.usgs.gov/owq/FieldManual/mastererrata.html*).

U.S. Geological Survey, 1999, National Elevation Database (NED): Sioux Falls, South Dakota, U.S. Geological Survey digital data.

U.S. Geological Survey, 2003a, Pesticides in streams—summary statistics; preliminary results from cycle I of the National Water Quality Assessment Program (NAWQA), 1992-2001: U.S. Geological Survey, data available on the World Wide Web, accessed Feb. 18, 2004, at URL *http://ca.water.usgs.gov/pnsp/pestsw/Pest-SW_2001_Text.html*

U.S. Geological Survey, 2003b, Yellowstone Volcano Observatory—Monitoring the largest volcanic system in North America: U.S. Geological Survey, Yellowstone Volcano Observatory: accessed Apr. 15, 2003, at URL *http://volcanoes.usgs.gov/yvo/*

Ward, J.R., and Harr, C.A., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analysis: U.S. Geological Survey Open-File Report 90-140, 71 p.

Wyoming Department of Environmental Quality, 1998, 1998 305(b) water quality assessment: Wyoming Department of Environmental Quality, Water Quality Division, October 1998 [variously paged].

Wyoming Department of Environmental Quality, 2001a, Wyoming surface water classification list: Wyoming Department of Environmental Quality, Water Quality Division, Surface Water Standards, June 21, 2001 [variously paged], accessed Mar. 13, 2003, at URL *http://deq.state.wy.us/wqd/surfacestandards/Downloads/2-3648-doc.pdf*

Wyoming Department of Environmental Quality, 2001b, Water quality rules and regulations, Chapter 1, Wyoming surface water quality standards: Wyoming Department of Environmental Quality, Water Quality Division, June 21, 2001 [variously paged], accessed May 3, 2003, at URL *http://deq.state.wy.us/wqd/surfacestandards/Downloads/11567-doc.pdf*

Wyoming Department of Environmental Quality, 2002, 2002 305(b) Water quality assessment: Wyoming Department of Environmental Quality, Water Quality Division [variously paged].

Yellowstone National Park, 1995, 1988 Fire Perimeter Map of Yellowstone National Park, Wyoming, Montana, Idaho: Spatial Analysis Center, Yellowstone National Park, digital map, accessed Mar. 3, 2003, at URL *http://www.nps.gov/gis/metadata/yell/yell_fire88perim.html*

Yellowstone National Park, 2001, Yellowstone National Park Facts: Yellowstone National Park, accessed Mar. 15, 2003, at URL *http://www.nps.gov/yell/technical/yellfact.htm*

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey 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.

Zelt, R.B., Boughton, G.K., Miller, K.A., Mason, J.P., and Gianakos, L.M., 1999, Environmental setting of the Yellowstone River Basin, Montana, North Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 98-4269, 112 p.

Miller and others—**Water-Quality Assessment of the Yellowstone River Basin, Montana and Wyoming—Water Quality of Fixed Sites, 1999-2001**—SIR 2004-5113

125 years of
science
for America

1879–2004

Printed on recycled paper