

Water Quality in the Yellowstone River Basin

Wyoming, Montana, and North Dakota, 1999–2001



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Front cover: Aerial image of Yellowstone River and Emigrant Peak in Paradise Valley, near Livingston, Mont. (*used with permission from Larry Mayer, larrymayer.com*).

Back cover: Left, hydrologist in field vehicle, filtering water samples for analysis of organic compounds (*photograph by Gregory K. Boughton, USGS*); right, scientist collecting a depth- and width-integrated sample from the Bighorn River near Greybull, Wyo. (*photograph by Nate Majerus, USGS*).

Water Quality in the Yellowstone River Basin, Wyoming, Montana, and North Dakota, 1999–2001

By David A. Peterson, Kirk A. Miller, Timothy T. Bartos, Melanie L. Clark,
Stephen D. Porter, and Thomas L. Quinn

Circular 1234

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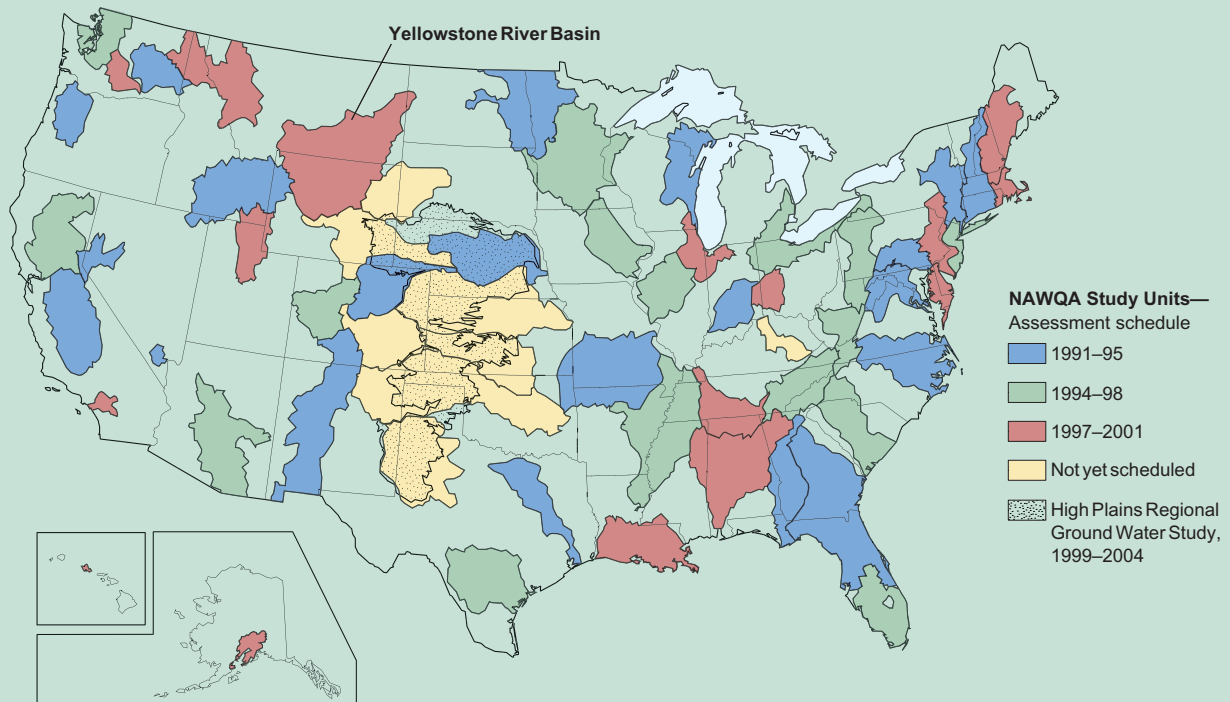
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National Water-Quality Assessment Program

The quality of the Nation's water resources is integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and also suitable for industry, irrigation, and habitat for fish and wildlife. Recognizing the need for long-term, nationwide assessments of water resources, the U.S. Congress has appropriated funds since 1991 for the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Scientists in the NAWQA Program work with partners in government, research, and public interest groups to assess the status and spatial extent of water-quality conditions, how water quality changes with time, and how human activities and natural factors affect water quality. This information is useful for guiding water-management and protection strategies, research, and monitoring in different hydrologic and land-use settings across the Nation.



The Yellowstone River Basin is one of 51 water-quality assessments initiated since 1991. Together, the 51 major river basins and aquifer systems, referred to as “Study Units,” include water resources used by more than 60 percent of the population in watersheds that cover about half of the land areas of the conterminous United States. Timing of the assessments varies because of the Program’s rotational design, in which one-third of all Study Units are intensively investigated for 3 to 4 years, with trends assessed every 10 years. As indicated on the map, the Yellowstone River Basin is part of the third set of intensive investigations, which began in 1997.

What kind of water-quality information does the NAWQA Program provide?

Water-quality assessments by a single program cannot possibly address all of the Nation's water-resources needs and issues. Therefore, it is necessary to define the context within which NAWQA information is most useful.

- **Total resource assessment**—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- **Source-water characterization**—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards, guidelines for the protection of aquatic life, and health advisories as a way to characterize the resource.
- **Compounds studied**—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA Web site at <http://water.usgs.gov/nawqa>.
- **Detection compared to risk**—Compounds are measured at very low concentrations, often 10 to 100 times lower than Federal or State standards and health advisories. Detection of compounds, therefore, does not necessarily translate to risks to human health or aquatic life. However, these analyses are useful for identifying and evaluating emerging issues, as well as for tracking contaminant levels over time.
- **Multiple scales**—Assessments are guided by a nationally consistent study design and uniform methods of sampling and analysis. Findings thereby pertain not only to water quality of a particular stream or aquifer, but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent, multiscale approach helps to determine if a water-quality issue is isolated or pervasive. It also allows direct comparisons of how human activities and natural processes affect water quality in the Nation's diverse environmental settings.

Introduction to this Report

“The Yellowstone River Basin NAWQA program has been beneficial to the State of Wyoming, particularly to the Department of Environmental Quality’s water-quality monitoring and assessment efforts.

“The ecological, bacteria, water-quality, and streamflow data collected have provided DEQ with the ability to assess the water quality much more comprehensively than what would be possible with DEQ data alone.”

Jeremy Zumberge, Monitoring Program Supervisor, Wyoming Department of Environmental Quality

“Information provided by the Yellowstone NAWQA project has been very useful to our program. The Yellowstone River periphyton study results are a fundamental aspect of DEQ’s fish and aquatic life use impairment determinations and a foundation for nutrient total maximum daily loads (TMDL) development.

“NAWQA Powder River data have been a critical part of trend analysis work. Without that data, we would have had very little recent information.”

Pat Newby, Water Quality Specialist, Montana Department of Environmental Quality

This report contains the major findings of a 1999–2001 assessment of water quality in the Yellowstone River Basin. It is one of a series of reports by the National Water-Quality Assessment (NAWQA) Program that present major findings in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is discussed in terms of local, State, and regional issues. Conditions in a particular basin or aquifer system are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

This report is intended for individuals working with water-resource issues in Federal, State, or local agencies, universities, public interest groups, or in the private sector. The information will be useful in addressing a number of current issues, such as the effects of agricultural and urban land use on water quality, human health, drinking water, source-water protection, hypoxia and excessive growth of algae and plants, pesticide registration, and monitoring and sampling strategies. This report also is for individuals who wish to know more about the quality of streams and ground water in areas near where they live, and how that water quality compares to the quality of water in other areas across the Nation.

The water-quality conditions in the Yellowstone River Basin summarized in this report are discussed in detail in other reports that can be accessed from <http://wy.water.usgs.gov/YELL/index.htm>. Detailed technical information, data and analyses, collection and analytical methodology, models, graphs, and maps that support the findings presented in this report, in addition to reports in this series from other basins, can be accessed from the national NAWQA Web site (<http://water.usgs.gov/nawqa>).



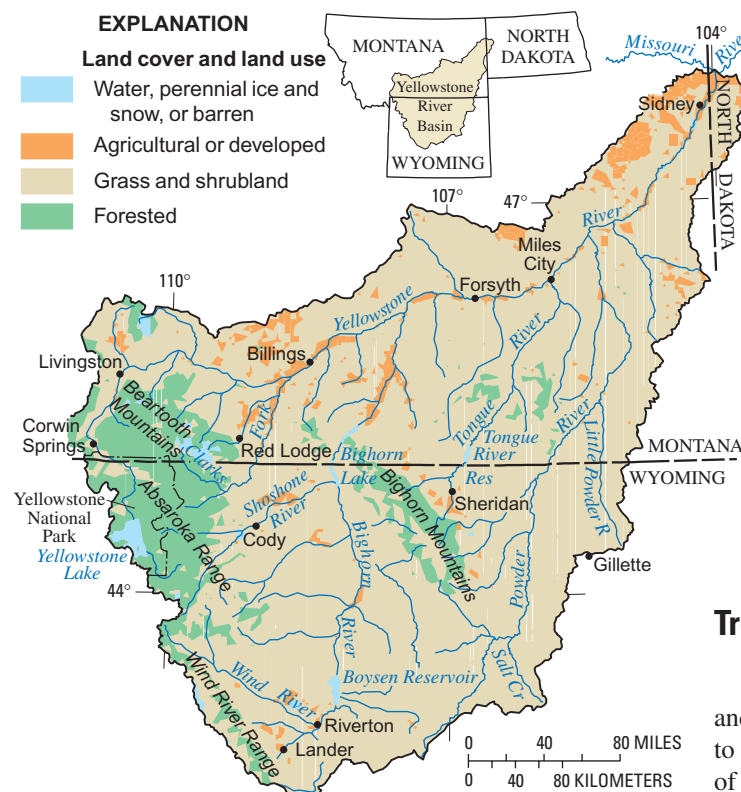
Yellowstone Lake in Yellowstone National Park
(photograph by Gregory K. Boughton, U.S. Geological Survey).

Summary of Major Findings

Stream and River Highlights

The water quality of streams in the Yellowstone River Basin largely is influenced by natural factors. Factors such as geology and climate can cause concentrations of dissolved solids, nutrients, and trace elements in streams to exceed guidelines for protection of human health and aquatic life. Although human activities also can influence concentrations of those same water-quality characteristics, concentrations of manufactured compounds such as pesticides generally were low in streams, fish tissue, and bed sediment compared to levels measured in other NAWQA Program studies across the Nation. Human activities also can influence concentrations of bacteria and aquatic biological communities.

- Concentrations of fecal coliform bacteria and *Escherichia coli*, which are indicators of fecal matter from warm-blooded animals, were higher in urban and agricultural streams than in forested or rangeland streams. Almost 40 percent of bacteria concentrations exceeded the Federal recreational criterion for moderate use (p. 7).



The Yellowstone River Basin covers 70,000 square miles in Wyoming, Montana, and North Dakota. Population in the basin is about 320,000; most communities are along river valleys in the plains. Ninety-eight percent of the water used in the basin is for irrigated crops. Ground water for domestic use in rural areas typically comes from shallow wells completed in Quaternary and Tertiary aquifers.

- Concentrations of total phosphorus in streams in the basins and plains, such as the Clarks Fork Yellowstone, Little Powder, and Powder Rivers, were elevated compared to those measured in other streams across the Nation, due in part to natural sources (p. 12). Phosphorus concentrations at most sampling sites exceeded the Federal goal of 0.1 milligram per liter for minimizing nuisance plant growth in flowing waters.
- Herbicides and their breakdown products were detected frequently in streams, but at low concentrations compared to national levels (p. 15). Organochlorine compounds were detected in many fish tissue samples and in one bed-sediment sample; concentrations generally were less than guidelines for the protection of wildlife (p. 16).
- Concentrations of trace elements in surface and ground water generally were less than guidelines for human health, but concentrations of selenium in some water samples indicated possible adverse effects to biota. Trace-element concentrations in bed sediment from mineralized areas (rock formations with high concentrations of minerals and trace elements) exceeded background levels and were large enough to possibly affect aquatic life (p. 18).
- Biological communities are degraded in some segments of the Yellowstone River. Algal, invertebrate, and fish communities in the segments near Billings and Forsyth were most affected (p. 20).

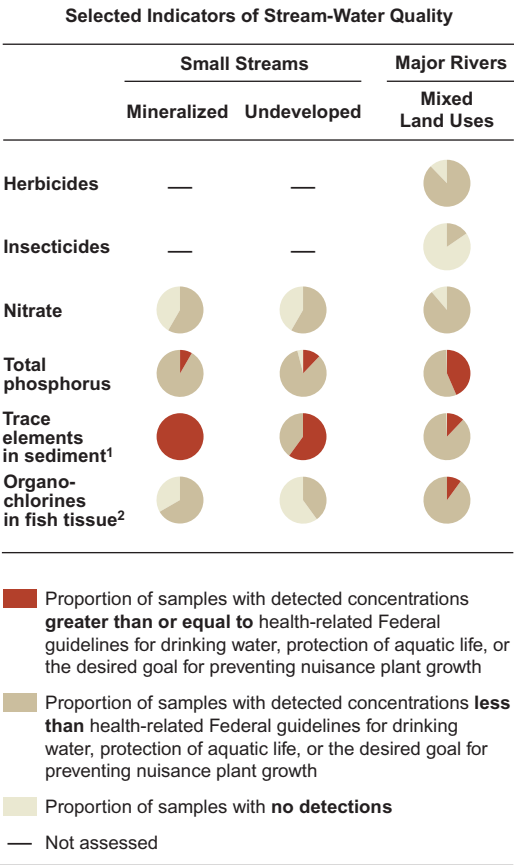
Major Influences on Streams

- Geology and land use (percentage of rangeland in the drainage area)
- Runoff and ground-water discharge from residential and agricultural areas
- Drought

Trends in Surface-Water Quality

A trend of increasing concentrations of sodium, chloride, and sodium-absorption ratio in the Powder River during 1968 to 1988 was described by Cary (1991). A mathematical model of the Powder River indicated dissolved-solids concentrations were influenced by discharge of oil-production water to a tributary, Salt Creek, during 1975 to 1988 (Lindner-Lunsford and others, 1992). Although discharge of oil-production water to Salt Creek has been reduced since 1988, the Powder River is currently (2003) of interest because of potential effects to water quality from discharge of water related to development of coalbed methane for energy supplies.

During the 1950s, water quality and aquatic life in the Yellowstone River were severely degraded by wastewater discharges from towns along the river (Bahls, 1976). Water-quality and biological conditions in the Yellowstone River improved during the 1970s, corresponding with improvements in wastewater-treatment practices. Biological conditions in the Yellowstone River in 2000 (p. 20) remain somewhat degraded, but not to the extent described by Bahls (1976).



¹ Arsenic, mercury, and metals.
² DDT and PCBs.

Ground-Water Highlights

Natural factors such as geology, aquifer properties, and ground-water recharge rates influence concentrations of dissolved solids, radon, trace elements, and other aspects of ground-water quality. Concentrations of dissolved solids in water samples from the Quaternary aquifers and lower Tertiary aquifers in the Yellowstone River Basin frequently exceeded the Federal secondary drinking-water guideline of 500 milligrams per liter. Low-density developments, often referred to as “rural ranchettes,” affect ground-water quality, but the water generally is suitable for domestic use.

- Concentrations of radon in 52 of 54 ground-water samples exceeded a proposed Federal drinking-water standard of 300 picocuries per liter. The radon concentrations also were high compared to those measured in other ground-water systems measured across the Nation (p. 9).

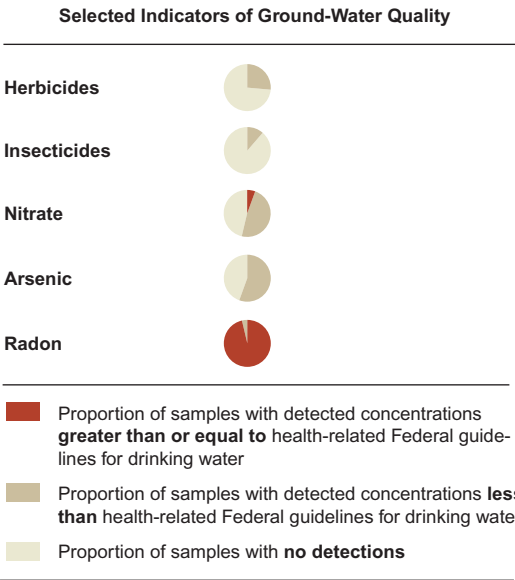
- Concentrations of bacteria, nitrate, and trace elements in ground water generally were less than human-health guidelines. Less than 10 percent of the measured nitrate concentrations exceeded the Federal drinking-water standard of 10 milligrams per liter (p. 13).
- Pesticides were detected more often in the shallow Quaternary aquifers than in the underlying lower Tertiary aquifers. The pesticides most frequently detected in ground water were atrazine and prometon (p. 14).
- Volatile organic compounds, many of which are associated with gasoline, were detected frequently in samples from the Quaternary aquifers and, to a lesser extent, the lower Tertiary aquifers. The concentrations were low compared to Federal drinking-water standards (p. 18).

Major Influences on Ground Water

- Geology
- Aquifer properties
- Irrigation
- Rural development

Trends in Ground-Water Quality

Many of the wells sampled for this study were new, so historical data are not available. The data collected in this study, however, will serve as a baseline against which any future changes in ground-water quality can be measured. In the rural ranchette study, age-dating techniques indicated much of the water was recharged in the early 1990s or earlier, so effects over the last 10 years may not be reflected in the samples collected in 2001 (p. 18). Continued monitoring is needed to track the effects of increasing development over time.



Introduction to the Yellowstone River Basin

From its headwaters in Yellowstone National Park and surrounding wilderness areas in Wyoming, the Yellowstone River flows more than 700 miles through Montana to its mouth at the Missouri River in North Dakota (fig. 1). Population density in the 70,000-square-mile basin is sparse, about five people per square mile on average. The largest city is Billings, Mont. (metropolitan-area population of about 127,000 in 1999).



Diversion dams for irrigation canals along the middle and lower Yellowstone River are popular fishing spots but can impair fish movement upstream (Graham and others, 1979) (photograph by David A. Peterson, U.S. Geological Survey).



Alfalfa, sugar beets, and other irrigated crops, grown in about 4 percent of the basin, are common in the river valleys and adjacent areas (photograph by Ronald B. Zelt, U.S. Geological Survey).



French voyagers called the Yellowstone River "Roche Jaune," which was translated as "Yellowstone" in the journals of the 1805 Lewis and Clark expedition (Linford, 1975) (photograph by Suzanne C. Roberts, U.S. Geological Survey).

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'

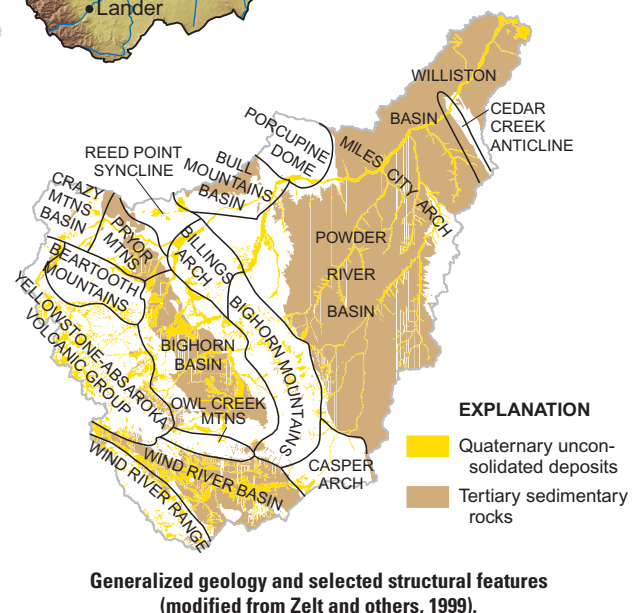
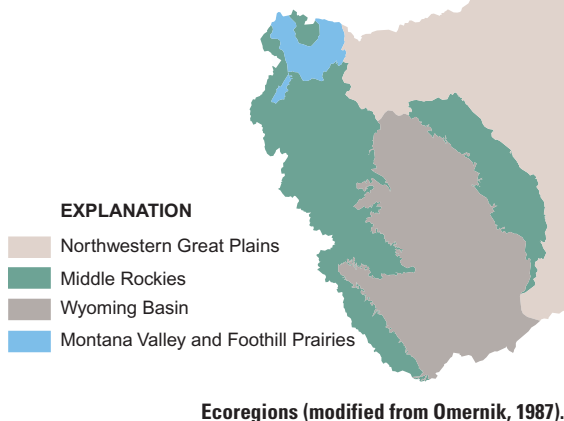


Figure 1. The Yellowstone River drains nearly 70,000 square miles, including the Nation's first national park, vast areas of grass and shrubland in the northwestern Great Plains and Wyoming Basin, forested areas in the Rocky Mountains, and small population centers, such as Billings, Montana.

The Yellowstone River Basin encompasses four ecoregions (Omernik, 1987: Northwestern Great Plains, Wyoming Basin, Middle Rockies, and Montana Valley and Foothill Prairies). Land cover throughout most of the basin is grass and shrubland in the Northwestern Great Plains and Wyoming Basin ecoregions (fig. 1). Coniferous forests and alpine areas in the Middle Rockies ecoregion cover about 20 percent of the basin, and land within Yellowstone National Park represents less than 5 percent of the total basin area. A small part of the basin is in the Montana Valley and Foothill Prairies ecoregion. Average annual precipitation ranges from about 6 inches in the driest parts of the Wyoming Basin to almost 60 inches in the wettest parts of the Middle Rockies (Zelt and others, 1999).

Surface-Water Resources

The Yellowstone River is one of the longest free-flowing rivers remaining in the continental United States. Irrigation diversion dams can be found in the middle and lower sections of the river, but there are no major impoundments on the main stem. The Yellowstone River changes from a cold, clear, mountain river at the headwaters to a warmer, more turbid river downstream on the plains.

Major tributaries to the Yellowstone River include the Clarks Fork Yellowstone River, Bighorn River, Tongue River, and Powder River. The tributaries can be divided into three categories: mountain, basin, and plains streams. The ecoregion is an important factor in classification of the hydrologic characteristics of the tributaries. Soda Butte Creek and the upper reaches of the Tongue River (mountain streams) are part of the Middle Rockies ecoregion. Drainage area of the mountain streams is relatively small, and streamflow is dominated by the melting of the annual snowpack. The Clarks Fork Yellowstone River and Bighorn River (basin streams) are part of the Wyoming Basin

ecoregion. Drainage area is large, and the flow from these streams contributes substantially in total flow volume and in per unit area to the Yellowstone River. The Powder River and Little Powder River (plains streams) are predominantly in the Northwestern Great Plains ecoregion. The flow cycle of plains streams is affected more by local and regional rain events than are the mountain streams. Plains streams also contribute less flow to the Yellowstone River per unit area than mountain streams.

The Bighorn River is the largest tributary to the Yellowstone River and represents about 32 percent of the basin. Storage reservoirs with capacities greater than 600,000 acre-feet, such as Bighorn Lake and Boysen Reservoir, are located on the Bighorn River or its tributaries. Smaller reservoirs are located on the Tongue River; the Clarks Fork and Powder River are free-flowing. The reservoirs are important from a water-quality perspective because warm, turbid water flowing into the reservoirs is

stored, and cold, clear water is released below the dams.

Most water used in the basin is surface water withdrawn to irrigate fields located primarily in the river valleys and nearby areas (fig. 2). The forested mountains are the source of water for most perennial streams, and the winter snowpack in the mountains strongly influences streamflow throughout the year. The mountain streams are dominated by a single annual snowmelt peak of moderate duration during late spring or early summer, with little variability in daily flows throughout the year. Other streams originate in the plains. Many of these streams are intermittent or ephemeral, and sporadic higher flows are the result of local snowmelt or intense rainstorms. Flow during dry periods originates from ground water.

A reduced snowpack and drought caused below-average streamflow during much of the sample-collection period (fig. 3). Annual mean streamflow at some sampling sites in 2001 was the

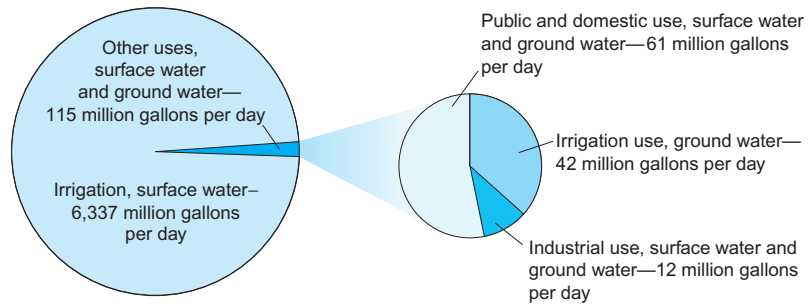


Figure 2. Surface water used for irrigation accounted for 98 percent of the average 6,452 million gallons per day of water used in the basin.

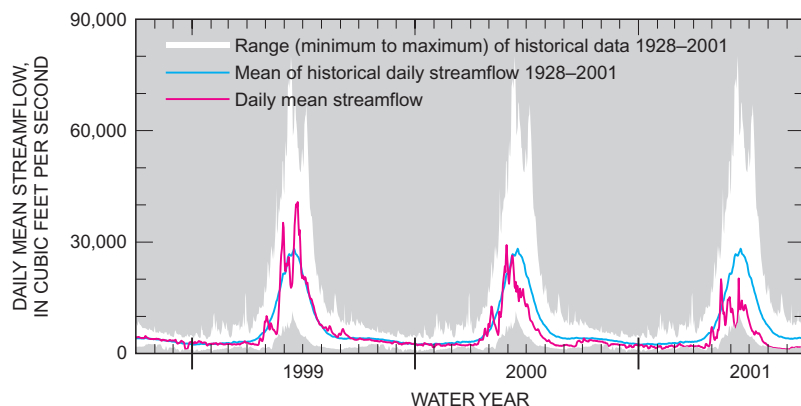


Figure 3. Flow of the Yellowstone River at Billings, Montana, **water years** 1999–2001. Streamflows in the basin were above average in water year 1999 but were less than average in 2000 and 2001.

lowest on record. At other sites, 2001 streamflow was the third or fourth lowest on record. Periods of low streamflow, such as during drought conditions, are characterized by large contributions of ground water, resulting in less dilution by runoff and larger concentrations of some dissolved constituents (p. 13).

Ground-Water Resources

The primary **aquifers** in the structural basins (for example, the Bighorn Basin in fig. 1) are unconsolidated deposits of Quaternary age and rocks of lower Tertiary, Mesozoic, and Paleozoic age. Rural residents often depend on shallow wells (less than 500 feet) that are completed in aquifers in Quaternary unconsolidated deposits or lower Tertiary consolidated sedimentary rocks.

The Quaternary unconsolidated deposits, primarily composed of sand and gravel interbedded with finer grained silt and clay, are limited in extent and occur mostly as alluvium or terrace deposits adjacent to and above narrow valleys along streams in the Yellowstone River Basin. In contrast, the lower Tertiary aquifers are widespread and primarily are composed of sandstone beds interbedded with fine-grained rocks such as shale, claystone, mudstone, or siltstone. The areal extent of Quaternary unconsolidated-deposit aquifers (Quaternary aquifers) coincides with much of the rural population and irrigated cropland, making these aquifers particularly susceptible to the effects from human activities at the land surface.

Biological Resources

Cold-water fishes, including trout, whitefish, and sculpin, dominate the fish community of streams in the mountains and foothills of the basin. The Yellowstone cutthroat trout is the only native trout in the basin (Behnke, 1992) and is one of about six fish species in the Yellowstone River Basin of special concern in the State of Montana. Other cold-

water native fishes commonly found in the basin include mountain whitefish and mottled sculpin (Baxter and Stone, 1995; Brown, 1971). Rainbow, brown, and brook trout are all introduced species. Native warm-water game fish such as channel catfish and sauger occur in many of the streams in the plains (Patton, 1997; and Hubert, 1993). Fish species richness in the Yellowstone River and other streams in the basin generally increases downstream, from the mountainous cold-water streams to the warm-water plains streams.

White and Bramblett (1993) described three zones of fish communities in the Yellowstone River. The upper one-third of the Yellowstone River, from the headwaters downstream to just upstream from the mouth of the Clarks Fork, is a cold-water zone inhabited by 16 fish species representing 6 families. The transition zone of the Yellowstone River extends downstream from Billings and to the mouth of the Bighorn River; 30 fish species representing 7 families are resident. The lower Yellowstone River contains a warm-water fish community, including the only federally listed endangered species in the basin, the pallid sturgeon. Other fish species of the warm-water zone of the Yellowstone River include paddlefish, several species of sucker, and various species of native and introduced minnows and game fish, totaling 49 species and 15 families.

Aquatic invertebrates (insects, worms, snails, crayfish, and mussels), algae, and substrate also follow a gradient from mountains to plains. In the Yellowstone River, most invertebrate species occupy only one or two zones, but a few species of mayfly, stonefly, and caddisfly larvae are found throughout the length of the Yellowstone River (Newell, 1977). Few species of mussels are found in Montana, but indigenous populations are largely intact (Gangloff and Gustafson, 2000). An exotic species, the New Zealand mudsnail, has invaded Yellowstone National Park and has the potential to substantially affect aquatic ecosystems because of their high densities (Richards, 2002). The bed substrate of the Yellowstone River changes from

boulders and cobbles in the upper reaches to predominantly gravel and finer material in the lower reaches.

Water-Quality Issues

The quality of surface water and ground water in the basin is affected by natural factors and **nonpoint source** and **point-source contaminants** associated with human development. For example, concentrations of **trace elements** (such as arsenic) and **major ions** (such as calcium and sulfate) in surface water and ground water are influenced by geologic factors, as are concentrations of suspended sediment and total phosphorus in surface water. Current water-quality conditions also reflect human influences, as indicated by the presence of **pesticide** compounds in surface water, ground water, bed sediment, and fish tissue. Human and animal activities influence concentrations of bacteria, nutrients, suspended sediment, and other chemical and physical characteristics. Discharge of saline ground water from large-scale coalbed methane production areas in the Powder River Basin of Wyoming potentially affects stream-water quality. Habitat characteristics also are of interest; for example, the large floods on the Yellowstone River during 1996 and 1997 prompted the State of Montana to assess the long-term effects of bank stabilization projects on the upper river (Governor's Upper Yellowstone River Task Force, 2001).

Additional Information

For additional information about the environmental setting and **stratification** for site selection in the NAWQA study of the Yellowstone River Basin, see Zelt and others (1999) or <http://wy.water.usgs.gov/YELL/htms/yellpubs.htm>.

Major Findings

Natural factors affect surface and ground-water chemistry

The diverse geology and climate of the Yellowstone River Basin are important factors affecting surface- and ground-water chemistry, including concentrations of **dissolved solids**, radon, nutrients, and trace elements. Throughout this report, standards and guidelines from various agencies and sources such as the U.S. Environmental Protection Agency (USEPA) (2002) **drinking-water standards** are provided as a basis for comparison, but are not intended in a regulatory sense.

Mountain streams generally are dilute, whereas naturally occurring dissolved solids in basin and plains streams commonly exceed the Federal drinking-water guideline

Dissolved minerals in mountain streams, such as Soda Butte Creek in Yellowstone National Park and the Tongue River near Sheridan, Wyo., are dominated by calcium and bicarbonate. Median concentrations of dissolved solids for these streams are low (less than 140 mg/L [milligrams per liter]) (fig. 4). During periods of snowmelt runoff in late spring, concentrations of dissolved solids are as low as 40 mg/L because of dilution by the meltwater.

In contrast to mountain streams, more than 95 percent of samples from the plains streams—the Little Powder and Powder Rivers—exceeded the USEPA secondary drinking-water guideline for dissolved solids of 500 mg/L. Secondary drinking-water guidelines are not enforceable but are intended as guides to esthetic values, such as taste and odor. Sodium and sulfate generally dominate the major ions of the Little Powder River and the Powder River;

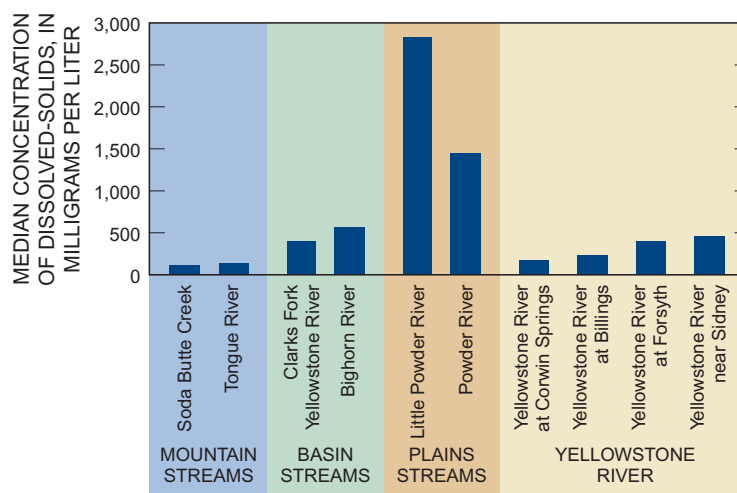


Figure 4. Dissolved solids are lower in mountain streams than in basin or plains streams.

chloride concentrations are substantially higher in these streams than in mountain streams. Evaporative salts that commonly accumulate on the soil surface in the plains are flushed to streams during runoff of precipitation.

Dissolved-solids concentrations in basin streams and in the main stem of the Yellowstone River are intermediate between those of mountain and plains streams. Median concentrations of dissolved solids on the Yellowstone River increased from 152 mg/L near its mountainous headwaters to 452 mg/L at the farthest downstream site.

Land-use practices also contribute dissolved solids to streams

Although natural factors are important, land-use practices, such as irrigation and oil and gas development, also contribute dissolved solids in the Yellowstone River Basin (Lindner-Lunsford and others, 1992). Effects of coalbed methane development on surface-water quality in the Tongue and Powder River Basins (fig. 5), which began in the late 1990s, are unclear. Data collected in these basins under the NAWQA Program prior to development

may serve as an important baseline for assessing possible future water-quality effects.

Ground-water chemistry in the Quaternary and lower Tertiary aquifers is naturally variable and generally high in mineral content

Calcium, sodium, bicarbonate, and sulfate were the predominant major ions in water from the Quaternary aquifers. In the lower Tertiary aquifers, sodium,

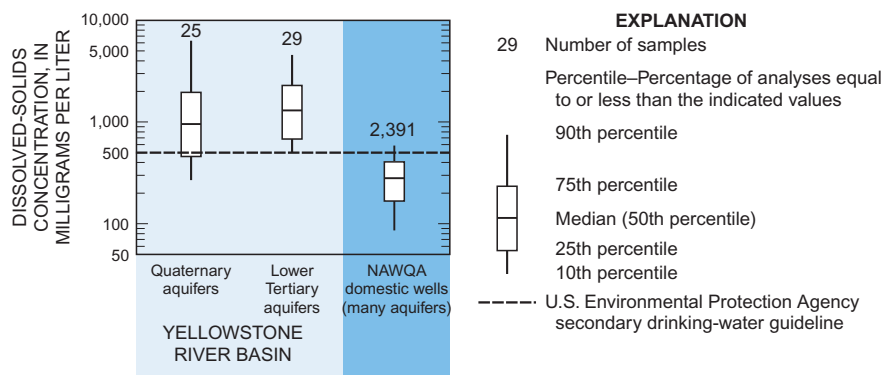


Figure 5. Ground water discharged from coalbed methane development in the Powder River Basin commonly is stored in surface impoundments (photograph by Jon P. Mason, U.S. Geological Survey).



Water from study unit aquifers was more mineralized than water from other aquifers in the Nation

Concentrations of dissolved solids in both aquifers sampled in the Yellowstone River Basin were higher than in most shallow wells sampled elsewhere in the Nation. The median concentrations of dissolved solids of 956 mg/L for samples from the Quaternary aquifers and 1,302 mg/L for samples from the lower Tertiary aquifers were much higher than the median of 280 mg/L from 2,391 domestic wells sampled nationally as part of the NAWQA Program from 1991 to 2001.



bicarbonate, and sulfate were the most common major ions. Water in both aquifers with high concentrations of dissolved solids often was dominated by sodium and bicarbonate, particularly in the lower Tertiary aquifers where natural geochemical processes, such as cation exchange and bacterially mediated sulfate reduction, are important.

Concentrations of dissolved solids in water samples from the Quaternary aquifers ranged from 128 to 24,300 mg/L, with a median of 956 mg/L. Waters from the lower Tertiary aquifers generally were more mineralized, ranging from 352 to 5,800 mg/L, with a median of 1,302 mg/L.

Concentrations of dissolved solids in both aquifers frequently exceeded the USEPA secondary drinking-water guideline of 500 mg/L. The guideline was exceeded in 18 of 25 wells in the Quaternary aquifers and 27 of 29 wells in the lower Tertiary aquifers. Despite elevated concentrations, both of these aquifers are commonly used for domestic supplies. Many residents treat their well water to reduce the dissolved solids and improve the overall water quality.

Although natural factors control mineral content, cropland practices such as irrigation also are likely to contribute dissolved solids to ground water underlying the Bighorn Basin. The water table generally is shallow in both aquifers in this part of the Yellowstone River Basin, especially in the Quaternary aquifers. Salts from irrigation water can accumulate in agricultural soils and then be transported to aquifers following subsequent rainfall or irrigation.

Coliform bacteria concentrations exceeded Federal guidelines frequently in streams, but rarely in ground water

Coliform bacteria, including total coliform, fecal coliform, and *Escherichia coli* (*E. coli*), are commonly used to assess the sanitary quality of water because their presence can indicate contamination by fecal material. Although coliform bacteria do not necessarily cause illness, large concentrations of

coliform bacteria can indicate the presence of other pathogens that cause the waterborne diseases gastroenteritis and bacillary dysentery, typhoid fever, and cholera (Myers and Sylvester, 1997). The criteria for evaluating concentrations of *E. coli* vary with intended use, ranging from designated beaches to infrequent full-body contact recreation (U.S. Environmental Protection Agency, 1986).

Recommended Federal limits for recreational contact were frequently exceeded during special coliform-bacteria study of streams

Fecal coliform concentrations exceeded USEPA's single-sample recommended limit of 400 col/100 mL (colonies per 100 milliliters) for primary contact recreation at 37 of 100 stream sites in the Wind River, Bighorn River, and Goose Creek (Sheridan area) Basins in Wyoming. Similarly, 38 percent of the samples contained *E. coli* concentrations greater than USEPA's single-sample recommended limit of 298 col/100 mL for moderate use, full-body contact

recreation, and 25 percent of the *E. coli* concentrations exceeded the single-sample recommended limit for infrequent use, full-body contact recreation of 576 col/100 mL. Median concentrations of fecal coliform and *E. coli* were highest in urban and agricultural streams (fig. 6), where likely sources of coliform bacteria contamination include sewage treatment plants, agricultural and domestic animal waste, wildlife waste, and septic systems.

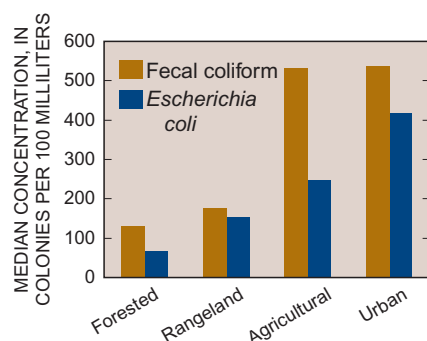


Figure 6. Median concentrations of coliform bacteria were highest in urban and agricultural areas.

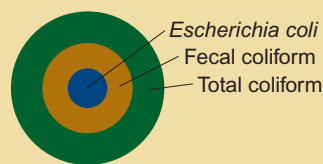
Additional Information

For additional information about the special coliform bacteria study, see Clark and Gamper (2003) or <http://wy.water.usgs.gov/YELL/htmls/yellpubs.htm>.

Coliform bacteria varied seasonally in streams

Median monthly concentrations of coliform bacteria generally increased in the late spring through June or July when peak concentrations occurred (fig. 7) in Soda Butte Creek, and the Yellowstone, Clarks Fork, Bighorn, Tongue, Little Powder, and Powder Rivers. The seasonal peak of more than 50 col/100 mL might result from increased runoff associated with lowland thunderstorms or snowmelt runoff. Concentrations of coliform bacteria declined in the late summer and fall, to less than 20 col/100 mL, when overland

What are coliform bacteria?



Coliform bacteria belong to the Enterobacteriaceae family of bacteria. The total coliform group includes bacteria that are found in the intestines of warm-blooded animals, as well as those found in soils, on vegetation, and in industrial waste. Fecal coliforms are a subgroup of the total coliforms that generally are from fecal sources, but at least one member of the fecal coliform group has been associated with industrial waste sources (U.S. Environmental Protection Agency, 1986). *Escherichia coli* is a specific subgroup of the fecal coliform group that is a natural inhabitant in the gastrointestinal tract of warm-blooded animals. The presence of *Escherichia coli* in recreational waters is direct evidence that fecal contamination from humans or other warm-blooded animals has occurred (Dufour, 1984).

runoff was less frequent. Concentrations of fecal coliform and *E. coli* for these streams generally were less than recommended limits for recreational contact throughout the year. Fecal coliform concentrations in four samples from the Bighorn, Little Powder, and Powder Rivers exceeded the recommended limit of 400 col/100 mL. Of the 145 samples collected, concentrations of *E. coli* in 11 samples exceeded the single-sample limit of 298 col/100 mL and concentrations in 6 samples exceeded the single-sample limit of 576 col/100 mL from the Clarks Fork, Bighorn, Little Powder, and Powder Rivers. Eighty percent of the samples that exceeded recommended limits for *E. coli* were collected in the summer. Recreational use of these streams generally is infrequent; however, the human health risk to exposure is highest during the summer when contact with waters is most likely to occur.

Coliform-bacteria concentrations in ground water were low compared to Federal guidelines

Total-coliform bacteria were detected in samples from 3 of 28 rural wells in Wyoming and Montana, and these exceeded the USEPA drinking-water standard of zero. No *E. coli* bacteria were detected in any well samples. Bacteria in ground water might not be a widespread issue in the basin, but the data indicate some contamination. Some domestic wells are not grouted and are, therefore, more susceptible to contamination from surface sources than the sealed monitoring wells used in this study.

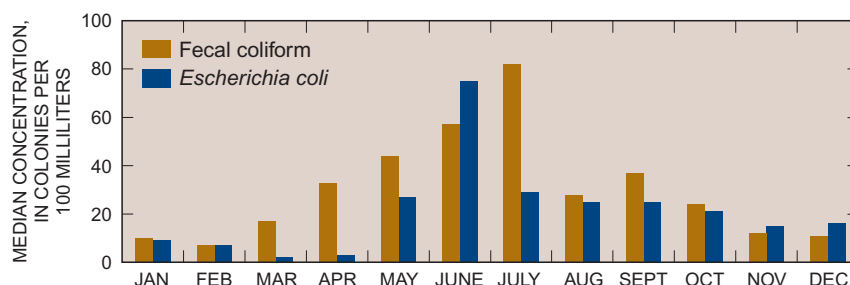


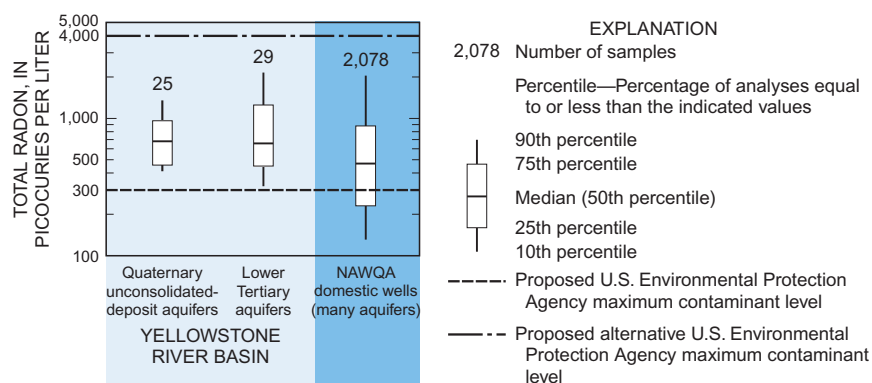
Figure 7. Median concentrations of coliform bacteria were highest in spring and summer.



Radon concentrations in ground water were generally high compared to rest of Nation

Radon is a colorless, odorless radioactive gas that forms during the decay of natural uranium in rocks and soil. Concentrations of radon are naturally elevated in water in the Quaternary and lower Tertiary aquifers sampled in the Yellowstone River Basin. The water flows through volcanic rocks and some types of sedimentary and metamorphic rocks that contain enriched amounts of radium, a decay product of uranium. Concentrations of radon in 52 of 54 samples exceeded the USEPA proposed drinking-water standard of 300 pCi/L (picocuries per liter).

One sample exceeded the USEPA proposed alternative drinking-water standard for radon of 4,000 pCi/L. About 75 percent of the ground-water samples collected in this study exceeded the national median of 470 pCi/L for radon in 2,078 domestic wells sampled in NAWQA studies across the Nation. Relatively high concentrations of radon also have been noted in the Upper Colorado River Basin (Spahr and others, 2000) and the South Platte River Basin (Dennehy and others, 1998). Radon is second only to cigarette smoking in causing lung cancer in the United States (Cothorn and Smith, 1987).



Median concentrations of radon in water samples from Quaternary and Tertiary aquifers in the Yellowstone River Basin were higher than in other parts of the Nation.

Nutrient concentrations vary seasonally and in relation to land use

Concentrations of total nitrogen were largest in rangeland streams

Flow-weighted average concentrations (see inset on p. 10) of total nitrogen were 1.9 mg/L in the Little Powder River and 2.6 mg/L in the Powder River during 1999–2001, where the land cover in each basin is about 80 percent rangeland. The nitrogen in these streams is mostly organic nitrogen and is correlated with large particulate organic carbon concentrations. Concentrations of total nitrogen were less than 1.6 mg/L for other streams sampled, decreasing proportionally with the percentage of rangeland (fig. 8). The smallest concen-

trations of total nitrogen were measured in predominantly forested basins. In a nationwide model of contaminant transport by Smith and others (1997) (fig. 9), about 60 percent of the average total nitrogen **yield** in the Yellowstone River Basin was estimated to be from nonagricultural sources. Nitrogen contributed from rangeland is under the nonagricultural source category in figure 9.

Nitrate concentrations were largest in the Clarks Fork Yellowstone and Bighorn Rivers, both of which are basin streams that drain a mix of residential, agricultural, and undeveloped areas. The average concentration of nitrate at both sites was 0.38 mg/L (fig. 10). In contrast, average concentrations of nitrate for the mountain streams, Soda Butte Creek and Tongue River, were less than 0.08 mg/L, which is considered the upper limit of naturally occurring concentrations for other undeveloped areas of the Nation (Clark and others, 2000). Concentrations of nitrate in the Yel-

lowstone River increased downstream from an average of about 0.08 mg/L at Corwin Springs to an average of greater than 0.3 mg/L near Sidney (fig. 1).

Nitrate concentrations in the samples from the main-stem Yellowstone River were largest during winter. The median concentration of nitrate at four sites on the Yellowstone River during

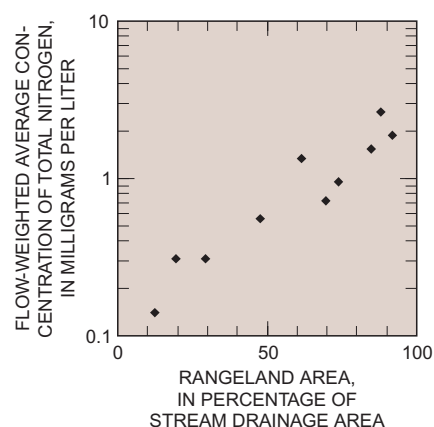


Figure 8. Concentrations of total nitrogen were largest in streams with most rangeland.

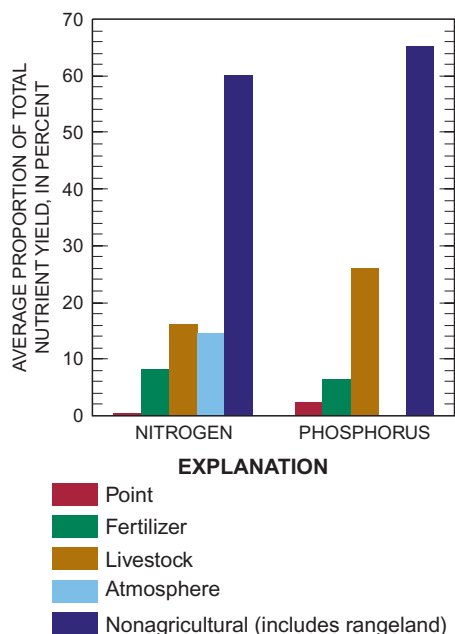


Figure 9. Sources of nitrogen and phosphorus in the Yellowstone River Basin were predominantly nonagricultural, as estimated from nationwide analysis using the SPARROW model (Smith and others, 1997).

January was 0.38 mg/L (fig. 11). Median concentrations in the Yellowstone River were less than the minimum reporting level during July and August. Lower streamflow during winter results in less dilution of nitrate-rich ground water discharging to the stream. Uptake of nitrate by algae—an important process during summer that reduces concentrations in stream water—is minimal during winter when solar inputs are minimal and water temperatures are near freezing.

Why are concentrations flow-weighted?

Nutrients and suspended sediment in streams are reported as flow-weighted average concentrations in this report. The flow-weighted average is calculated by first multiplying each sample concentration by its associated streamflow value, then dividing the sum of these products by the sum of the streamflows. The result is a concentration that is representative of the annual mass of the constituent transported by each stream. Flow-weighting concentrations is particularly important in a plains stream such as the Little Powder River, where daily flows are low for most of the year and stormflows usually are large and of short duration. For these streams, the flow-weighted average concentration likely is substantially larger than a most-probable concentration for any given day.

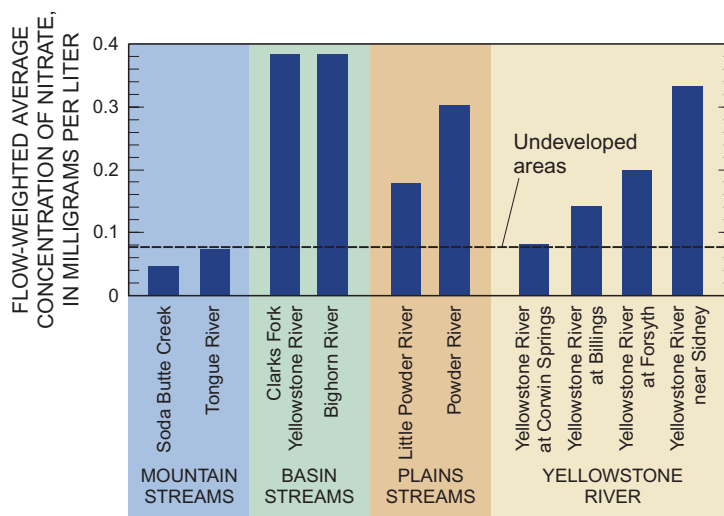


Figure 10. Concentrations of nitrate in mountain streams were less than concentrations for other developed areas. Concentrations of nitrate were largest in basin streams.

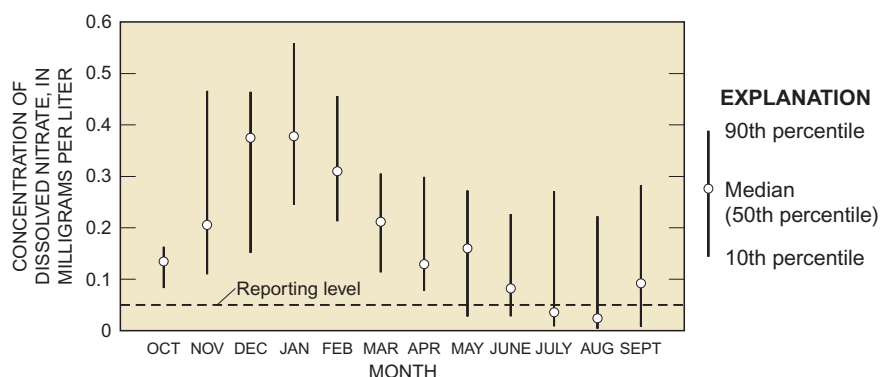


Figure 11. Nitrate concentrations in the Yellowstone River were largest during the winter and smallest during summer. Concentrations below reporting level are estimates.

Natural sources contribute phosphorus and suspended sediment to streams

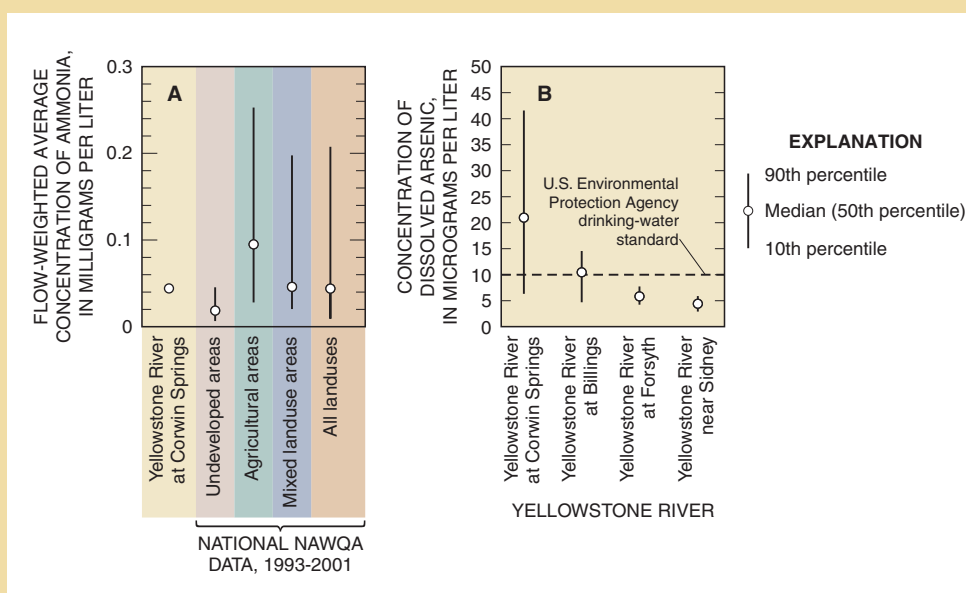
Flow-weighted average concentrations of phosphorus at three of four sampling sites on the Yellowstone River and in four tributary streams exceeded the USEPA goal of 0.1 mg/L for minimizing nuisance plant growth. Average concentrations of total phosphorus ranged from 0.2 mg/L to 2.1 mg/L for predominantly (50 percent or greater) rangeland streams.

Concentrations of phosphorus in soils and sediments of the Western United States are large relative to those in the Eastern United States (Shacklette and Boerngen, 1984) because phosphorus occurs naturally in the igneous

Geothermal sources contribute nutrients and trace elements to the Yellowstone River

The flow-weighted average concentration of ammonia as nitrogen (hereinafter, ammonia) of 0.04 mg/L in the Yellowstone River at Corwin Springs, near the headwaters, was about twice as large as the median flow-weighted average concentrations in streams in other undeveloped areas of the Nation (graph A). Concentrations of ammonia in streams in undeveloped basins typically are closer to a background concentration of about 0.02 mg/L (Clark and others, 2000). One possible source of the large concentrations of ammonia at the Corwin Springs site is leaching of organic-rich sedimentary rocks by the high-temperature waters (D. Kirk Nordstrom, USGS, written commun., 2000; Love and Good, 1970). The largest concentrations in the Yellowstone River at Corwin Springs (as high as 0.23 mg/L) occur in the fall and winter months when inputs from geothermal sources are less diluted by surface runoff. Ammonia is common in many geothermal waters of Yellowstone National Park, where concentrations greater than 600 mg/L have been measured in some springs (Ball and others, 1998, p. 23).

Median concentrations of dissolved arsenic in samples from the Yellowstone River at Corwin Springs and at Billings exceeded the USEPA drinking-water standard of 10 micrograms per liter (graph B), probably because of the natural occurrence of arsenic in geothermal waters (Hem, 1985). In streams in and around Yellowstone National Park, arsenic remains in solution (Nimick and others, 1998). Downstream decreases in the concentration of arsenic—from Corwin Springs to Sidney—probably result from increased dilution by tributary inflows.



and marine sedimentary rocks that are prevalent. Phosphorus tends to attach to soil sediment particles so that the transport of these particles in suspension in streams typically causes concentrations of total phosphorus to increase with increasing concentrations of suspended sediment (U.S. Geological Survey, 1999). In the Yellowstone River Basin, nonagricultural sources of phosphorus (such as suspended sediment, although sediment concentrations might be affected indirectly by agriculture) were estimated to have contributed about 65 percent of the total phosphorus yield; human activities, such as fertilizer applications and raising stock, also contribute phosphorus to streams (fig. 9).

The sparse vegetative cover and erodible soils in the basins and plains areas contribute to larger suspended-sediment concentrations in basin and plains streams than in mountain streams (fig. 12). Flow-weighted average concentrations of suspended sediment generally were proportional to the area of rangeland in the stream drainage (fig. 13), and were correlated with surficial Tertiary-age sedimentary rocks that are susceptible to erosion.

Sediment yields (total amount contributed per unit area) generally were large from major tributary basins, such as the Clarks Fork Yellowstone, Big-horn, and Powder Rivers (fig. 14). The maximum annual sediment yield was



Figure 12. Runoff from rainstorms transports high concentrations of sediment in plains streams such as the Little Powder River (photograph by Ronald B. Zelt, U.S. Geological Survey).



Phosphorus concentrations in streams in undeveloped and mixed land-use areas are among the largest in the Nation

Flow-weighted average concentrations of total phosphorus at sites on the Little Powder River, Powder River, and Clarks Fork Yellowstone River ranked in the upper 11 percent of their respective land-use categories and the upper 13 percent of all samples collected during 1993–2001 in NAWQA studies across the Nation. Land in the Little Powder River and Powder River Basins is primarily undeveloped rangeland, whereas the Clarks Fork Yellowstone River Basin includes a variety of land uses, such as residential, agricultural, and undeveloped areas. The high concentrations of phosphorus in soils and high suspended-sediment concentrations in the streams are the primary causes of the large concentrations of total phosphorus in samples from undeveloped areas. In areas of mixed land use, human-related sources are important. For example, Smith and others (1997) estimated that fertilizer and manure contributed 45 percent of phosphorus to the Clarks Fork Yellowstone River.

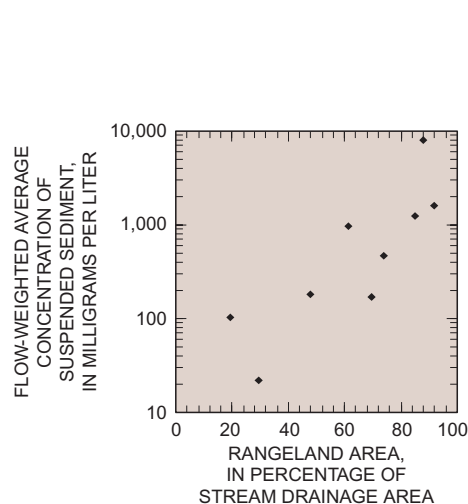
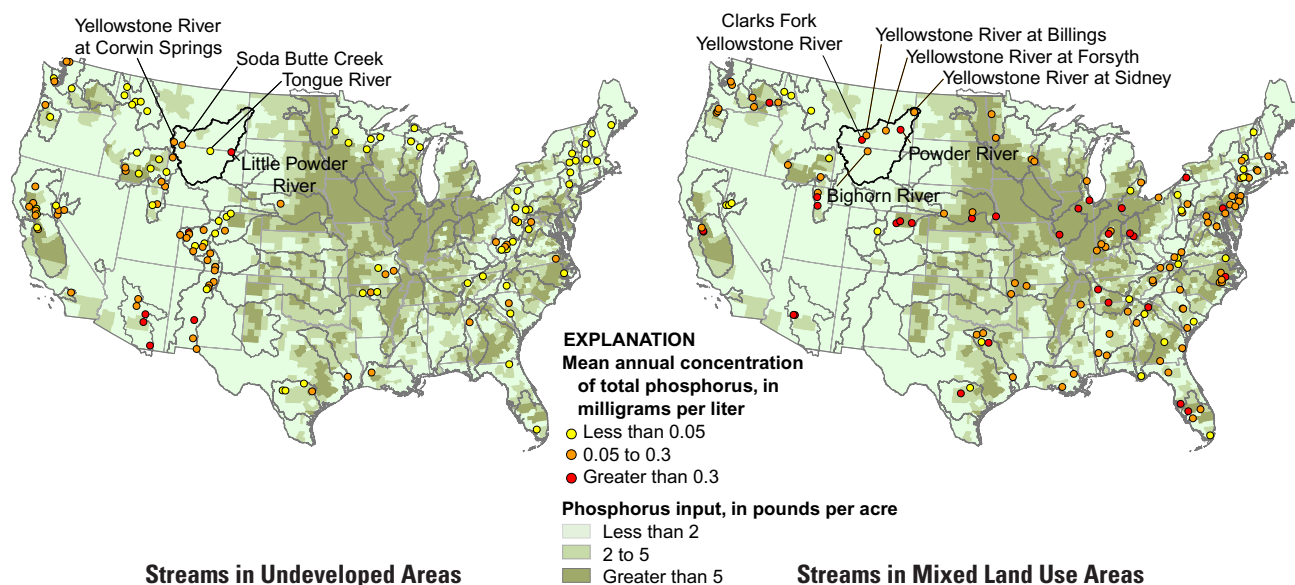


Figure 13. Suspended-sediment concentrations generally increase with the percentage of rangeland.

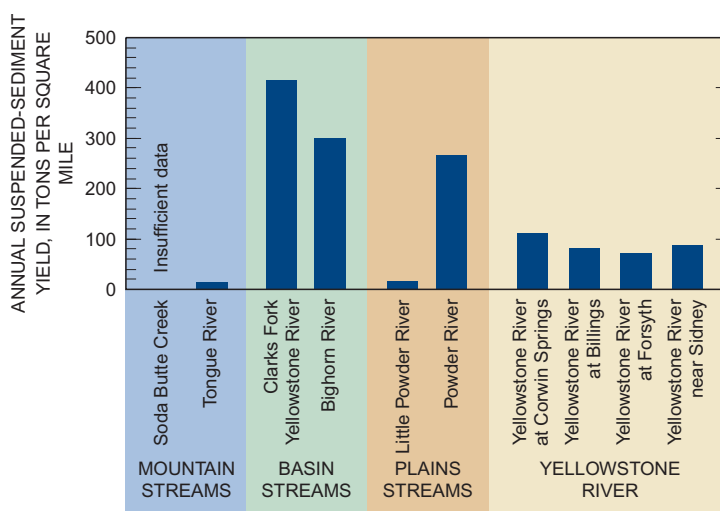


Figure 14. Suspended-sediment yields were largest in basin and plains streams that have little vegetation and soils that are susceptible to erosion.

400 tons per square mile in the Clarks Fork Yellowstone River. Sediment yields did not vary much in the Yellowstone River from the upstream segments to the downstream segment at Sidney. Large reservoirs on the Bighorn River store much of the sediment, thus reducing sediment transport to the Yellowstone River.

Concentrations of nitrate in ground water generally were low, but occasionally exceeded the Federal drinking-water standard

Concentrations of nitrate in 32 percent of the wells in Quaternary aquifers and 17 percent of the wells in the lower Tertiary aquifers exceeded 2 mg/L, which generally indicates ground-water contamination from human sources (Mueller and Helsel, 1996). Median concentrations of nitrate were about 0.2 mg/L for the Quaternary aquifers and about 0.08 mg/L for the lower Tertiary aquifers.

Concentrations of nitrate in 8 percent of samples collected from

Quaternary aquifers and 3 percent from the lower Tertiary aquifers exceeded the USEPA drinking-water standard of 10 mg/L. Drinking water with concentrations greater than this standard can result in insufficient levels of oxygen in the blood of infants and other health problems (Centers for Disease Control and Prevention, 1996).

Concentrations of nitrate in ground water are, in part, related to the percentage of different land uses surrounding the wells. Nitrate concentrations in Quaternary aquifers increased with the percentage of cropland and other agricultural land; nitrate concentrations decreased as the percentage of rangeland and riparian land increased. A similar relation was observed in samples from the lower Tertiary aquifers—nitrate concentrations increased with the percentage of cropland overlying the aquifer. Patterns observed in this study are typical of those observed in other ground-water systems across the Nation, where nitrate concentrations commonly are higher in shallow ground water underlying agricultural areas than in shallow ground water underlying other land-use areas (Mueller and Helsel, 1996).

Pesticides were detected frequently in streams, ground water, and fish tissue, but at low concentrations

Pesticides were frequently detected in streams

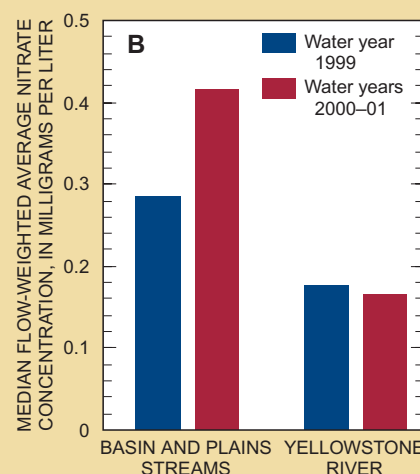
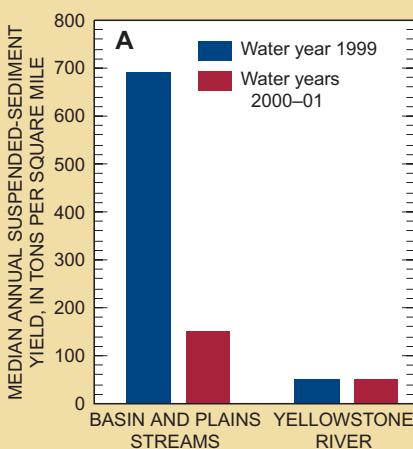
At least one pesticide compound was detected in 87 percent of 136 water samples collected at three mixed land-use sites on the Yellowstone River and two mixed land-use sites on the Clarks Fork Yellowstone and Bighorn Rivers. Of the 47 different pesticide compounds analyzed, 20 were detected, including 14 herbicides, 5 insecticides, and 1 breakdown product (fig. 15). Atrazine, the most frequently detected herbicide, was identified in 75 percent of the samples and accounted for the highest concentration of any pesticide measured in the study—0.328 µg/L (micrograms per liter). Frequent detections of atrazine in streams may result

Drought is an important factor in determining water-quality characteristics

Suspended-sediment yields were larger in basin and plains streams during 1999 than during the drought years 2000–2001 (graph A). The erodible soils of the basins and plains areas are transported in runoff to streams during storms. Less runoff during drought periods results in less sediment being delivered to streams.

In contrast, flow-weighted concentrations of nitrate in the basin and plains streams were smaller during 1999 than during 2000–2001 (graph B).

The larger nitrate concentrations during the drought years were caused in part by less dilution of nitrate-rich ground water discharging to the streams. Miller (1999) described substantial increases in concentrations of dissolved constituents in the upper reaches of the Yellowstone River during a previous drought. Total nitrogen concentrations in these streams decreased or remained the same between the two periods.



from its moderate to high mobility in soils and its extensive use; it is the 10th most heavily used pesticide in the basin of all pesticides analyzed for this study. Atrazine also can move long distances through atmospheric transport (Goolsby and others, 1995). Triallate, the most heavily applied pesticide in the basin of the pesticides that were analyzed (U.S. Department of Commerce, 1995), was detected in 38 percent of the stream samples. Insecticides were detected less frequently than most herbicides. Chlorpyrifos, the most frequently detected insecticide, was identified in 5 percent of the samples. Organophosphate insecticides tend to have low application rates and break down rapidly in the environment (Nowell and others, 1999).

Pesticides seldom occurred alone in streams. Mixtures of two or more compounds were detected in 102 samples (75 percent). About 33 percent of the stream samples contained four or more pesticide compounds. One sample from the Bighorn River contained a mixture of 10 different compounds—8 herbicides, 1 insecticide, and 1 breakdown product. Multiple pesticide compounds were detected in individual samples throughout the year but varied seasonally in streams. The seasonality reflected mainly the timing and amount of chemical use and the frequency and magnitude of runoff from precipitation and irrigation. For example, 71 percent of the samples containing mixtures of four or more pesticides were collected during May to September following pesticide applications. Detections of one or more pesticide compounds during the winter months may indicate that ground water contributes some pesticides to streams because these compounds typically are not used in the winter. Possible risks to humans and aquatic life from pesticide compounds in the Yellowstone River Basin remain unclear because standards and guidelines for drinking water and aquatic life have not been established for many of the compounds and their breakdown products. Moreover, existing standards do not address exposure to mixtures of pesticides.

Pesticides were detected in both aquifers

Pesticides were detected in water from the Quaternary and lower Tertiary aquifers but were detected more frequently in samples collected from Quaternary aquifers (fig. 15). At least one pesticide compound was detected in 14 of 25 wells in the Quaternary aquifers and in 4 of 29 wells in the lower Tertiary aquifers. Mixtures of two or more pesticides were detected in 11 wells in the Quaternary aquifers and in two wells in the lower Tertiary aquifers. The occurrences of such mixtures in the Yellowstone River Basin aquifers are typical of other aquifers sampled by NAWQA across the Nation (Gilliom, 2001).

Cropland overlies 22 percent of the Quaternary aquifers in the area studied. Application of water exceeding crop requirements can result in water-soluble pesticides being transported through soils to shallow aquifers (Barbash and Resek, 1996). The Quaternary aquifers typically are unconfined and the water table is shallow, making these aquifers vulnerable to surficial contaminants.

The lower Tertiary aquifers are less vulnerable to contamination than the Quaternary aquifers because less area is overlain by irrigated cropland (only about 10 percent) and because of the hydrologic condition. The water table is deeper, and the aquifer consists of consolidated rocks that inhibit or reduce the flow of water and dissolved pesticides to these aquifers.

Herbicides were detected in ground water much more frequently than insecticides (fig. 15). Nine different herbicides and one insecticide were detected in samples from wells in the Quaternary aquifers; only two herbicides and no insecticides were detected in samples from wells in the lower Tertiary aquifers. Atrazine was the pesticide detected most frequently (29 percent) in the Quaternary aquifers. Dieldrin was the only insecticide detected in ground-water samples, occurring in only one well in the Quaternary aquifers. Most of the pesticides detected in ground water in both aquifers are commonly associated with agriculture. However, the second-most frequently detected pesticide, prometon, is commonly used

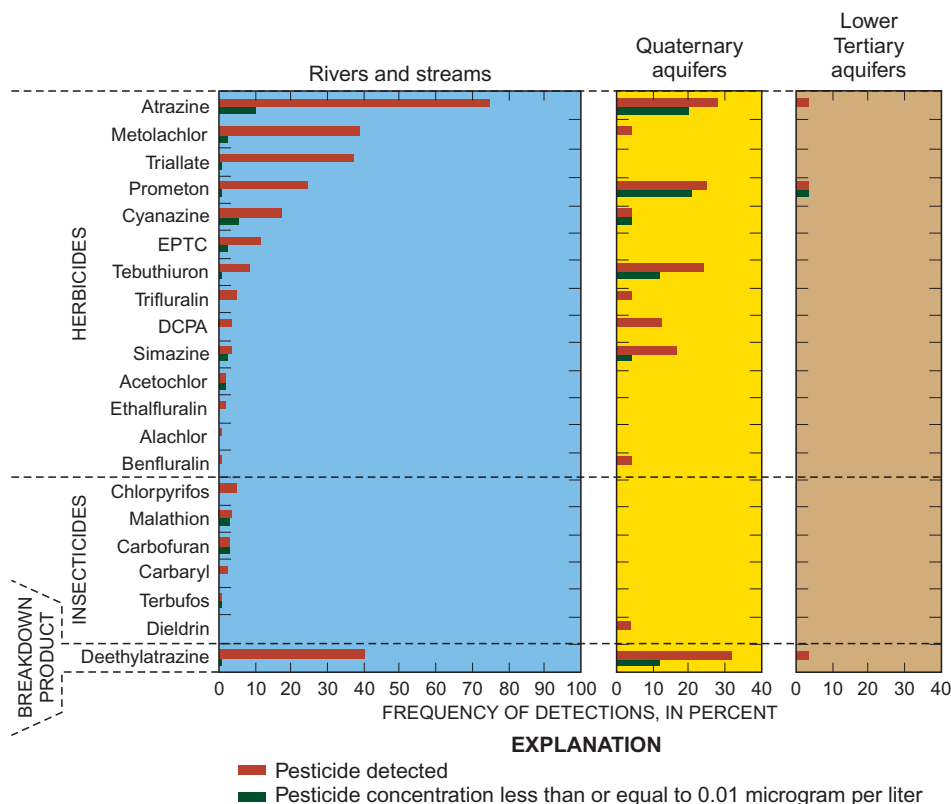
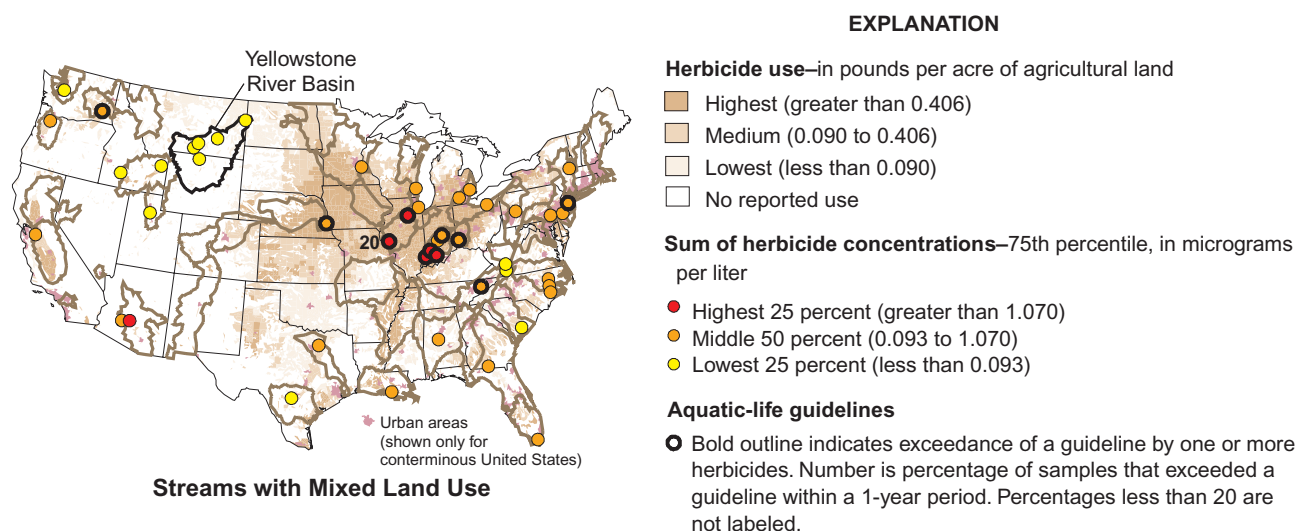


Figure 15. Herbicides were detected more often than insecticides in streams and aquifers.



Herbicide concentrations in surface water were among the lowest in the Nation

Concentrations of herbicides in samples from five mixed land-use stream sites in the Yellowstone River Basin were relatively low compared to samples from 42 stream sites draining mixed land-use settings across the Nation. Concentrations measured at Yellowstone River Basin sites ranked in the lowest 25 percent of concentrations measured nationwide and were similar to the ranking for sites in the adjacent States of Idaho and Utah. Concentrations of herbicides in samples from the five sites in the Yellowstone River Basin ranked 145th or lower when compared to 153 streams sites that drain agricultural, urban, or mixed land-use settings across the Nation. The low concentrations in this basin most likely reflect the low use of herbicides, particularly when compared to herbicide use in the Midwest and Eastern United States.



for weed control along roads and other public areas and also is incorporated into asphalt used for road construction and repair. Prometon also is detected frequently in ground water throughout the United States (Squillace and others, 2002).

Breakdown products of pesticides were present in streams and ground water

Deethylatrazine, a breakdown product of atrazine, was detected in about 40 percent of all stream samples, and was present in all streams where pesticides were monitored. In wells in the Quaternary aquifers, deethylatrazine was detected more frequently than any other pesticide compound and at a slightly higher frequency (33 percent) than

atrazine (29 percent). In lower Tertiary aquifers, deethylatrazine was detected in only one well.

Concentrations of pesticides and other organic compounds in fish tissue and bed sediment varied with land use

Organochlorine pesticides, such as the insecticides DDT, dieldrin, and chlordane, were detected in fish from several sites draining areas with mixed land uses. The compound detected most often in 22 fish-tissue samples was DDE (fig. 16). Another breakdown product of DDT, DDD, also was detected in about 30 percent of the samples. Pesticides were not detected in fish-tissue samples from undeveloped areas, with the exception of those in the northwestern

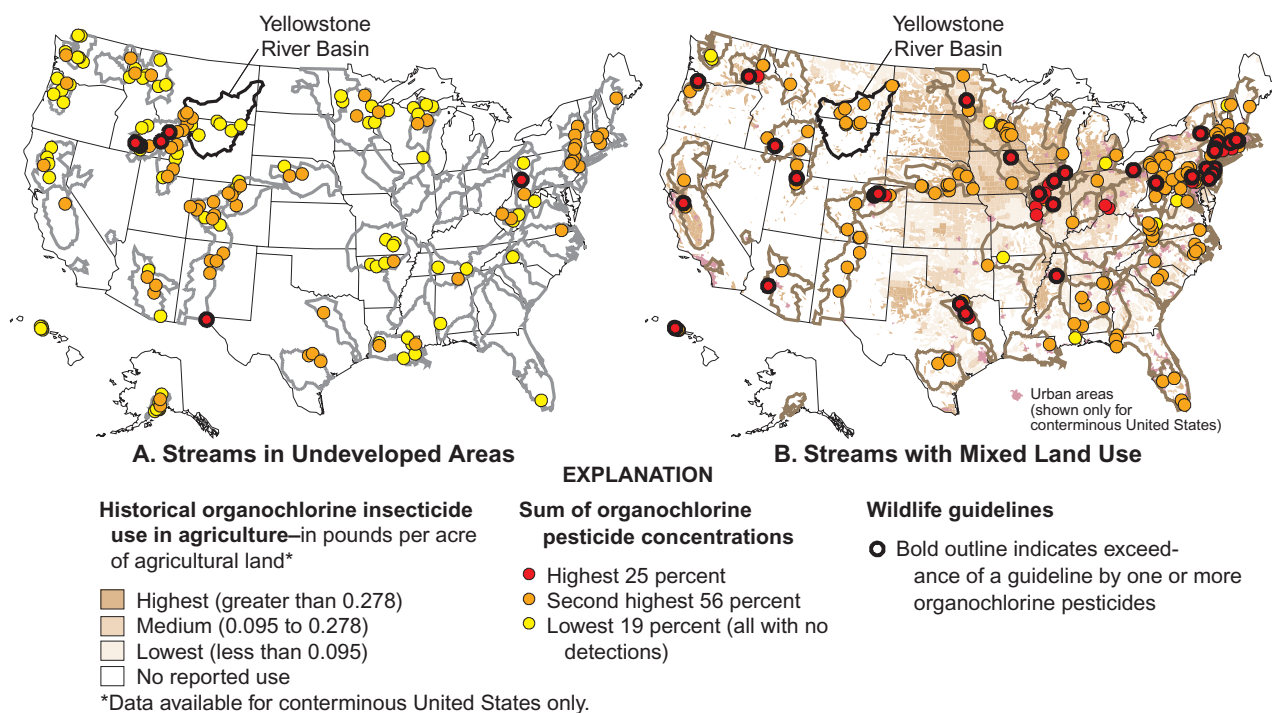
part of the basin (see sidebar on p. 17). Bed-sediment samples collected in conjunction with the fish-tissue samples generally did not contain detectable concentrations of pesticides. One exception was a bed-sediment sample from Goose Creek that contained DDT at a concentration of 2.2 micrograms per kilogram dry weight.

Polychlorinated biphenyls, more commonly known as PCBs, were detected in 3 of 22 fish-tissue samples. The highest concentration of total PCBs in fish tissue (190 micrograms per kilogram wet weight in common carp from Goose Creek near Sheridan) exceeded the New York State recommendation of 110 micrograms per kilogram dry weight for protection of piscivorous (fish-eating) wildlife (Newell and others, 1987). The recommendation from New York is used here as a point of reference

Concentrations of pesticide compounds in fish from the Yellowstone River Basin were low to moderate compared to the rest of the Nation



Fish-tissue samples from 6 of 10 sites draining undeveloped land in the Yellowstone River Basin contained no detectable concentrations of organochlorine insecticide compounds, such as DDE and chlordane. Those sites included rangeland sites and forested mountain sites. This finding is consistent with national findings. About 50 percent of 165 sites in undeveloped areas sampled by NAWQA during 1992–2001 contained no detectable concentrations of pesticides (map A). Pesticide concentrations in fish from areas of mixed land uses in the Yellowstone River Basin were in the second-highest 56 percent on a national basis (map B). None of the concentrations of pesticides in fish tissue from the basin was in the highest 25 percent nationally nor did they exceed guidelines for the protection of fish-eating wildlife. Similarly, concentrations of organochlorine pesticides in bed sediment, PCBs in fish tissue and bed sediment, and semi-volatile organic compounds in bed sediment generally were low in the basin, compared to national concentrations.



because no National or State guidance is available for the basin. PCBs were not detected in any the bed-sediment samples from the basin.

Higher concentrations and more compounds were detected in fish tissue than in the bed-sediment samples from the Yellowstone River Basin, suggesting that fish are more sensitive indicators of organic contamination than bed sediment. The physical and chemical properties of the organochlorine pesticides and PCBs lead to their accumulation in

sediment and tissue rather than water (Nowell and others, 1999).

Concentrations of **semivolatile organic compounds** in bed sediment generally were less than guidelines established by the Canadian Council of Ministers of the Environment (2000). The exceptions were two sites near urban areas of Billings and Sheridan that contained a broad suite of compounds, including **polycyclic aromatic hydrocarbons** (PAHs). Concentrations of benzo(a)pyrene, fluoranthene, and other

PAHs in bed sediment were in the range of concentrations that poses possible adverse effects to aquatic life.

Additional Information

For additional information about organic compounds in fish tissue and bed sediment of the Yellowstone River Basin, see Peterson and Boughton (2000).

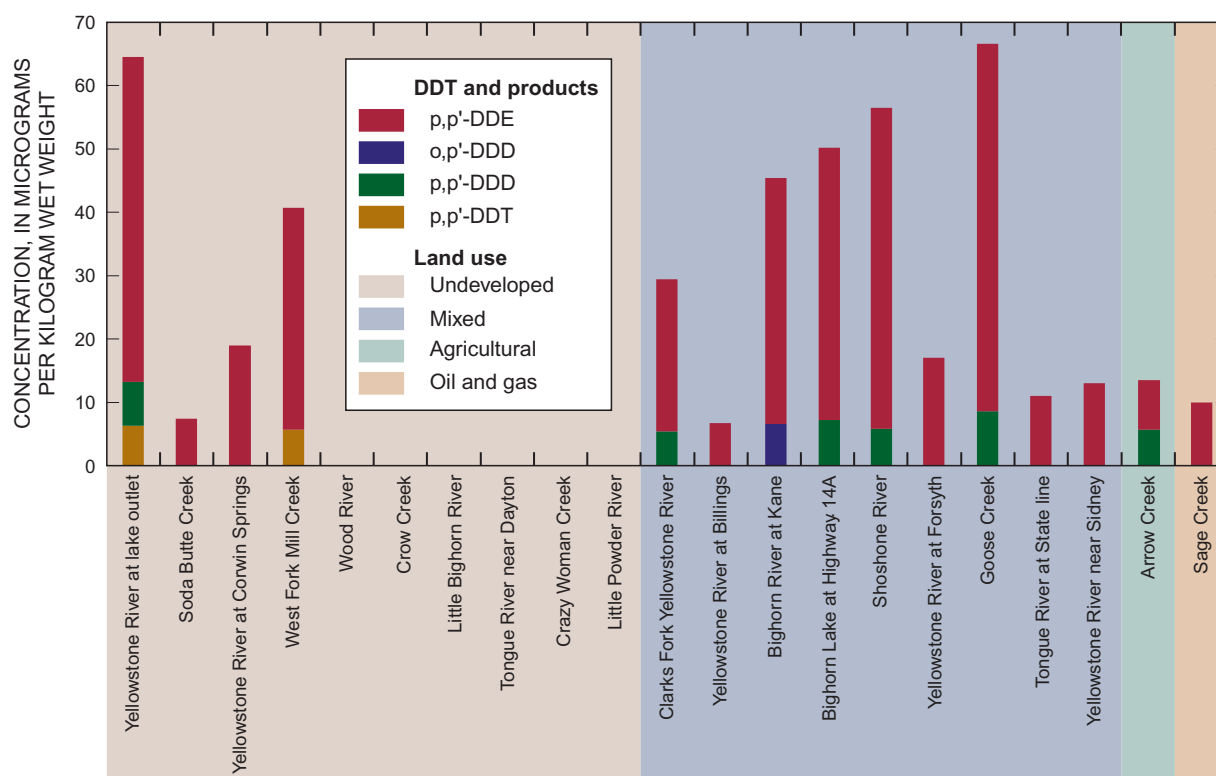


Figure 16. Concentrations of DDT and its breakdown products, DDD and DDE, in fish tissue generally were higher at sites with mixed land use and those near Yellowstone National Park than in other undeveloped areas.

What guidelines are available for evaluating bed sediment?

The guidelines for evaluating organic compounds and trace elements in bed sediment from the Canadian Council of Ministers of the Environment (CCME) (2000) are used in this report because no Federal or State regulations from the states in the study area are available. The CCME defined an interim sediment-quality guideline (ISQG) and a probable effects level (PEL). Concentrations of contaminants in bed sediment below the ISQG are not likely to cause adverse effects to aquatic biota, whereas concentrations above the PEL often are associated with adverse effects to aquatic life. Concentrations between the ISQG and the PEL are in an intermediate range associated with possible effects to biota.

The Environmental Legacy of DDT

General use of DDT in the United States was prohibited in 1972 because of concerns about its toxic effects to humans and wildlife and the environmental persistence and biomagnification of the compound. The presence of DDT in cutthroat trout collected in 1998 from the Yellowstone River near Fishing Bridge in Yellowstone National Park indicates this insecticide is persistent in the environment. Those fish, as well as cutthroat trout from a mountain stream north of the park, contained the parent DDT compound and breakdown products of DDT at concentrations that were among the highest (up to 64.5 micrograms per kilogram) in the basin. A possible source of the DDT in the fish samples might be DDT sprayed in the northern part of Yellowstone Park in 1957 to control spruce budworm (Cope, 1961). Brown trout samples collected in 1957 by Cope (1961) from the Yellowstone River at Corwin Springs (7 miles downstream from the park) contained about 100 times more total DDT than a brown trout sample collected from the same site in 1998. The apparent attenuation of the DDT during the 41 years between samples likely results from breakdown, burial in sediment, and transport of the compound downstream.

Commonly detected volatile organic compounds in Quaternary aquifers are associated with gasoline

Volatile organic compounds (VOCs)—including manufactured organic chemicals used in gasoline, fuel oils, lubricants, solvents, fumigants, pesticides, and sometimes as byproducts of chlorine disinfection (trihalomethanes)—were detected frequently in water samples collected from the Quaternary aquifers. At least one VOC was detected in 21 of 25 wells (about 84 percent). Of the 85 VOCs analyzed, 9 different compounds were detected, 5 of which are commonly associated with gasoline. The VOC 1,2,4-trimethylbenzene was detected most frequently (18 of 25 wells) and at the highest concentrations. Other gasoline-associated hydrocarbons detected were benzene (9 wells), isopropylbenzene (2 wells), 2-ethyltoluene (1 well), and *p*-isopropyltoluene (1 well). The other VOCs detected were solvents: carbon disulfide (4 wells), *n*-propylbenzene (1 well), tetrahydrofuran (1 well), and tetrachloroethene (1 well).

In contrast, one or more VOCs were detected in only 14 of 29 wells (48 percent) in the lower Tertiary aquifers. The VOCs detected in the lower Tertiary aquifers were different from those detected in the Quaternary aquifers—only two detections (benzene) were of gasoline compounds. Other VOCs detected were solvents or trihalomethanes: chloromethane (8 of 29 wells), carbon disulfide (4 wells), tetrahydrofuran (4 wells), trichloromethane (3 wells), tetrachloroethene (1 well), and bromodichloromethane (1 well).

Concentrations of VOCs in both aquifers were low, always below established USEPA drinking-water standards for these compounds.

Ground water underlying low-density development generally is suitable for domestic use

The quality of shallow groundwater underlying low-density development outside of Sheridan and Lander, Wyo. and Red Lodge, Mont., generally is suitable for domestic use without treatment. Effects of human activities associated with residential development, such as septic systems; fertilizer and pesticide use on lawns, pastures, and gardens; manure from horses and pets; and increases in road construction and vehicular traffic were minimal at the time of sampling (2001). Pesticides and VOCs were detected infrequently in 29 wells installed for this study (10 each in Lander and Sheridan and 9 in Red Lodge). Concentrations of pesticides and VOCs always were below applicable drinking-water standards. Concentrations of nitrate were all below the background concentration of 2 mg/L, indicating minimal effects from human activities. Total coliform bacteria were detected infrequently (in 3 wells), and *E. coli* were never detected. Traces of methylene blue active substances—ingredients in laundry detergents—were detected in 11 wells, indicating possible aquifer contamination from septic-tank effluents.

Chlorofluorocarbon age-dating indicated much of the water had recharged the shallow aquifers during the early 1990s or earlier. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect low-density development surrounding the Sheridan, Lander, and Red Lodge areas during the past decade. Continued monitoring is needed to determine effects on water quality from increasing residential development over time.

Some trace-element concentrations in streams and bed sediment exceeded aquatic-life guidelines

Trace elements occur naturally in the environment, and many, such as copper and selenium, are required micronutrients for life (Sorenson, 1991). In excessive concentrations, however, trace elements can be toxic and can negatively affect growth, reproduction, and other biological functions.

Mineralized areas are located in the northwestern part of the basin, where concentrations of copper, lead, chromium, zinc, and other trace elements in bed sediment tended to be high (fig. 17). Concentrations of copper, arsenic, lead, and chromium in bed-sediment samples from the mineralized areas sometimes were within the range of concentrations that indicates possible adverse effects to aquatic life as defined by the Canadian Council of Ministers of the Environment (CCME) (2000).

Concentrations of copper in cutthroat trout and in bed sediment from Soda Butte Creek, a mineralized watershed, were among the highest from the basin. The concentrations of copper in bed sediment from Soda Butte Creek and other mineralized sites in the basin, as well as some of the mixed



Figure 17. Streams in mineralized areas, such as the Wood River in the Absaroka Range, often have high concentrations of trace elements in bed sediment (photograph by Gregory K. Boughton, U.S. Geological Survey).

land-use sites, were within the CCME intermediate range of possible adverse effects to aquatic life. The concentrations of copper from Soda Butte Creek, however, were below levels associated with adverse effects to biota in a previous study of Soda Butte Creek by Nimmo and others (1998). Sources of copper in the bed sediment of Soda Butte Creek include an upstream former mine-tailings impoundment. Concentrations of copper in water samples from Soda Butte Creek and other NAWQA sampling sites in the Yellowstone River Basin were less than the hardness-based criterion for the protection of aquatic life.

Concentrations of dissolved arsenic in stream samples were as large as 42 µg/L in the Yellowstone River at Corwin Springs, where arsenic naturally occurs in geothermal waters. The median concentration of arsenic in the Yellowstone River at Corwin Springs was 21.0 µg/L; 78 percent of the arsenic concentrations at this site exceeded the USEPA drinking-water standard of 10 µg/L. Concentrations were lower, but still elevated, farther downstream at Billings, where the median was 10.5 µg/L (p. 11); 60 percent of the concentrations from the site at Billings exceeded the USEPA drinking-water standard. Human ingestion of arsenic in water can damage the skin and circulatory systems and may result in increased risk of cancer. The arsenic concentration in many of the bed-sediment samples was in the CCME intermediate range of concentrations that indicates possible adverse effects to aquatic biota. One bed-sediment sample, containing 41 micrograms per gram arsenic from the Yellowstone River at Corwin Springs, was in the CCME range of concentrations that indicates probable effects to aquatic biota (the arsenic PEL is 17 micrograms per gram).

Concentrations of dissolved selenium in streams were as large as 4.6 µg/L in the Powder River. The flow-weighted average concentration for water years 2000 and 2001 was 2.5 µg/L. Although these concentrations are less than the aquatic chronic criterion of 5 µg/L, concentrations of total recoverable selenium in water

greater than 2 µg/L may produce adverse effects on some fish and wildlife (U.S. Department of Interior, 1998). Selenium may accumulate to toxic concentrations in the food chain when concentrations in the water are in the 0.5- to 3-µg/L range (Lemly, 1996). Compared to data for irrigation drainage studies (U.S. Department of the Interior, 1998), the concentration of selenium in many fish-liver samples from the basin was higher than the background range but lower than levels of concern for protection of fish and wildlife; the concentration of selenium in bed-sediment samples was within the background range and generally less than the levels of concern.

Selenium concentrations were larger in the Powder River and other streams in the basin draining a high proportion of Upper Cretaceous sedimentary rocks of marine origin, in which selenium occurs naturally, than in those streams that drain proportionally smaller areas of such rocks (fig. 18). For example, the median concentration of dissolved selenium was 1.3 µg/L in stream basins with greater than 20 percent Cretaceous sedimentary rocks, whereas the median was only 0.7 µg/L in basins with no such rock. Previous investigations have documented mobility of selenium in alkaline soils in the arid regions of the Western United States. Concentrations of dissolved selenium also are larger in streams draining irrigated lands with those characteristics (U.S. Department of Interior, 1998).

Concentrations of mercury in edible portions of game fish reached a maximum of 0.676 microgram per gram (wet weight) in skinless fillets of walleye from Bighorn Lake. This concentration is in the range of concentrations used by the Montana Department of Public Health and Human Services (2003) to issue a fish-consumption advisory for Bighorn Lake. Concentrations of mercury in walleye from Bighorn Lake and its two major tributaries, the Bighorn River and the Shoshone River, exceeded the USEPA criterion of 0.3 milligram methylmercury per kilogram of fish (U.S. Environmental Protection Agency, 2003). Concentrations of mercury in fish from the Tongue River and the Yellow-

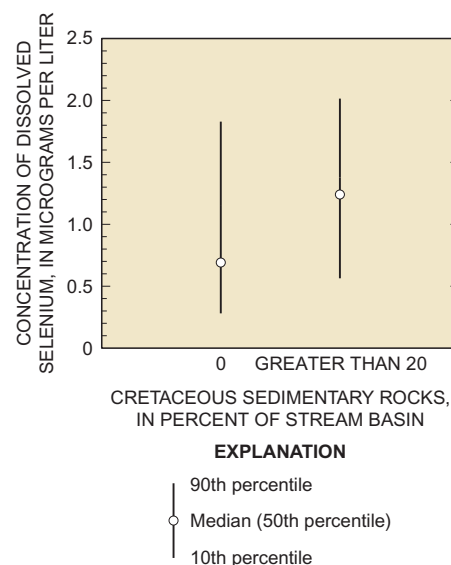


Figure 18. Selenium concentrations are larger from basins with more surface exposure of Cretaceous rocks.

stone River were less than the USEPA criterion. The mean concentration of mercury in fish fillets from the Yellowstone River Basin ranked 5th highest among 20 NAWQA basins sampled across the Nation, but concentrations of total and methyl mercury in water and sediment were lower, comparatively (Brumbaugh and others, 2001). Mercury concentrations in fish samples were best correlated with methylmercury concentration in water samples, but chemical and physical processes associated with reservoirs also might be a factor influencing mercury concentrations in fish from the Yellowstone River Basin (Brumbaugh and others, 2001). Generally, less than 10 percent of the total mercury in bed-sediment samples from the Yellowstone River Basin was in the form of methylmercury, which is more toxic to biota than elemental mercury.

Additional Information

For additional information about trace elements in fish tissue and bed sediment, see Peterson and Boughton (2000). Trace elements in bed sediment also are discussed by Peterson and Zelt (1999) and Boughton (2001).

Trace elements in ground water were generally low compared to drinking-water standards and guidelines

Nearly all of the concentrations of trace elements in the 25 wells completed in the Quaternary aquifers were less than Federal standards and guidelines. Of the 29 wells completed in the lower Tertiary aquifers, the Federal drinking-water standard was exceeded once for antimony, boron, cadmium, and selenium and twice for molybdenum. Concentrations of uranium exceeded the Federal drinking-water standard of 20 $\mu\text{g/L}$ in samples from four wells in the Quater-

nary aquifers and two wells in the lower Tertiary aquifers.

Some wells contained high concentrations of iron and manganese—both trace elements were detected at concentrations greater than USEPA secondary drinking-water guidelines of 0.3 mg/L for iron and 0.05 mg/L for manganese. Although nontoxic, these two elements can limit the uses of the ground water or require treatment because they can cause staining of plumbing fixtures and laundry, as well as creating taste and odor problems.

Periphyton and invertebrate communities are degraded in some segments of the Yellowstone River

Low to moderate concentrations of algae are desirable because algae produce oxygen and provide food and shelter for other aquatic life. Excessive concentrations of algae, however, can result in inadequate dissolved-oxygen concentrations, with harmful effects to other aquatic life, and can detract from esthetic properties and recreational uses. Excessive growths of algae typically are associated with nutrient enrichment, also known as **eutrophication**.

The periphyton chlorophyll-*a* concentrations in the upper segments of

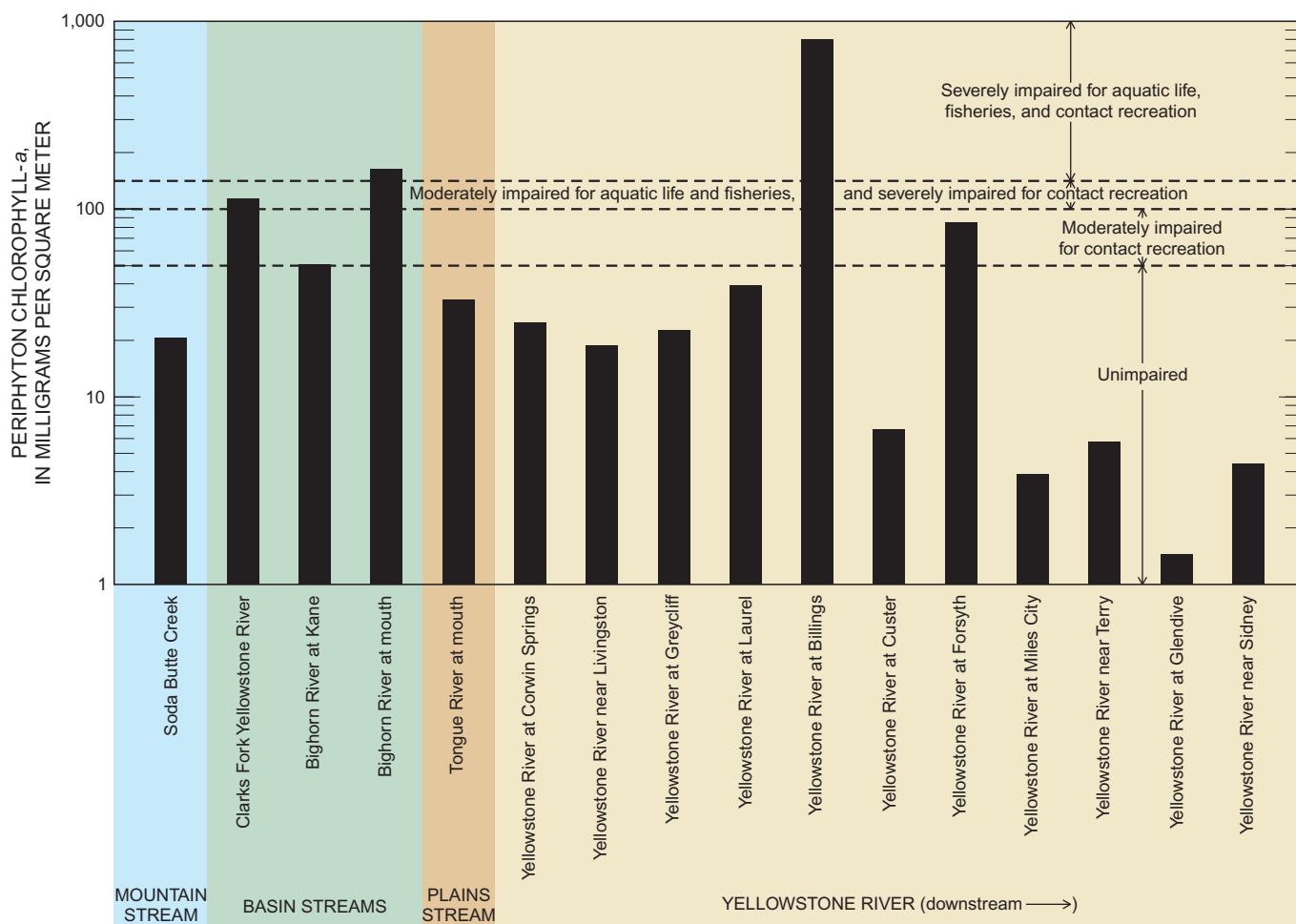


Figure 19. Periphyton chlorophyll-*a* concentrations during August 2000 exceeded screening-level criteria for the protection of designated uses listed by the Montana Department of Environmental Quality (2003).

the Yellowstone River at Corwin Springs and Livingston were about 20–25 mg/m² (milligrams per square meter) (fig. 19). The maximum concentrations of chlorophyll-*a* in the Yellowstone River were 800 mg/m² at Billings, and 85 mg/m² at Forsyth, on the middle segments of the river. Chlorophyll-*a* concentrations were less than 10 mg/m² in the lower segments of the river, from Miles City to Sidney. The maximum concentrations of chlorophyll-*a* detected in the Yellowstone River were at Billings, downstream from the confluence with the Clarks Fork Yellowstone River, and at Forsyth, downstream from the confluence of the Bighorn River. Chlorophyll-*a* concentrations were 110 mg/m² in the Clarks Fork Yellowstone River and 160 mg/m² in the Bighorn River at the mouth (Peterson and Porter, 2002). Some of the concentrations of chlorophyll-*a* sampled at sites in Montana exceeded criteria for designated uses specified by the Montana Department of Environmental Quality (2003). Concentrations of chlorophyll-*a* in samples from the Yellowstone River at Billings and the Bighorn River at the mouth were in the range of severely impaired conditions for the protection of aquatic life and fisheries (greater than 150 mg/m²) and severely impaired conditions for contact recreation (greater than 100 mg/m²) (fig. 19). The concentrations of chlorophyll-*a* in samples from the Clarks Fork Yellowstone River and the Yellowstone River at Forsyth were in the range of either moderately impaired or severely impaired conditions for the designated uses.

The types of algae found in the periphyton community also indicated nutrient enrichment in the middle segments of the Yellowstone River. The percentage of algal species indicative of eutrophication increased with periphyton biomass, and eutrophic species accounted for about 50 percent of algal community structure in the middle segments of the river.

Sources of nutrient enrichment that contribute to periphyton growth include ammonia from geothermal springs in the Yellowstone River headwaters (p. 11) and tributary inflows containing nutri-

ents from natural, agricultural, and rural residential sources, notably in the Clarks Fork Yellowstone and Bighorn River Basins. Water samples collected during August 2000 indicated concentrations of nitrate, a critical nutrient for algae, generally were below reporting limits in the Yellowstone River but were higher in the Clarks Fork and Bighorn Rivers. The apparent lack of nitrate in the Yellowstone River, while at the same time the chlorophyll concentrations and algal community composition indicated nutrient enrichment, could be a reflection of uptake of the nutrient by the algae. For example, Dodds (2003) describes rapid assimilation of nutrients from the water column by a large biomass of primary producers, resulting in nutrient concentrations below the reporting limits. The seasonal variation in nitrate concentrations in the main stem of the Yellowstone River (fig. 11, p. 10) likely is influenced by algal uptake.

Aquatic invertebrates (aquatic insects, snails, and worms) are a **biological indicator** commonly used by State

and Federal agencies to evaluate stream quality and adverse effects potentially resulting from physical disturbance to habitat and eutrophication, such as organic enrichment, high rates of microbial respiration, and inadequate dissolved-oxygen concentrations (Barbour and others, 1999; Hilsenhoff, 1987). A predominance of mayfly, stonefly, and caddisfly species (Ephemeroptera, Plecoptera, and Trichoptera—also known as EPT—taxa that are pollution intolerant) in streams and rivers generally indicates good water quality and habitat conditions, whereas aquatic communities dominated by midges and worms (pollution-tolerant taxa) typically reflect degraded or poor water quality and habitat.

EPT taxa were predominant in the upper segments of the Yellowstone River at Corwin Springs and Livingston, as well as in lower segments of the river from Miles City to Sidney (fig. 20). Higher percentages of tolerant midge and worm taxa in most of the middle

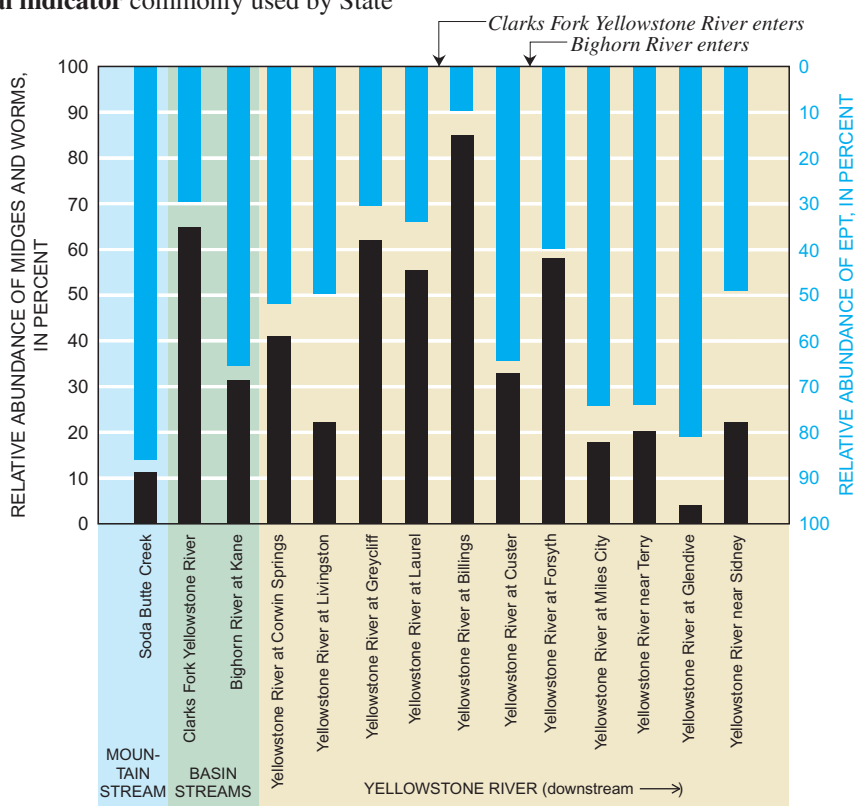


Figure 20. The high percentage of pollution-intolerant mayflies, stoneflies, and caddisflies indicates good water quality and habitat conditions in the upper and lower sections of the Yellowstone River, but a lower percentage indicates degraded conditions in the middle sections.

segments of the river, however, indicate somewhat degraded conditions. Tolerant taxa dominated the invertebrate community of the Yellowstone River at sites downstream from the two largest tributaries, the Clarks Fork Yellowstone and Bighorn Rivers. Invertebrate data (EPT abundance) indicated degraded conditions in the Clarks Fork Yellowstone River but relatively good conditions in mountain tributaries. Invertebrates in the family Simuliidae (blackfly larvae) were common in samples from the Yellowstone River at Livingston and Sidney. Blackfly larvae are filter feeders on particulate organic material suspended in flowing waters and are associated with a wide range of stream conditions.

Additional Information

For additional information on algal and invertebrate communities in the Yellowstone River Basin, see Peterson and Porter (2002) and Peterson and others (2001).

Fish communities reflect water-quality and habitat conditions

Fish-community composition can be used as an indicator of environmental stresses, such as degraded water quality or habitat (Barbour and others, 1999). High percentages of introduced species, tolerant species, and fish with external anomalies reflect environmental stresses, whereas lower percentages of such species and anomalies are considered desirable. External anomalies such as deformities, eroded fins, lesions, and tumors (DELT) might indicate sublethal environmental stresses, intermittent stresses, behavioral stresses, or chemically contaminated substrates (Moulton and others, 2002).

Cold-water fish communities in mountain tributaries and at the uppermost site on the Yellowstone River (Corwin Springs) contained few species when compared to the more diverse

warm-water fish communities in the basin tributaries, plains streams, and lower Yellowstone River (fig. 21). Members of the trout family dominated the cold-water fish communities; sculpin, longnose dace, and suckers also were noted. The sites farther downstream on the Yellowstone River contained 12 to 13 species, representing several families of warm-water fishes including drum, mooneyes, minnows, suckers, catfish, pike, and perch. The lower reaches of the Yellowstone River contained fish such as sauger and sturgeon that are better adapted to warm, turbid water than are trout.

Most of the fish captured were native species, with exceptions at two sites. The fish community of the Tongue River, a mountain stream, contained a high proportion of brown trout and rainbow trout that were introduced to enhance the sport fishery. The warm-water fish community of the Little Powder River, a plains stream, contained many young-of-the-year black bullheads that are classified as an introduced species, although that status is not certain (Baxter and Stone, 1995). The preponderance of black bullheads also caused the Little Powder River to have a higher proportion (74 percent) of fish classified as tolerant to environmental stress than other sites in 1998 (fig. 21). Five fish samples collected from the Little Powder River during 1998 to 2002 indicated a substantial year-to-year variation in fish communities, with a range of 16 to 75 percent tolerant fish. Tolerance ratings were assigned to fish species by using regional and national sources such as Zaroban and others (1999) and Barbour and others (1999).

The highest rates of anomalies in the Yellowstone River Basin were in fish from the Yellowstone River at Billings and Forsyth, where about 15 to 20 percent of the fish had lesions or eroded fins (fig. 21). Although anomalies were noted in several species at each site, members of the sucker family showed the highest rate of anomalies. Eroded fins and lesions (Smith and others, 2002) were the most common external anomalies in the fish samples from Billings and Forsyth. The cause of the anomalies

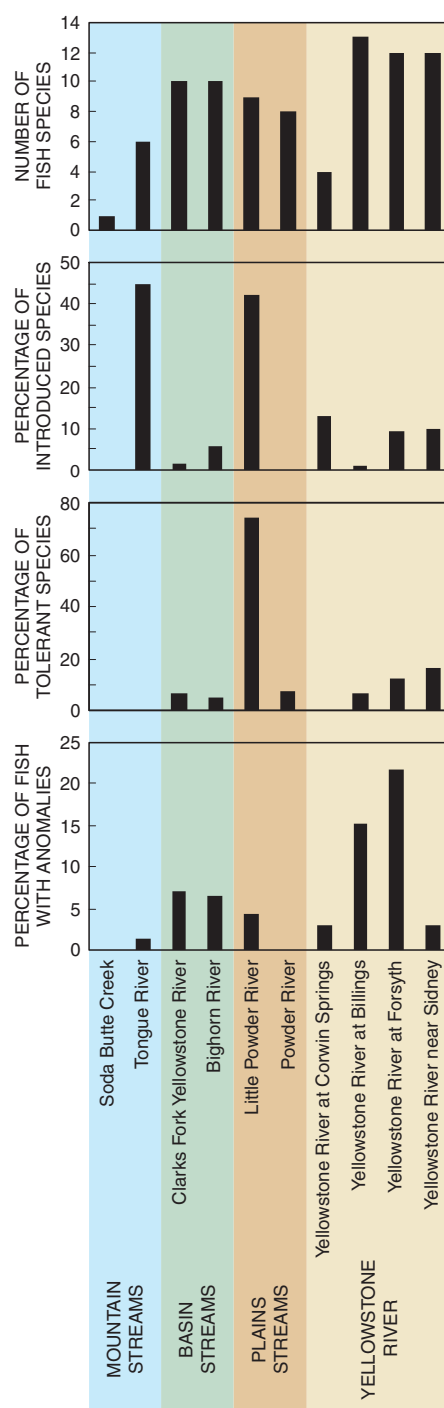


Figure 21. Fish from the Yellowstone River at Billings and Forsyth had more anomalies and intermediate percentages of introduced and tolerant species compared to other sites.

is not known. Less than 10 percent of the fish collected from the Yellowstone River at Forsyth during 2002–03 had external DELT anomalies; comparable data were not available from the Billings site.

Study Unit Design

The Yellowstone River Basin study design blends an assessment of local water-quality issues within a nationally consistent design that incorporates a multiscale, interdisciplinary approach consisting of stream chemistry, stream ecology, and ground-water chemistry (Gilliom and others, 1995) (<http://water.usgs.gov/nawqa>). Surface-water and ecological studies focused primarily on the Yellowstone River, from its upper reaches near Corwin Springs, Mont., to lower segments near Sidney, Mont., as well as major tributaries draining the residential, agricultural, and undeveloped basins, and rangeland plains. Ground-water studies focused primarily on the Quaternary and lower Tertiary aquifers underlying the Bighorn Basin.

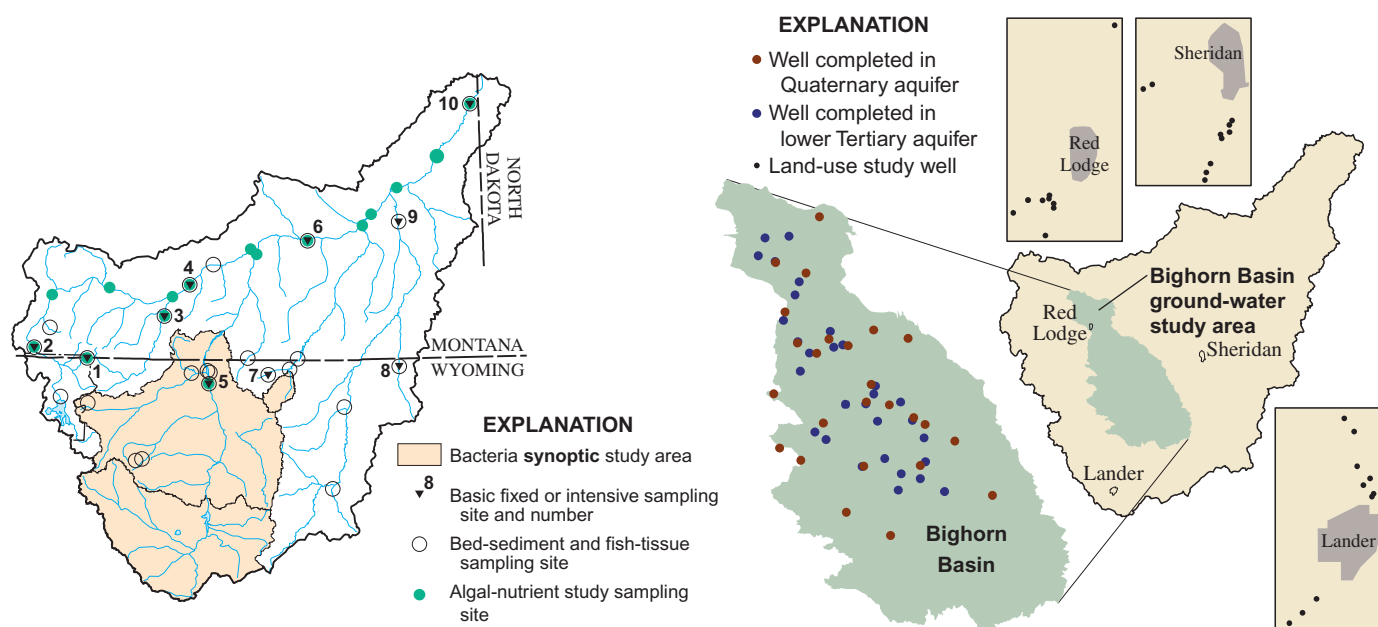


Electrofishing on the Tongue River near Dayton, Wyoming (photograph by Stephen D. Porter, U.S. Geological Survey).

Additional Information

Additional information on streamflow and chemistry data for surface water, ground water, fish tissue, and bed sediment as well as taxonomic data for biota are available at: <http://wy.water.usgs.gov/YELL/htms/data.htm>

Water-quality data and collection and analytical methodologies can be accessed at <http://water.usgs.gov/nawqa>



Basic and intensive stream-sampling sites, Yellowstone River Basin, 1999–2001

Map number	USGS site identifier	Site name	Drainage area (square miles)	Largest category of land cover and land use (percent)
1	06187915	Soda Butte Creek at Yellowstone National Park boundary near Silver Gate, Montana	31.2	Forest (66)
2	06191500	Yellowstone River at Corwin Springs, Montana	2,623	Forest (67)
3	06208500	Clarks Fork Yellowstone River at Edgar, Montana	2,032	Range (45)
4	06214500	Yellowstone River at Billings, Montana	11,795	Forest (41)
5	06279500	Bighorn River at Kane, Wyoming	15,765	Range (73)
6	06295000	Yellowstone River at Forsyth, Montana	40,339	Range (58)
7	06298000	Tongue River near Dayton, Wyoming	204	Forest (74)
8	06324970	Little Powder River above Dry Creek near Weston, Wyoming	1,235	Range (84)
9	06326500	Powder River near Locate, Montana	13,189	Range (82)
10	06329500	Yellowstone River near Sidney, Montana	69,103	Range (65)

Study component	What data are collected and why	Number and types of sites sampled	Sampling frequency and period
Stream Chemistry			
Basic fixed sites	Samples were analyzed for major ions, nutrients, organic carbon, and suspended sediment. Samples were analyzed for trace elements at five sites. Selected samples were analyzed for bacteria. Daily streamflow data also were collected. Data were collected to describe the occurrence and distribution of constituents.	Ten sites, consisting of 6 sites on tributaries representing mineralized, forested, rangeland, and mixed land-use areas; and 4 sites on the Yellowstone River, representing areas of mixed land use.	Monthly, plus additional high-flow samples, January 1999 through October 2001.
Intensive fixed sites	In addition to data collected for basic fixed sites, samples were analyzed for pesticides. Data were collected to describe the occurrence of pesticides and to refine descriptions of seasonal variability of multiple constituents.	Three of the basic fixed sites representing areas with more intensive agricultural land use.	Biweekly to monthly plus additional high-flow samples, January 1999 through December 1999.
Bacteria synoptic	Samples were analyzed for fecal coliform and <i>Escherichia coli</i> to determine the distribution and abundance of coliform bacteria.	One hundred sites on small and large streams with varying land use in the Wind River, Bighorn River, and Goose Creek Basins of Wyoming.	June and July 2000.
Stream Ecology			
Basic and intensive fixed sites	Measurements of instream habitat and riparian areas, and samples of algae, invertebrates, and fish community. Biological and habitat indicators of stream quality.	Stream sizes included three small, wadeable tributaries that were land-use indicator sites , larger tributaries that integrated land uses in the basins, and four large river sites on the main stem Yellowstone River.	All were sampled once during August–September 1999.
Multiyear and multi-reach sites	Measurements of habitat and samples of algae, invertebrates, and fish community. To test variability between years and between reaches.	Two fixed sites were selected for multiyear sampling, and one site for multireach sampling.	Multiyear sites were sampled once per year during 1999–2001 for all data types, and in 1998 for fish. Three reaches were sampled at one site once during 2001.
Bed-sediment and fish-tissue survey	Bed-sediment and fish-tissue samples were analyzed for organic compounds and trace elements, to determine occurrence and distribution.	Twenty-four sites were sampled, including the 10 basic and intensive sites, and 14 other land-use indicator and integrator sites .	Once during July to September 1998.
Algal-nutrient study	Samples of nutrients, algae, invertebrates, and measurements of water properties and selected habitat characteristics, to evaluate the trophic condition of the Yellowstone River and tributaries.	Samples were collected at 11 sites on the main stem Yellowstone River and five sites on tributaries.	Once during August 2000.
Ground-Water Chemistry			
Major aquifer survey—Quaternary unconsolidated-deposit aquifers	Major ions, trace elements, nutrients, volatile organic compounds, pesticides, pesticide breakdown products, and radiochemicals (including radon). To broadly assess water quality in these aquifers.	Twenty-four monitoring wells installed for this study plus 1 domestic well.	Once in October 1999 to March 2000.
Major aquifer survey—lower Tertiary aquifers	Major ions, trace elements, nutrients, volatile organic compounds, pesticides, pesticide breakdown products, and radiochemicals (including radon). To broadly assess water quality in these aquifers.	Fifteen domestic wells, 8 wells used for both domestic and stock purposes, and 6 stock wells.	Once in July 2000 to June 2001.
Land-use monitoring well survey	Major ions, trace elements, nutrients, volatile organic compounds, pesticides, pesticide breakdown products, methylene blue active substances, chlorofluorocarbons (for age dating), and radon. To determine the effects of land use on shallow ground-water quality in these aquifers.	Installed 29 wells about 5 to 10 feet below the water table underlying low-density development surrounding Sheridan (Wyoming), Lander (Wyoming), and Red Lodge (Montana).	Once in June to September 2001.

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Glossary

Aquifer A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Basic fixed sites Sites on streams at which streamflow is measured and samples are collected for temperature, salinity, suspended sediment, major ions and metals, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of streamwater in relation to hydrologic conditions and environmental settings.

Biological indicator A quantitative measure of biological conditions that may reflect habitat disturbance, chemical contamination, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), or fish provides a record of water quality and stream conditions that water-chemistry indicators might not reveal.

Chlorofluorocarbons A class of volatile compounds consisting of carbon, chlorine, and fluorine. Commonly called freons, and have been used in refrigeration mechanisms, as blowing agents in the fabrication of flexible and rigid foams, and, until several years ago, as propellants in spray cans.

DDT Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States.

Dissolved solids Amount of minerals, such as salt, that are dissolved in water; amount of dissolved solids is an indicator of salinity or hardness.

Drinking-water standard or guideline A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Eutrophication The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Flow-weighted average A concentration calculated by first multiplying each sample concentration by its associated streamflow value, then dividing the sum of these products by sum of the streamflows. The resultant mean value accounts for the effects of variable streamflow on concentrations.

Major ions Constituents commonly present in concentrations exceeding 1.0 milligram per liter. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.

Indicator sites Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions; most indicator-site basins have drainage areas ranging from 20 to 200 square miles.

Integrator or mixed-use site Stream sampling site located at an outlet of a drainage basin that contains multiple environmental settings. Most integrator sites are on major streams with relatively large drainage areas.

Intensive fixed sites Basic fixed sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides for 1 year. Most NAWQA Study Units have one to two integrator intensive fixed sites and one to four indicator intensive fixed sites.

Nonpoint source A contaminant source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source contaminant.

Pesticide A chemical applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents, or other "pests."

Point-source contaminant Any substance that degrades water quality and originates from discrete locations such as discharge pipes, drainage ditches, wells, concentrated livestock operations, or floating craft.

Polycyclic aromatic hydrocarbon (PAH) A class of organic compounds with a fused-ring structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of uncombusted coal and oil. PAHs include benzo(a)pyrene, fluoranthene, and pyrene.

Semivolatile organic compound (SVOC) Operationally defined as a group of synthetic organic compounds that are solvent-extractable and can be determined by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, and polycyclic aromatic hydrocarbons (PAHs).

Stratification Subdivision of the environmental framework. The basin is divided into areas that exhibit reasonable homogeneous environmental conditions, as determined by both natural and human influences.

Synoptic sites Sites sampled during a short-term investigation of specific water-quality conditions during selected seasonal or hydrologic conditions to provide improved spatial resolution for critical water-quality conditions.

Trace element An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc.

Water year The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2000, is referred to as the water year 2000.

Yield The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

Appendix—Water-Quality Data from the Yellowstone River Basin in a National Context

Concentrations and detection frequencies of the most commonly detected constituents, constituents that exceed a drinking-water standard or aquatic-life guideline, or constituents that are of regulatory or scientific importance, are presented below. Plots of other pesticides, nutrients, VOCs, and trace elements assessed in the Yellowstone River Basin are available at our Web site at:

<http://water.usgs.gov/nawqa/graphs>

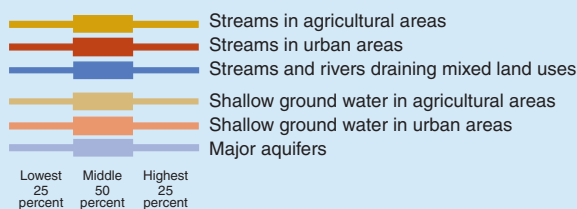
These summaries of chemical concentrations and detection frequencies from the Yellowstone River Basin are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant growth. These graphical summaries provide a comparison of chemical concentrations and detection frequencies between (1) surface- and ground-water resources, (2) agricultural, urban, and mixed land uses, and (3) shallow ground water and aquifers commonly used as a source of drinking water.

CHEMICALS IN WATER

Concentrations and detection frequencies, Yellowstone River Basin, 1999–2001

- ◆ Detected concentration in Study Unit
- 66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency
- Not measured or sample size less than two
- 12 Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

National ranges of detected concentrations, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and the desired goal for preventing nuisance plant growth due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment

- Drinking-water quality (applies to ground water and surface water)
- Protection of aquatic life (applies to surface water only)
- Prevention of nuisance plant growth in streams
- * No benchmark for drinking-water quality
- ** No benchmark for protection of aquatic life

Data in this appendix were compiled in a nationally consistent manner to facilitate comparisons among NAWQA Study Units. Some data presented in the body of this report may be compiled in a different manner to better describe variability in the Yellowstone River Basin Study Unit.

For example, the graph for atrazine shows that detections and concentrations in the Yellowstone River Basin generally (1) are lower than national findings in streams in areas of mixed land use; (2) do not exceed USEPA drinking-water standards in streams that drain areas of mixed land use; (3) are slightly greater, on average, in ground water than in streams.

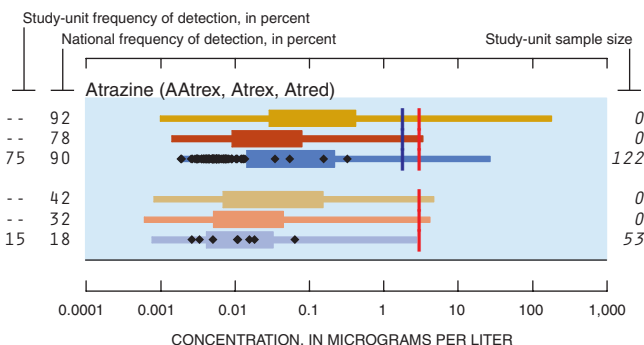
NOTE to users:

- The analytical detection limit varies among the monitored chemicals, thus frequencies of detections are not comparable among chemicals.
- It is important to consider the frequency of detection along with concentration. For example, *p,p'*-DDE was detected more frequently in fish tissue from streams draining mixed land use areas in the Yellowstone River Basin than in mixed land-use streams nationwide (100 percent compared to 92 percent) but generally was detected at lower concentrations.

Quality-control data for these analytes indicate relatively frequent low-level contamination of samples during sample processing for analysis. Results for these analytes cannot, therefore, be presented using the generalized methods that were applied to other analytes in this Appendix. Analysis of results for analytes potentially affected by contamination requires special statistical treatment beyond the scope of this report. For more information about these analytes and how to interpret data on their occurrence and concentrations, please contact the appropriate NAWQA Study Unit.

Trace elements in ground water: aluminum, barium, boron, cadmium, chromium, cobalt, copper, lithium, nickel, strontium, zinc
SVOCs in bed sediment: phenol, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, di-*n*-butylphthalate, diethylphthalate
Insecticides in water: *p,p'*-DDE

Pesticides in water—Herbicides



Other herbicides detected

Acetochlor (Harness Plus, Surpass) **
 Benfluralin (Balan, Benefin, Bonalan, Benefex) **
 Cyanazine (Bladex, Fortrol)
 2,4-D (Aqua-Kleen, Lawn-Keep, Weed-B-Gone)
 DCPA (Dacthal, chlorthal-dimethyl) **
 Deethylatrazine (Atrazine metabolite, desethylatrazine) **
 Diuron (Crisuron, Karmex, Direx, Diurex) **
 EPTC (Eptam, Farmarox, Alirox) **
 Ethalfuralin (Sonalan, Curbit) **
 Metolachlor (Dual, Pennant)
 Prometon (Pramitol, Princep, Gesagram 50, Ontrac 80) **
 Simazine (Princep, Caliber 90, Gesatop, Simazat)
 Tebuthiuron (Spike, Tebusan)
 Triallate (Far-Go, Avadex BW, Tri-allate) *
 Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
 Acifluorfen (Blazer, Tackle 2S) **
 Alachlor (Lasso, Bronco, Lariat, Bullet) **
 Bentazon (Basagran, Bentazone, Bendioxide) **
 Bromacil (Hyvar X, Urox B, Bromax)
 Bromoxynil (Buctril, Brominal) *
 Butylate (Sutan +, Genate Plus, Butilate) **
 Clopyralid (Stinger, Lontrel, Reclaim) * **
 2,4-DB (Butyrac, Butoxone, Embutox Plus) *
 Dacthal mono-acid (Dacthal metabolite) * **
 Dicamba (Banvel, Dianat, Scotts Proturf)
 Dichlorprop (2,4-DP, Seritox 50, Kildip) * **
 2,6-Diethylaniline (metabolite of Alachlor) * **
 Dinoseb (Dinosebe)
 Fenuron (Fenulon, Fenidim) * **
 Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon) **
 Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
 MCPA (Rhomene, Rhonox, Chiptox)
 MCPB (Thistrol) * **
 Metribuzin (Lexone, Sencor)
 Molinate (Ordram) * **
 Napropamide (Devrinol) * **
 Neburon (Neburea, Neburyl, Noruben) * **
 Norflurazon (Evital, Predict, Solicam) * **
 Oryzalin (Surflan, Dirimal) * **
 Pebulate (Tillam, PEBC) * **
 Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
 Picloram (Grazon, Tordon)
 Pronamide (Kerb, Propyzamid) **
 Propachlor (Ramrod, Satecid) **
 Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
 Propham (Tuberite) **
 2,4,5-T
 2,4,5-TP (Silvex, Fenoprop)
 Terbacil (Sinbar) **
 Thiobencarb (Bolero, Saturn, Benthicarb, Abolish) * **
 Triclopyr (Garlon, Grandstand, Redeem) * **

Pesticides in water—Insecticides**Insecticides detected**

Aldicarb (Temik, Ambush, Pounce)
 Carbaryl (Carbamine, Denapon, Sevin)
 Carbofuran (Furadan, Curaterr, Yaltox)
 Chlorpyrifos (Brodan, Dursban, Lorsban)
 Dieldrin (Panoram D-31, Octalox)
 Malathion (Malathion)
 Terbufos (Contraven, Counter, Pilarfox) **

Insecticides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
 Acifluorfen (Blazer, Tackle 2S) **
 Alachlor (Lasso, Bronco, Lariat, Bullet) **
 Bentazon (Basagran, Bentazone, Bendioxide) **
 Bromacil (Hyvar X, Urox B, Bromax)
 Bromoxynil (Buctril, Brominal) *
 Butylate (Sutan +, Genate Plus, Butilate) **
 Clopyralid (Stinger, Lontrel, Reclaim) * **
 2,4-DB (Butyrac, Butoxone, Embutox Plus) *
 Dacthal mono-acid (Dacthal metabolite) * **
 Dicamba (Banvel, Dianat, Scotts Proturf)
 Dichlorprop (2,4-DP, Seritox 50, Kildip) * **
 2,6-Diethylaniline (Metabolite of Alachlor) * **
 Dinoseb (Dinosebe)
 Fenuron (Fenulon, Fenidim) * **
 Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon) **
 Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
 MCPA (Rhomene, Rhonox, Chiptox)
 MCPB (Thistrol) * **
 Metribuzin (Lexone, Sencor)
 Molinate (Ordram) * **
 Napropamide (Devrinol) * **
 Neburon (Neburea, Neburyl, Noruben) * **

Norflurazon (Evital, Predict, Solicam) * **
 Oryzalin (Surflan, Dirimal) * **
 Pebulate (Tillam, PEBC) * **
 Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
 Picloram (Grazon, Tordon)
 Pronamide (Kerb, Propyzamid) **
 Propachlor (Ramrod, Satecid) **
 Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
 Propham (Tuberite) **
 2,4,5-T
 2,4,5-TP (Silvex, Fenoprop)
 Terbacil (Sinbar) **
 Thiobencarb (Bolero, Saturn, Benthicarb, Abolish) * **
 Triclopyr (Garlon, Grandstand, Redeem) * **
 Aldicarb sulfone (Standak, aldoxycarb)
 Aldicarb sulfoxide (Aldicarb metabolite)
 Azinphos-methyl (Guthion, Gusathion M) *
 Diazinon (Basudin, Diazatol, Knox Out)
 Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton) **
 Ethoprop (Mocap, Ethoprophos) * **
 Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
 alpha-HCH (alpha-BHC, alpha-lindane) **
 gamma-HCH (Lindane, gamma-BHC, Gammexane)
 3-Hydroxycarbofuran (Carbofuran metabolite) * **
 Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
 Methomyl (Lanox, Lannate, Acinate) **
 Methyl parathion (Pennacp-M, Folidol-M, Metacide, Bladan M) **
 Oxamyl (Vydate L, Pratt) **
 Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
 Phorate (Thimet, Granutox, Geomet, Rampart) * **
 Propargite (Comite, Omite, Ornamite) * **
 Propoxur (Baygon, Blattanex, Uden, Propotox) * **

Volatile organic compounds (VOCs) in ground water**VOCs detected**

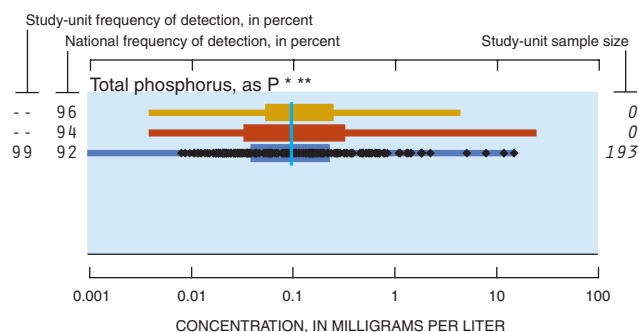
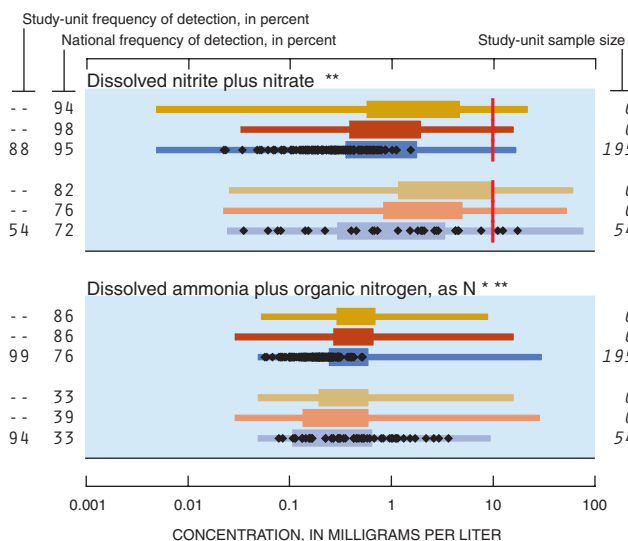
Benzene
 Bromodichloromethane (Dichlorobromomethane) **
 Carbon disulfide * **
 Chloromethane (Methyl chloride) **
 1,2-Dimethylbenzene (*o*-Xylene) **
 1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene) **
 Ethylbenzene (Phenylethane)
 2-Ethyltoluene (*o*-Ethyltoluene) * **
 Isopropylbenzene (Cumene) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
 Methylbenzene (Toluene)
n-Propylbenzene (Isocumene) * **
 Tetrachloroethene (Perchloroethene)
 Tetrahydrofuran (Diethylene oxide) * **
 Trichloromethane (Chloroform)
 1,2,4-Trimethylbenzene (Pseudocumene) * **

VOCs not detected

Acetone (Acetone) * **
 Bromobenzene (Phenyl bromide) * **
 Bromochloromethane (Methylene chlorobromide) **
 Bromoethene (Vinyl bromide) * **
 Bromomethane (Methyl bromide) **
 2-Butanone (Methyl ethyl ketone (MEK)) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
 3-Chloro-1-propene (3-Chloropropene) * **
 1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
 1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
 Chlorobenzene (Monochlorobenzene)
 Chloroethane (Ethyl chloride) * **
 Chloroethene (Vinyl chloride) **
 1,2-Dibromo-3-chloropropane (DBCP, Nemagon) **
 Dibromochloromethane (Chlorodibromomethane) **
 1,2-Dibromoethane (Ethylene dibromide, EDB) **
 Dibromomethane (Methylene dibromide) * **
trans-1,4-Dichloro-2-butene ((*Z*)-1,4-Dichloro-2-butene) * **

1,3-Dichlorobenzene (*m*-Dichlorobenzene)
 1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
 Dichlorodifluoromethane (CFC 12, Freon 12) **
 1,2-Dichloroethane (Ethylene dichloride)
 1,1-Dichloroethane (Ethylidene dichloride) **
 1,1-Dichloroethene (Vinylidene chloride) **
trans-1,2-Dichloroethene ((E)-1,2-Dichloroethene) **
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene) **
 Dichloromethane (Methylene chloride)
 1,2-Dichloropropane (Propylene dichloride) **
 2,2-Dichloropropane ***
 1,3-Dichloropropane (Trimethylene dichloride) ***
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene) **
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene) **
 1,1-Dichloropropene ***
 Diethyl ether (Ethyl ether) **
 Diisopropyl ether (Diisopropylether (DIPE)) **
 Ethenylbenzene (Styrene) **
 Ethyl methacrylate (Ethyl methacrylate) **
 Ethyl tert-butyl ether (Ethyl-*t*-butyl ether (ETBE)) **
 1,1,2,3,4,4-Hexachloro-1,3-butadiene (Hexachlorobutadiene)
 1,1,1,2,2,2-Hexachloroethane (Hexachloroethane) **
 2-Hexanone (Methyl butyl ketone (MBK)) ***
 Iodomethane (Methyl iodide) ***
 Methyl acrylonitrile (Methacrylonitrile) **
 Methyl methacrylate (Methyl-2-methacrylate) **
 Methyl *tert*-butyl ether (MTBE) **
 4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) **
 Methyl-2-propenoate (Methyl acrylate) ***
 Naphthalene
 2-Propenenitrile (Acrylonitrile) **
 1,1,2,2-Tetrachloroethane **
 1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
 Tetrachloromethane (Carbon tetrachloride)
 1,2,3,4-Tetramethylbenzene (Prenitene) **
 1,2,3,5-Tetramethylbenzene (Isodurene) ***
 Tribromomethane (Bromoform) **
 1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) **
 1,2,4-Trichlorobenzene
 1,2,3-Trichlorobenzene (1,2,3-TCB) *
 1,1,1-Trichloroethane (Methylchloroform) **
 1,1,2-Trichloroethane (Vinyl trichloride) **
 Trichloroethene (TCE)
 Trichlorofluoromethane (CFC 11, Freon 11) **
 1,2,3-Trichloropropane (Allyl trichloride) **
 1,2,3-Trimethylbenzene (Hemimellitene) ***
 1,3,5-Trimethylbenzene (Mesitylene) ***
tert-Amyl methyl ether (TAME) ***

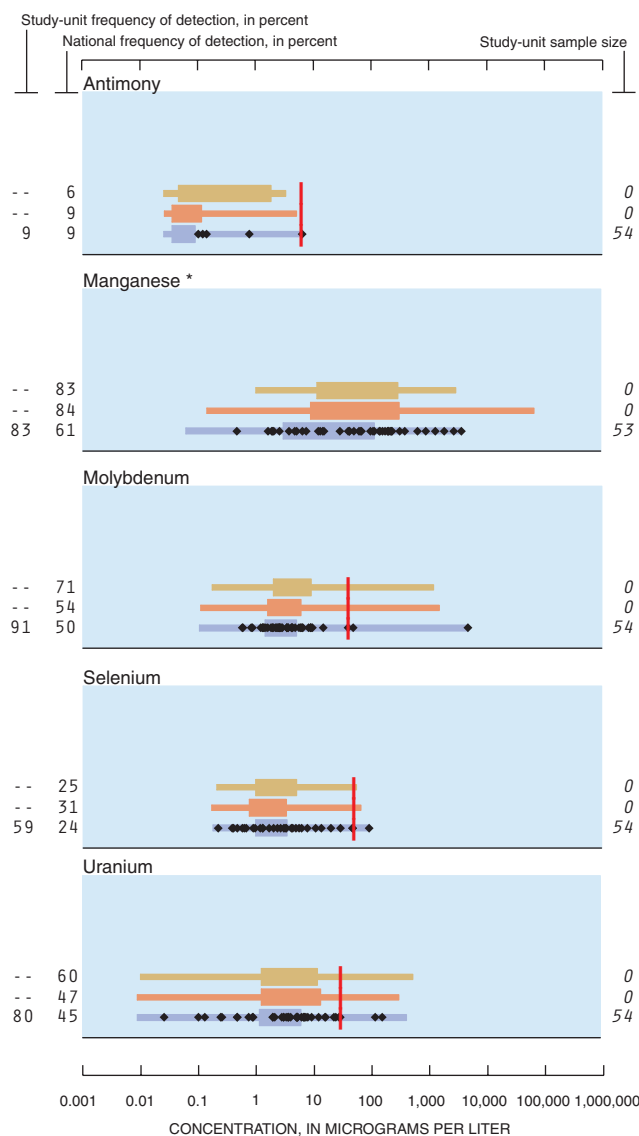
Nutrients in water

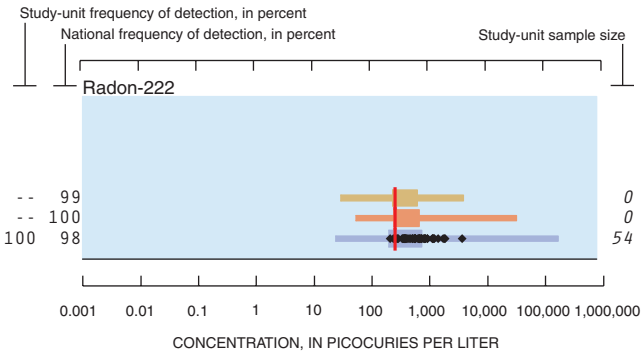


Other nutrients detected

Orthophosphate as P **
 Ammonia **

Trace elements in ground water





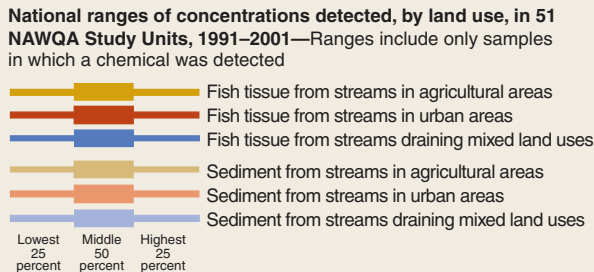
Other trace elements detected

- Arsenic
- Beryllium
- Lead
- Thallium
- Vanadium *

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Yellowstone River Basin 1999–2001— Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

- ◆ Detected concentration in Study Unit
- 66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency
- Not measured or sample size less than two
- 12 Study-unit sample size

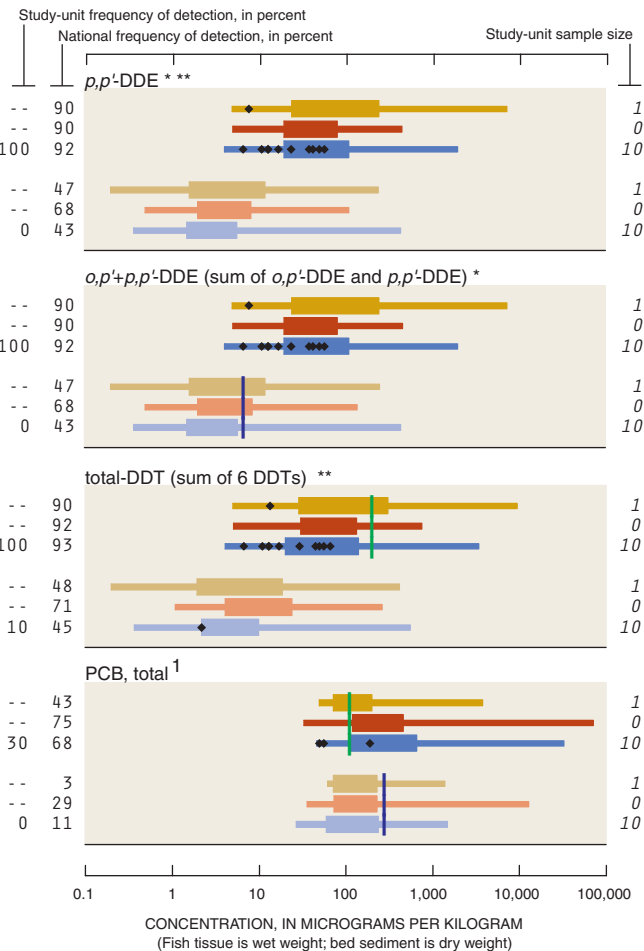


National benchmarks for fish tissue and bed sediment

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment.

- Protection of fish-eating wildlife (applies to fish tissue)
- Protection of aquatic life (applies to bed sediment)
- * No benchmark for protection of fish-eating wildlife
- ** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment



¹ The national detection frequencies for total PCB in sediment are biased low because about 30 percent of the samples nationally had elevated detection limits compared to this Study Unit. See <http://water.usgs.gov/nawqa/> for additional information.

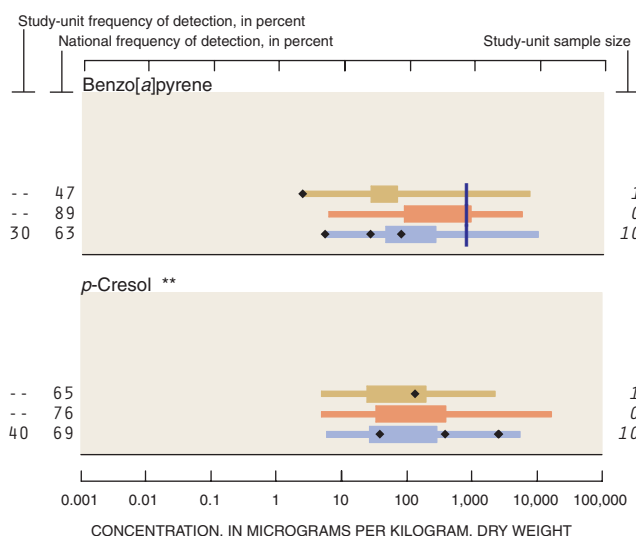
Other organochlorines detected

- total-Chlordane (sum of 5 chlordanes)
- o,p'*+*p,p'*-DDD (sum of *o,p'*-DDD and *p,p'*-DDD) *
- o,p'*+*p,p'*-DDT (sum of *o,p'*-DDT and *p,p'*-DDT) *
- Dieldrin (Panoram D-31, Octalox) *
- Dieldrin+aldrin (sum of dieldrin and aldrin) **
- p,p'*-Methoxychlor (Marlate, methoxychlor) ***
- Pentachloroanisole (PCA, pentachlorophenol metabolite) ***

Organochlorines not detected

- Chloroneb (chloronebe, Demosan) ***
- DCPA (Dacthal, chlorthal-dimethyl) ***
- Endosulfan I (alpha-Endosulfan, Thiodan) ***
- Endrin (Endrine)
- gamma-HCH (Lindane, gamma-BHC, Gammexane) *
- Total HCH (sum of alpha, beta, gamma, and delta-HCH) **
- Heptachlor epoxide (Heptachlor metabolite) *
- Heptachlor+heptachlor epoxide **
- Hexachlorobenzene (HCB) **
- Isodrin (Isodrine, Compound 711) ***
- o,p'*-Methoxychlor ***
- Mirex (Dechlorane) **
- cis*-Permethrin (Ambush, Astro, Pounce) ***
- trans*-Permethrin (Ambush, Astro, Pounce) ***
- Toxaphene (Camphechlor, Hercules 3956) ***

Semivolatile organic compounds (SVOCs) in bed sediment



Other SVOCs detected

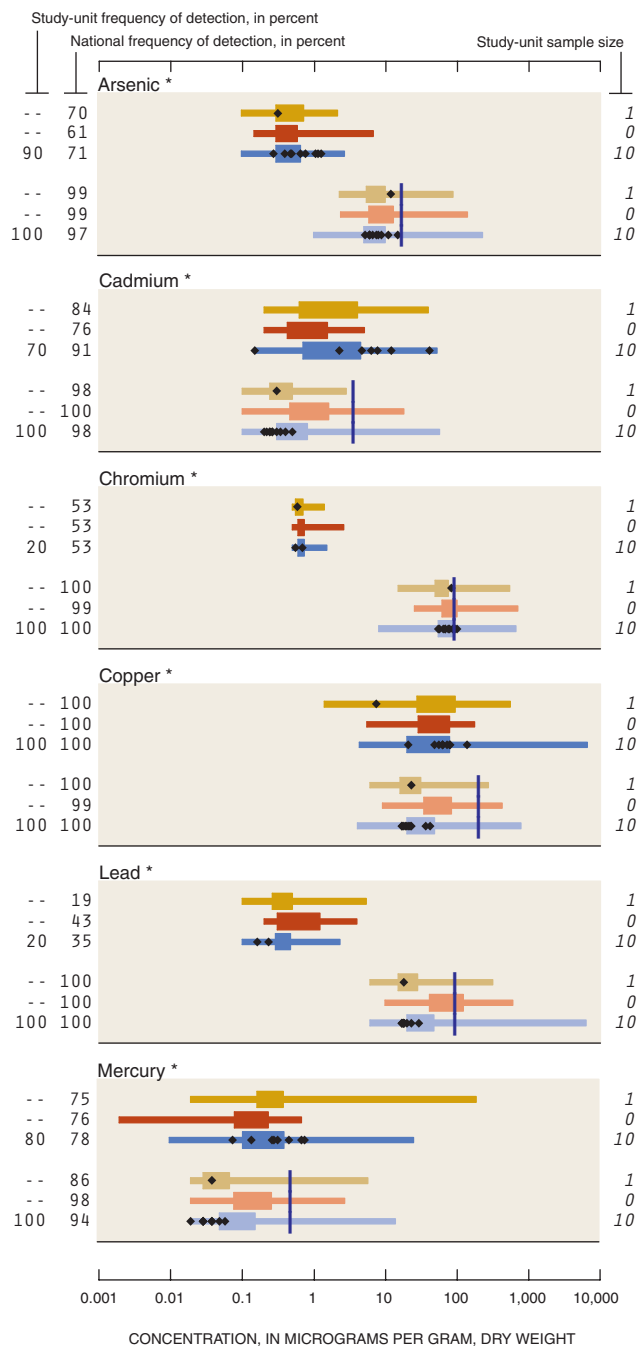
Acenaphthene
Acridine **
Anthracene
Anthraquinone **
Benz[a]anthracene
Benzo[b]fluoranthene **
Benzo[g,h,i]perylene **
Benzo[k]fluoranthene **
9*H*-Carbazole **
Chrysene
Di-*n*-octylphthalate **
Dibenz[a,h]anthracene
Dibenzothiophene **
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
3,5-Dimethylphenol **
Fluoranthene
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
2-Methylantracene **
4,5-Methylenepheneanthrene **
1-Methylphenanthrene **
Naphthalene
Phenanthrene
Pyrene

SVOCs not detected

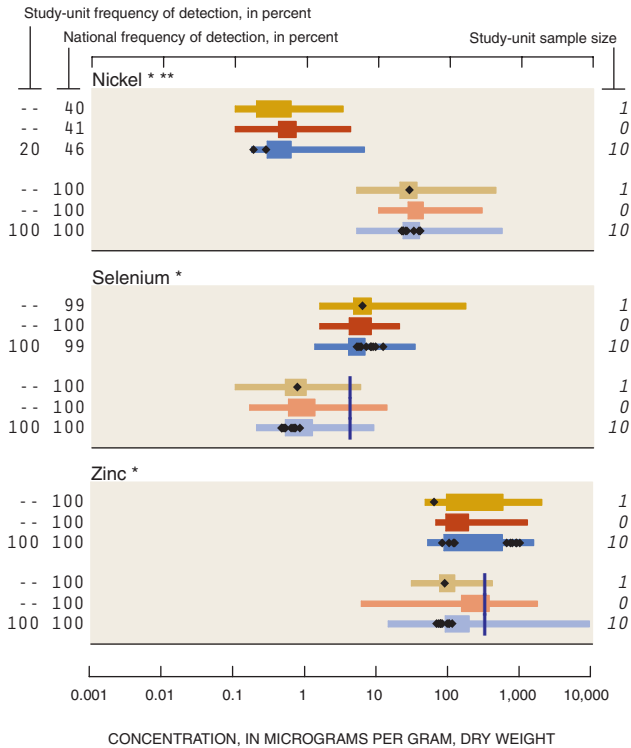
Acenaphthylene
C8-Alkylphenol **
Azobenzene **
Benzo[c]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis (2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB) **
1,2-Dimethylnaphthalene **
Dimethylphthalate **
2,4-Dinitrotoluene **
Isophorone **
Isoquinoline **

1-Methyl-9*H*-fluorene **
1-Methylpyrene **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Phenanthridine **
Quinoline **
1,2,4-Trichlorobenzene **
2,3,6-Trimethylnaphthalene **

Trace elements in fish tissue (livers) and bed sediment



34 Water Quality in the Yellowstone River Basin



Trace element not detected

Silver

Coordination with agencies and organizations in the Yellowstone River Basin was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee.

Federal agencies

U.S. Department of the Interior
Bureau of Land Management
Bureau of Reclamation
National Park Service
Yellowstone National Park
Bighorn Canyon National Recreation Area
U.S. Fish and Wildlife Service
U.S. Environmental Protection Agency
U.S. Department of Agriculture
Forest Service
Natural Resources Conservation Service

Universities

University of Montana, Bozeman
University of Montana, Missoula
University of Wyoming, Laramie

State Agencies

Wyoming Game and Fish Dept.
Wyoming Dept. of Environmental Quality
Montana Fish, Wildlife, and Parks Dept.
Montana Dept. of Environmental Quality
Wyoming Water Development Commission
Wyoming Dept. of Agriculture
Montana Dept. of Natural Resources and Conservation
North Dakota Dept. of Health
Wyoming State Engineer

Other public and private organizations

Upper Yellowstone River Task Force
Wind River Environmental Quality Council
Crow Tribes
Northern Cheyenne Tribe
Yellowstone Ecosystem Studies

Local Agencies

County Conservation Districts, Wyoming and Montana
Wyoming Association of Conservation Districts
Montana Association of Conservation Districts
Yellowstone River Coalition of Conservation Districts

We thank the following individuals for contributing to this effort.

Field work to collect water-quality samples was a combined effort from many USGS people from Wyoming and Montana, and in particular, Peter Wright and Stacy Kinsey. Their dedication to high-quality work through many miles and sometimes adverse weather conditions is greatly appreciated. Others who assisted in similar fashion include Karen Watson, Laura Hallberg, and Jon Mason, as well as many others from the Casper, Riverton, Billings, Fort Peck, and Cheyenne offices. We also thank the landowners that let us drill wells on their property or allowed us access to sampling sites.

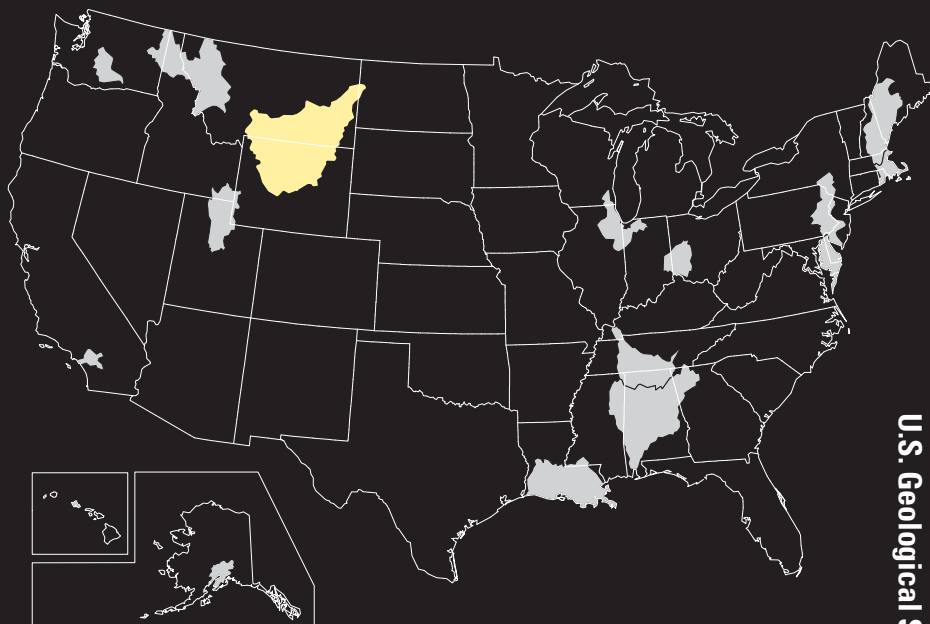
Collection of ecology samples was accomplished by USGS people including Ron Zelt, Stacy Kinsey, Peter Wright, Ivan James, Rod DeWeese, Karen Watson, Tommie Leman, Greg Boughton, and others. Field assistance for sampling of fish communities was provided by the Wyoming Game and Fish Department, including Bob McDowell, Bill Bradshaw, Bud Stewart, and Mike Welker, as well as from Montana Fish, Wildlife, and Parks, including Mike Vaughn, Vic Riggs, and Joel Tohtz. The assistance of Pete Ramirez, Kim Dickerson, and Bill Olsen from the U.S. Fish and Wildlife Service also is gratefully acknowledged.

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NAWQA

National Water-Quality Assessment (NAWQA) Program Yellowstone River Basin



Peterson and others—Water Quality in the Yellowstone River Basin
U.S. Geological Survey Circular 1234



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