A Synoptic Study of Fecal-Indicator Bacteria in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000

Water-Resources Investigations Report 03-4055

Prepared as part of the
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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

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By Melanie L. Clark and Merry E. Gamper

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Cheyenne, Wyoming
2003

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Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resource Locator (URL):
<http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

FOREWORD

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

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

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

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

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
kilogram	2.205	pound (lb)

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) as follows:

$$°F = 9/5(°C) + 32$$
$$°C = 5/9(°F - 32)$$

Abbreviated water-quality units used in this report:

col/100 mL	colonies per 100 milliliters
µm	micrometer
mg/L	milligrams per liter
mL	milliliters
NTU	nephelometric turbidity units
µS/cm	microsiemens per centimeter at 25 degrees Celsius
<	less than
>	greater than

Abbreviations used in this report:

EPA	U.S. Environmental Protection Agency
NAWQA	National Water-Quality Assessment Program
NLCD	National Land Cover Data
RPD	Relative percent difference
USGS	U.S. Geological Survey
WDEQ	Wyoming Department of Environmental Quality
YRB	Yellowstone River Basin

A Synoptic Study of Fecal-Indicator Bacteria in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000

By Melanie L. Clark and Merry E. Gamper

ABSTRACT

A synoptic study of fecal-indicator bacteria was conducted during June and July 2000 in the Wind River, Bighorn River, and Goose Creek Basins in Wyoming as part of the U.S. Geological Survey's National Water-Quality Assessment Program for the Yellowstone River Basin. Fecal-coliform concentrations ranged from 2 to 3,000 col/100 mL (colonies per 100 milliliters) for 100 samples, and *Escherichia coli* concentrations ranged from 1 to 2,800 col/100 mL for 97 samples. Fecal-coliform concentrations exceeded the U.S. Environmental Protection Agency's recommended limit for a single sample for recreational contact with water in 37.0 percent of the samples. *Escherichia coli* concentrations exceeded the U.S. Environmental Protection Agency's recommended limit for a single sample for moderate use, full-body recreational contact with water in 38.1 percent of the samples and the recommended limit for infrequent use, full-body recreational contact with water in 24.7 percent of the samples.

Fecal-indicator-bacteria concentrations varied by basin. Samples from the Bighorn River Basin had the highest median concentrations for fecal coliform of 340 col/100 mL and for *Escherichia coli* of 300 col/100 mL. Samples from the Wind River Basin had the lowest median concentrations for fecal coliform of 50 col/100 mL and for *Escherichia coli* of 62 col/100 mL.

Fecal-indicator-bacteria concentrations varied by land cover. Samples from sites with an urban land cover had the highest median concentrations for fecal coliform of 540 col/100 mL and for *Escherichia coli* of 420 col/100 mL. Maximum concentrations for fecal coliform of 3,000 col/100 mL and for *Escherichia coli* of 2,800 col/100 mL were in samples from sites with an agricultural land cover. The lowest median concentrations for fecal coliform of 130 col/100 mL and for *Escherichia coli* of 67 col/100 mL were for samples from sites with a forested land cover.

A strong and positive relation existed between fecal coliform and *Escherichia coli* (Spearman's Rho value of 0.976). The majority of the fecal coliforms were *Escherichia coli* during the synoptic study. Fecal-indicator-bacteria concentrations were not correlated to streamflow, water temperature, dissolved oxygen, pH, specific conductance, and alkalinity. Fecal-indicator-bacteria concentrations were moderately correlated with turbidity (Spearman's Rho values of 0.662 and 0.640 for fecal coliform and *Escherichia coli*, respectively) and sediment (Spearman's Rho values of 0.628 and 0.636 for fecal coliform and *Escherichia coli*, respectively).

Escherichia coli isolates analyzed by discriminant analysis of ribotype patterns for samples from the Bighorn River at Basin, Wyoming, and Bitter Creek near Garland, Wyoming, in the Bighorn River Basin were determined to be from nonhuman and human sources. Using a confidence interval of 90 percent, more of the isolates from both sites were classified as being from nonhuman than human sources; however, both samples had additional isolates that were classified as unknown sources.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began full implementation of the National Water-Quality Assessment (NAWQA) Program. The objectives of the NAWQA Program are to: 1) describe current water-quality conditions for a large part of the Nation's freshwater streams and aquifers; 2) describe how water quality is changing over time; and 3) improve our understanding of the primary natural and human factors that affect water-quality conditions. In order to achieve these objectives, over 50 Study Units containing important river basins and aquifer systems were selected that represent diverse hydrogeologic settings and over 60 percent of the national water use and population.

The Yellowstone River Basin (YRB) was selected to be one of these NAWQA Study Units. The YRB Study Unit consists of the 182,000 km^2 (square kilometers) area that is drained by the Yellowstone River and its tributaries, including the Clarks Fork Yellowstone, Wind/Bighorn, Tongue, and Powder Rivers. Of the total area, 51 percent is in Montana, 48 percent is in Wyoming, and 1 percent is in North Dakota (Miller and Quinn, 1997). Activities by the NAWQA Program in the YRB Study Unit began in 1997. A 3-year intensive data-collection period during 1999-2001 included the collection of ground-water, stream-water, and biological data.

The NAWQA Program assesses stream quality based on water-column chemistry, bed sediment and fish tissue, and ecological studies. Water-column chemistry of the YRB was assessed using a fixed-site network that included sampling for a wide range of constituents with a high sampling frequency at a limited number of sites and synoptic studies that targeted selected constituents with a low sampling frequency at a large number of sites. A synoptic study to determine the distribution of fecal-indicator bacteria was conducted at 100 sites in three basins in the YRB in Wyoming—the Wind River, the Bighorn River, and the Goose Creek Basins (fig. 1). These basins were selected for study because of the known presence of fecal-indicator bacteria. Each site was sampled once during June-July, 2000.

Background

Fecal-indicator bacteria, including total coliform, fecal coliform, *Escherichia coli* (*E. coli*), fecal streptococci, and enterococci, are used to assess the sanitary quality of water because their presence can be an indication that contamination by fecal material has occurred. Fecal contamination can be from point or nonpoint sources. The primary point source of bacterial contamination is sewage treatment outfalls. Nonpoint sources are diffuse in nature and include: 1) agricultural—animal waste, application of manure to fields, crop irrigation from contaminated storage ponds; 2) urban/residential—failed septic systems, pet waste, landfill leakage; 3) recreational—direct discharge of sewage or waste; and 4) wildlife waste (Wilhelm and Maluk, 1998).

Fecal-indicator bacteria do not necessarily cause illness themselves; however, they are found in association with pathogens. Large levels of fecal-indicator bacteria indicate the possible presence of pathogens that cause such waterborne diseases as gastroenteritis and bacillary dysentery, typhoid fever, and cholera (Myers and Sylvester, 1997). Pathogens can pose a health risk even at low concentrations. Because of the difficulties in analyzing for the actual pathogens, fecal-indicator bacteria are widely used to assess the potential for their presence.

Fecal coliforms commonly are used as the fecal-indicator bacteria for determining the sanitary conditions of recreational waters. Fecal coliforms are defined as the subgroup of total coliforms able to ferment lactose with the production of gas in 24 hours at an incubation temperature of 44.5^{o}C (Dufour, 1977). Despite their name, at least one member of the fecal-coliform group, *Klebsiella*, has non-fecal sources, including pulp and paper mill effluents, textile processing plant effluents, cotton mill wastewaters, and sugar beet wastes (U.S. Environmental Protection Agency, 1986). The presence of *E. coli* in recreational waters is direct evidence that fecal contamination from humans or other warm-blooded animals has occurred (Dufour, 1977; Cabelli, 1977).

The presence of fecal-indicator bacteria, primarily fecal coliform, has been documented in the Wind River, Bighorn River, and Goose Creek Basins of the YRB. In the Wind River Basin, fecal-coliform concentrations greater than 400 col/100 mL (colonies per 100 milliliters) occasionally were measured at a site on

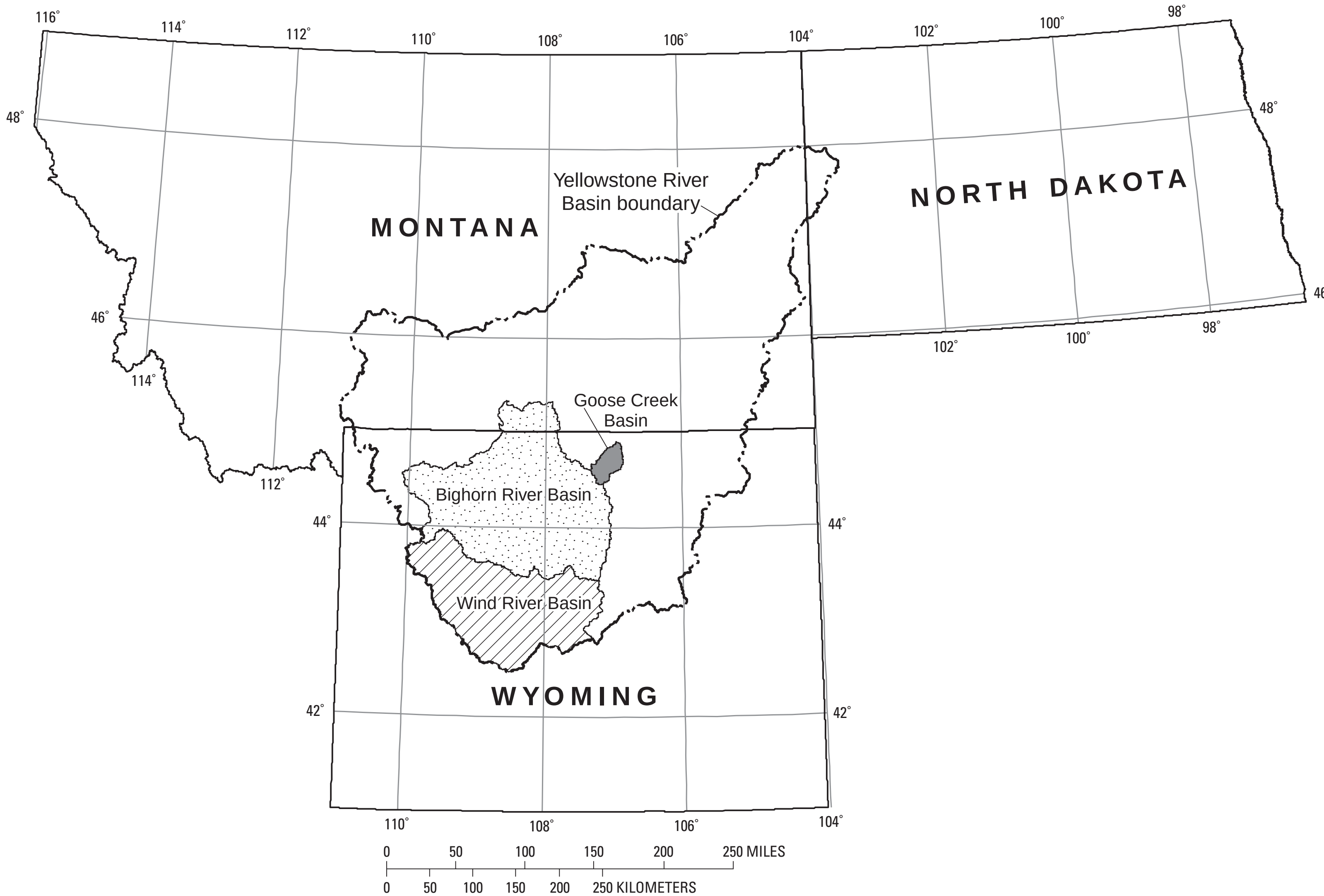


Figure 1. Location of the Wind River, Bighorn River, and Goose Creek Basins in the Yellowstone River Basin.

the Little Wind River near Riverton, Wyo. for the period 1990-99 (Clark and Norris, 2000). Preliminary data prepared for the Popo Agie Conservation District indicate fecal-indicator bacteria, including *E. coli*, were found at elevated concentrations in the Middle Fork Popo Agie River, a tributary in the Wind River Basin (J. States, consultant, written commun., 2001). Stream reaches in the Bighorn River and Goose Creek Basins were assessed as being impaired by fecal coliform for contact recreation in the Wyoming 305(b) water-quality assessment for 2000 (Wyoming Department of Environmental Quality, 2000). Additional monitoring programs by the State have confirmed the presence of fecal coliform in these basins (J. Smith, Wyoming Department of Environmental Quality, oral commun., 2000). In an interim report prepared for the Hot Springs Conservation District and the Wyoming Department of Agriculture on a water-quality study in Hot Springs County in Wyoming, concentrations of fecal coliform exceeding 2,000 col/100 mL were reported for Kirby Creek, a tributary to the Bighorn River, during 1999 (G. Hurley, consultant, written commun., 2000). Concentrations of fecal coliform exceeding 1,000 col/100 mL were reported for Bitter Creek, a tributary to the Shoshone River in the Bighorn River Basin, during 1977 to 1982 (Wenzel, 1984). The study cited the Powell Sewage Treatment Plant and small private wastewater systems with inadequate construction as sources contributing bacteria to Bitter Creek. A water-quality assessment study by the Sheridan County Conservation District during 1996 to 1999 found fecal-coliform concentrations that exceeded water-quality criteria in the Tongue River drainage near Goose Creek. The concentrations exceeded water-quality criteria more often during the recreational season (May 1 to September 30) than during the non-recreational season (Sheridan County Conservation District, 2000).

The presence and distribution of fecal-indicator bacteria has been related to land-cover characteristics in other study areas. Embrey (1992) determined fecal-indicator-bacteria concentrations were higher in agricultural and urban settings compared to rangeland and forested settings in the Yakima River Basin, Washington. For streams in North and South Carolina, Wilhelm and Maluk (1998) found that maximum fecal-indicator-bacteria concentrations were within agricultural areas, whereas the highest median concentrations were within urban areas. A study of the distribution of fecal-indicator bacteria along a gradient of residential development in Alaska found urban areas served by sewer systems had significantly higher concentrations than rural areas served by septic systems; however, differences due to variability in population density could not be distinguished (Frenzel and Couvillion, 2002). Cattle grazing has been linked to the presence of fecal-indicator bacteria in agricultural (Howell and others, 1995) and rangeland settings (Jawson and others, 1982; Sherer and others, 1988; Stephenson and Street, 1978).

Need exists to distinguish between fecal-indicator bacteria associated with human waste as opposed to other warm-blooded animal waste because human fecal wastes represent a greater risk with regard to recreational water quality (Cabelli, 1977). Human feces more readily carry enteric pathogens that infect humans, including *Salmonella* spp., *Shigella* spp., hepatitis A virus, and Norwalk group viruses, compared to nonhuman feces (Parveen and others, 1999). However, agricultural animals also may carry pathogens that are harmful to humans, including *E. coli* 0157:H7, *Salmonella* spp., and *Shigella* spp. (Dombek and others, 2000). Most basins have multiple host sources, including humans, pets, agricultural animals, and wildlife.

Historically, a common field technique for differentiating sources of fecal pollution was based on ratios of fecal coliform to fecal streptococci; a ratio of greater than or equal to 4.0 was used to indicate a human source and a ratio less than or equal to 0.7 was used to indicate a nonhuman source of fecal material (Geldreich and Kenner, 1969). A later study found the source of contamination could not be determined using this technique because the ratio was not constant for samples from the same origin, and the fecal streptococci test was too general (Pourcher and others, 1991). More recent work describes newer techniques for microbial source tracking. For example, a field study in Puget Sound reported different serotypes of RNA coliphages for different fecal sources. Samples from streams in a predominantly urban area were serotyped as implicating human sources, whereas samples from streams in a rural and agricultural area were serotyped as implicating nonhumans (Embrey, 2001). Antibiotic resistance analysis is another technique used to identify sources of bacteria. Because antibiotics are so widely used in human and agricultural animals, bacteria from these sources develop different patterns of resistance. One method of antibiotic resistance analysis uses fecal streptococci to differentiate fecal sources (Wiggins, 1996; Wiggins and others, 1999). A field study using this method found that the fecal streptococci were from cattle sources in greater than 78 percent of the isolates (Hagedorn and others, 1999). Other contributions were from waterfowl, deer, and unknown sources. Another method of antibiotic resistance analysis uses *E. coli* to differentiate fecal sources. A field study of *E. coli* isolates from Apalachicola Bay found that *E. coli* from point sources showed greater antibiotic resistance than isolates from nonpoint sources, indicating human and nonhuman sources, respectively (Parveen and others, 1997). Two DNA methods for differentiating *E. coli* sources are rep-PCR DNA fingerprinting (Dombek and others, 2000) and discriminant analysis of ribotype patterns (Parveen and others, 1999; Carson and others, 2001). A field study in Grand Teton National Park in western Wyoming found that isolated colonies of *E. coli* from a stream in the Park contained ribotype patterns that matched avian, deer, canine, elk, rodent, and human sources (Farag and others, 2001).

Purpose and Scope

This report describes a synoptic study conducted in the Wind River, Bighorn River, and Goose Creek Basins of the YRB in Wyoming during June-July 2000. The objectives of this report are to:

1. Describe the distribution of fecal-indicator bacteria in the Wind River, Bighorn River, and Goose Creek Basins.
2. Describe the distribution of fecal-indicator bacteria as it relates to land cover.
3. Describe the relation between *E. coli* and fecal coliform.
4. Describe the relations between fecal-indicator bacteria and other water-quality constituents.
5. Present results for *E. coli* samples that were analyzed using a microbial source-tracking method.

Acknowledgments

This report resulted from the efforts of many people. The authors graciously thank the Hot Springs, Meeteetse, Shoshone, South Bighorn, and Washakie Conservation Districts for providing additional funding to increase the number of sampling sites in the Bighorn River Basin and providing field assistance. The authors also thank the Popo Agie, Powell-Clarks Fork, and the Sheridan County Conservation Districts, Lower Wind River Natural Resource District, U.S. Forest Service, Wind River Environmental Quality Council, and the Wyoming Department of Environmental Quality for their assistance in site determinations. Thanks are extended to the USGS people that helped with the field work for this study, including Eric Blajszczak, Jason Feltner, Nathan Majerus, Kirk Miller, Thomas Pointon, Wilfrid Sadler, Karen Watson, and Peter Wright. Sue Roberts and Emily Sabado assisted with the preparation of this report.

ENVIRONMENTAL SETTING

The Wind River and Bighorn River compose a large part of the YRB in Wyoming. The drainage area for the Wind River Basin covers about 20,300 km^2 before the river changes name to the Bighorn River at the “Wedding of the Waters.” The drainage area for the Bighorn River Basin above Bighorn Lake at Kane, Wyo. is the largest of the three basins in the synoptic study and covers about 40,800 km^2, which includes the area drained by the Wind River. The Shoshone River Basin at Kane, Wyo., also part of the Bighorn River Basin above Bighorn Lake, drains an additional 7,740 km^2. Goose Creek is tributary to the Tongue River in the eastern drainage area of the YRB. The Goose Creek Basin is a small basin and covers about 1,060 km^2 at Acme, Wyo.

The Wind River, Bighorn River, and Goose Creek Basins all have the same general physiography of high mountains and lowland basins. The Bighorn River Basin and parts of the Wind River and Goose Creek Basins are part of the Middle Rocky Mountains province. Lowland basins of the Wind River Basin are part of the Wyoming Basin province, and lowlands of the Goose Creek Basin are part of the Unglaciated Missouri Plateau section (Zelt and others, 1999). All three basins are geologically similar, with Precambrian rocks at the center of the high mountains that are flanked by Paleozoic and Mesozoic sedimentary rocks. Tertiary rocks, partially overlain by Quaternary alluvium, are typical of the lowland basins. In the Wind and Bighorn River Basins, Eocene rocks associated with the Absaroka volcanic field also are present (Zelt and others, 1999).

Cold winters and warm summers characterize the climates of the lowland basins (Western Regional Climate Center, 2002). All three basins have a similar range of minimum and maximum mean monthly temperatures during the year (table 1). Annual precipitation varies among the basins. Annual precipitation is about 180 millimeters in Greybull, Wyo., about 220 millimeters in Riverton, Wyo., and about 380 millimeters in Sheridan, Wyo. Maximum temperatures decrease and annual precipitation increases with increasing elevation in all three basins.

The distribution of the land cover for the basins was determined using the National Land Cover Data (NLCD), a 30-meter resolution, raster-based dataset. Details of the NLCD land-cover classification process are discussed in Vogelmann, Sohl, Campbell, and Shaw (1998) and Vogelmann, Sohl, and Howard (1998). The land-cover classifications in the synoptic-study basins included: water (open water, snow/ice), developed (residential, commercial, industrial, transportation), barren (bare rock/sand/clay, quarries/strip mines/pits, transitional), forested upland (deciduous, evergreen and mixed forest), shrubland, herbaceous upland natural/semi-natural vegetation (grasslands/herbaceous), herbaceous planted/cultivated (pasture/hay, row crops, small grains, fallow, urban and recreation grasses), and wetland (woody wetlands, emergent herbaceous wetlands).

The distributions of land cover in the Wind and Bighorn River Basins are similar; the Goose Creek Basin has a higher percentage of forested upland and less shrubland (fig. 2). Land cover in the Wind River Basin includes: shrubland (62 percent), herbaceous upland natural/semi-natural vegetation (21 percent), forested upland (10 percent), and herbaceous planted/cultivated (4 percent). Water, developed, barren, and wetland land covers each overlie one percent or less of the area in the Wind River Basin. Land cover in the Bighorn River Basin includes: shrubland (52 percent), herbaceous upland natural/semi-natural vegetation (27 percent), forested upland (15 percent), and herbaceous planted/cultivated (4 percent). Water, developed, barren, and wetland land covers each overlie less than one percent of the area in the Bighorn River Basin. Land cover in the Goose Creek Basin includes: forested upland (41 percent), herbaceous upland natural/semi-natural vegetation (35 percent), herbaceous planted/cultivated (15 percent), shrubland (5 percent), and wetland (2 percent). Water, developed, and barren land covers each overlie one percent or less of the area in the Goose Creek Basin.

Table 1. *Minimum and maximum mean monthly air temperatures for climate stations in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming.*

Climate station	Basin	Mean monthly: Temperature minimum (month)	Mean monthly: Temperature maximum (month)	Period of record
Riverton, Wyo.	Wind River	-10°C (January)	21°C (July)	1918-2000
Greybull, Wyo.	Bighorn River	-8°C (January)	22°C (July)	1951-2000
Sheridan, Wyo.	Goose Creek	-6°C (January)	21°C (July)	1948-2000

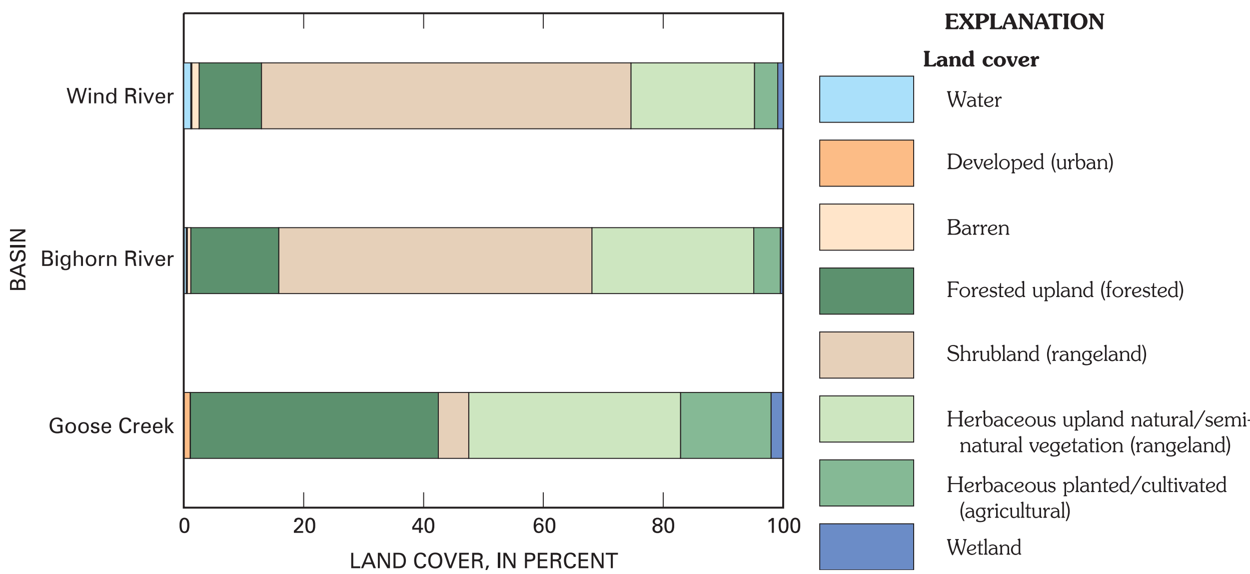


Figure 2. Relative distribution of land cover in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming.

SAMPLING SITES AND METHODS

Sampling sites were selected based on land cover, site access, presence of an existing or historical stream gage, and input from local agencies. Twenty-three sites were sampled along the Wind River, Little Wind River, and selected tributaries (fig. 3), 53 sites were sampled along the Bighorn River, Shoshone River, and selected tributaries (fig. 4), and 24 sites were sampled along Big Goose Creek, Little Goose Creek, Goose Creek, and selected tributaries (fig. 5). Map numbers, USGS site numbers, and site names for sites in all three basins are listed in table 2.

Methods used during field measurements, sample collection, and fecal-indicator-bacteria sample processing are described in the following sections. Methods used during data analysis, including comparisons to water-quality criteria, land-cover classification for sites, and statistical analysis, and microbial source-tracking methods also are described.

Field Measurements and Sample Collection

Measurements of standard NAWQA field water-quality constituents were made during the sample-collection visits of the synoptic study. Standard methods for sample collection and field measurements of water-quality constituents are described in the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997 to 2002). Streamflow was measured using the methods described in Rantz and others (1982) during the sample-collection visit when a stream gage did not exist. Streamflow for sites with gages were either measured or computed from stage-streamflow ratings. Most of the streams for this synoptic study were wadeable, and samples were collected using a DH-81 sampler and equal-width-integrating sampling techniques in order to cross-sectionally composite the samples. For non-wadeable streams, samples were collected with a D-95 sampler, and multiple-vertical sampling techniques were used if an acceptable bridge or cableway existed. Samples from a few sites were collected using a hand-dip method because the sites either were too shallow for a sampler or did not have an acceptable bridge or cableway.

Air temperature, water temperature, and dissolved oxygen were measured on-site at the time of sample collection. Cross-sectionally composited samples were used for measurements of pH, specific conductance, turbidity, and filtered alkalinity. Specific conductance and pH were determined using electronic meters. Turbidity was measured using a Hach 2100P portable field turbidimeter, sensitive to 1,000 NTU (nephelometric turbidity units). Alkalinity samples were filtered through a 0.45-micrometer plate filter and titrated with an inflection-point method using incremental additions of sulfuric acid. Two deviations from standard procedures for pH, specific conductance, turbidity, and filtered alkalinity were necessary because of the scale of the synoptic study: 1) samples were prepared and analyzed for these constituents at a central field laboratory as quickly as possible after collection rather than on site, and 2) constituents were not determined in triplicate because sample volumes were limited. Suspended-sediment samples were cross-sectionally composited and sent to the sediment laboratory at the USGS Montana District office for analysis (Lambing and Dodge, 1993).

Sterile conditions are required for the collection, preservation, and storage of samples for fecal-indicator bacteria. Details on methods used for agar preparation and fecal-indicator-bacteria processing are described in Myers and Sylvester (1997) and U.S. Environmental Protection Agency (2000). To help minimize analytical variability, all samples were processed using the same equipment and same person at a central field laboratory. Multiple aliquots of stream water (generally 3 mL (milliliters), 10 mL, 30 mL, and 100 mL) were processed through the membrane filters to increase the likelihood of an ideal enumeration. Enumeration methods are described in Myers and Sylvester (1997). Fecal-indicator-bacteria concentrations are listed as ‘E’ for estimated, with a qualifier ‘k’ when counts were outside the ideal range of 20 to 60 colonies for fecal coliform or 20 to 80 colonies for *E. coli*. A few concentrations are listed as ‘E’ for estimated, without the non-ideal colony count qualification because only a partial plate was readable. Waters with large sediment concentrations or poorly formed colonies can result in a plate that is unreadable or only partially readable. *E. coli* concentrations are not listed for three sites because the entire plate was unreadable and an estimate could not be made.

Quality-control samples, including blanks and replicates, were collected during the synoptic study. Sampling equipment blanks, membrane-filtration equipment blanks, and membrane-filtration procedure blanks were processed with sterile water to determine if contamination occurred during the sample collection or processing. Sampling equipment blanks were processed for each sampler bottle and nozzle. Membrane-filtration equipment blanks were processed for every sample before sample aliquots were processed to assure that the filtration equipment and buffer water were sterile. Membrane-filtration procedure blanks were processed after the filtration process to assure that the rinsing procedures used during sample processing were adequate. Generally, procedure blanks are processed at least every fourth sample (Francy and others, 2000). Twenty-five percent of samples were processed with the procedure blanks, although not necessarily after every fourth sample due to the large number of samples and limitations on incubator space at a given time.

Replicate samples were analyzed to determine variability of fecal-indicator-bacteria concentrations resulting from sample processing procedures. The equation used for determining the relative percent difference (RPD) between the environmental sample and the replicate samples is:

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

Replicate samples were processed from the same bottle as the environmental sample.

Data Analysis

Data in this report are compared to water-quality criteria for assessing relative magnitude of fecal-indicator-bacteria concentrations. During 2000, the State of Wyoming used fecal-coliform water-quality criteria for assessing sanitary water quality based on the criteria recommended in 1976 by the U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 1976). The State of Wyoming criteria for fecal coliform for a water body are not a single number but are based on multiple samples, the class of water, time of year, and location relative to sewage treatment outfalls (Wyoming Department of Environmental Quality, 1990). Historically, EPA studies determined that statistically significant swimming-associated gastrointestinal illness may occur when concentrations of fecal coliform are greater than 400 col/100 mL for a single sample (U.S. Environmental Protection Agency, 1976).

E. coli was determined to have a stronger relation to swimming-associated gastrointestinal illness than fecal coliform and, as such, was determined to be a better fecal-indicator bacteria for monitoring recreational

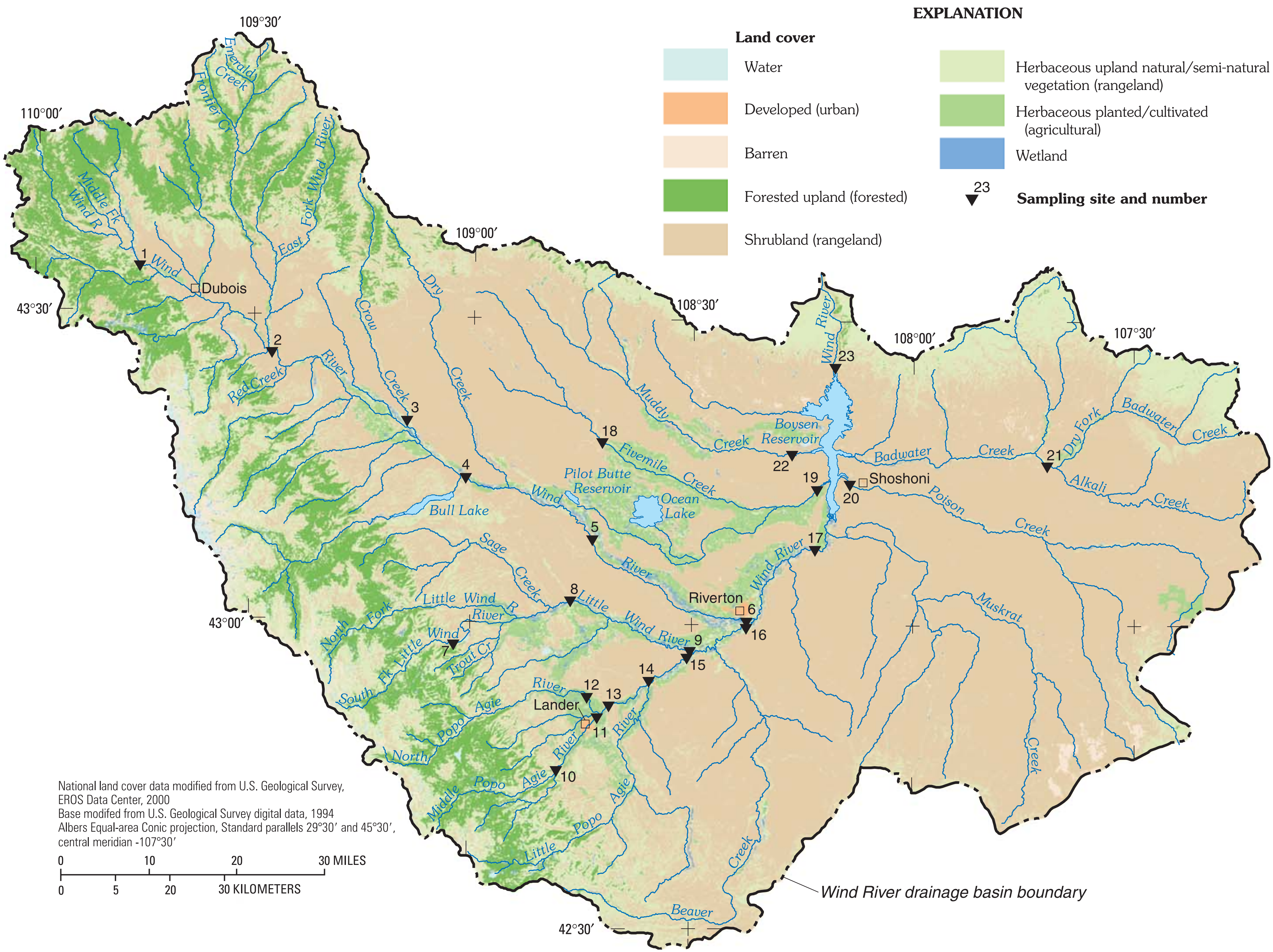


Figure 3. Location of sampling sites in the Wind River Basin, Wyoming, July 2000.

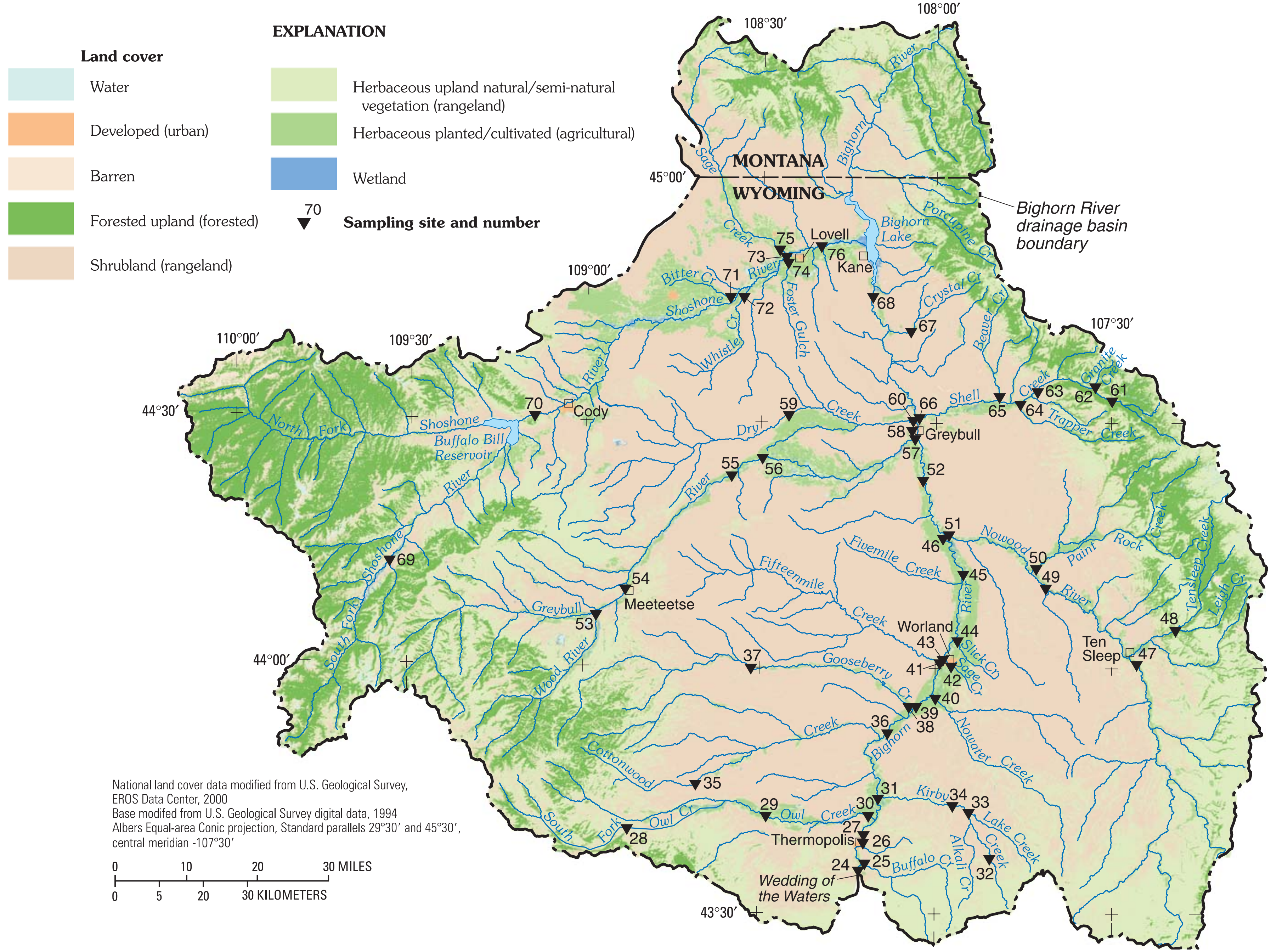


Figure 4. Location of sampling sites in the Bighorn River Basin, Wyoming, July 2000.

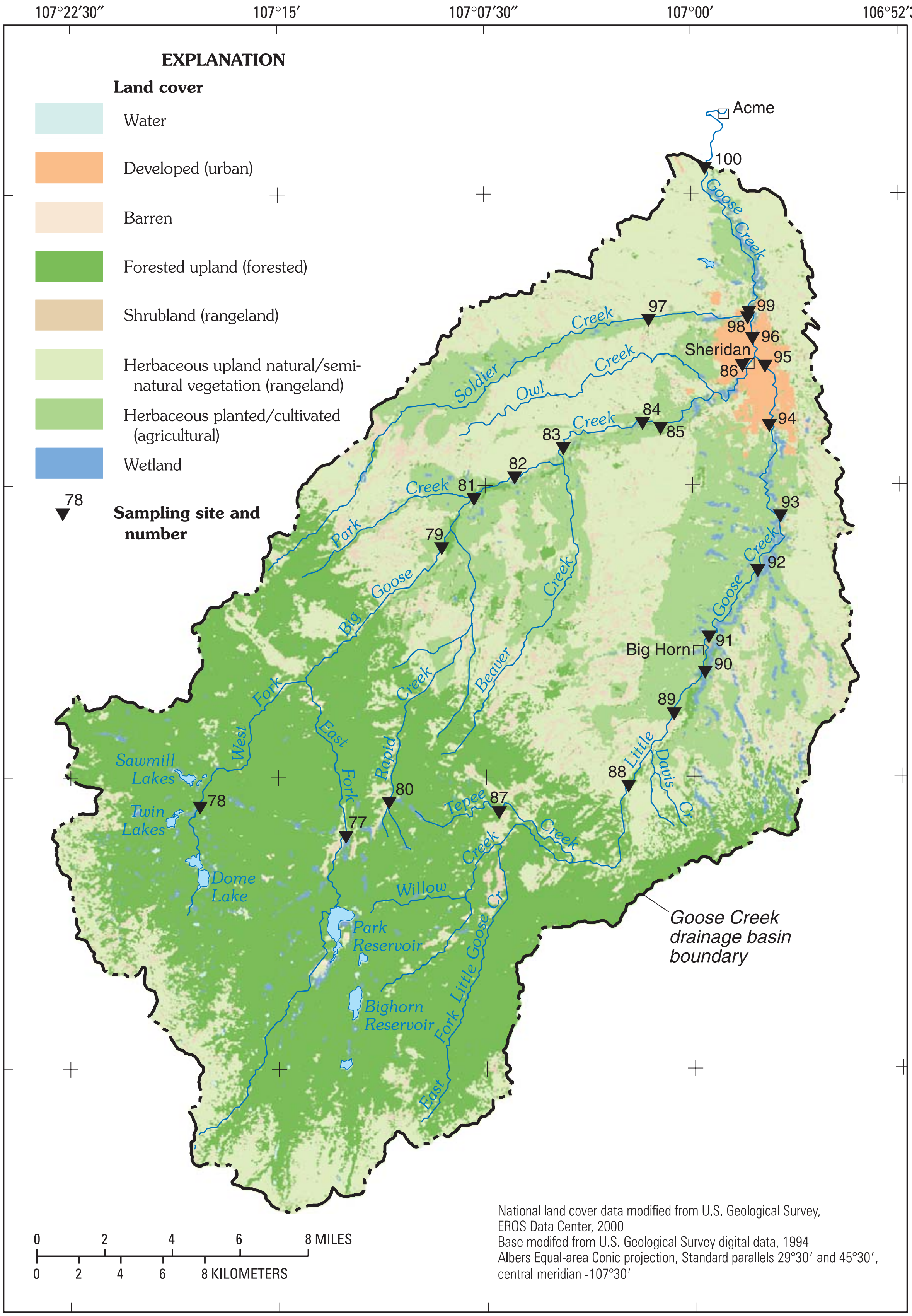


Figure 5. Location of sampling sites in the Goose Creek Basin, Wyoming, June 2000.

Table 2. *Site information for sampling sites in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000*

Site map number (figs. 4, 5, 6)	USGS Site No.	Site name	Site map number (figs. 4, 5, 6)	USGS Site No.	Site Name
1	06218500	Wind River near Dubois, Wyo.	51	06274220	Nowood River at Manderson, Wyo.
2	06220800	Wind River above Red Creek, near Dubois, Wyo.	52	06274300	Bighorn River at Basin, Wyo.
3	431950109085501	Crow Creek near confluence with Wind River, near Lenore, Wyo.	53	440617108572801	Wood River near mouth, near Meeteetse, Wyo.
4	06225500	Wind River near Crowheart, Wyo.	54	06276500	Greybull River at Meeteetse, Wyo.
5	06227600	Wind River near Kinnear, Wyo.	55	442328108350101	Greybull River near Park County line, below Meeteetse, Wyo.
6	06228000	Wind River at Riverton, Wyo.	56	442514108293700	Greybull River at Avent School, near Burlington, Wyo.
7	06228350	South Fork of the Little Wind River above Washakie Reservoir, near Fort Washakie, Wyo.	57	442815108032600	Greybull River at mouth, at Greybull, Wyo.
8	430211108463201	Little Wind River in Ethete, Wyo.	58	442919108024901	Bighorn River at Greybull, Wyo.
9	06231000	Little Wind River above Arapahoe, Wyo.	59	443055108252101	Dry Creek near Emblem, Wyo.
10	06231600	(Middle) Popo Agie River below the Sinks, near Lander, Wyo.	60	06278000	Dry Creek at Greybull, Wyo.
11	425054108423401	Middle Popo Agie River in Lander, Wyo.	61	443246107295701	Shell Creek above Shell Creek Campground, near Shell, Wyo.
12	425250108433201	North Fork Popo Agie River near mouth, near Lander, Wyo.	62	06278400	Granite Creek near Shell Ranger Station, near Shell, Wyo.
13	06232600	Popo Agie River at Hudson Siding, near Lander, Wyo.	63	06278500	Shell Creek near Shell, Wyo.
14	06233500	Little Popo Agie River at Hudson, Wyo.	64	443223107453901	Trapper Creek near mouth, near Shell, Wyo.
15	06233900	Popo Agie River near Arapahoe, Wyo.	65	443229107503501	Beaver Creek near mouth, near Greybull, Wyo.
16	06235500	Little Wind River near Riverton, Wyo.	66	06279090	Shell Creek near Greybull, Wyo.
17	06236100	Wind River above Boysen Reservoir, near Shoshoni, Wyo.	67	06279440	Crystal Creek near Greybull, Wyo.
18	06244500	Fivemile Creek above Wyoming Canal, near Pavillion, Wyo.	68	06279500	Bighorn River at Kane, Wyo.
19	06253000	Fivemile Creek near Shoshoni, Wyo.	69	06280300	South Fork Shoshone River near Valley, Wyo.
20	06255500	Poison Creek near Shoshoni, Wyo.	70	06281700	Shoshone River above Demaris Springs, near Cody, Wyo.
21	06256650	Badwater Creek at Lysite, Wyo.	71	06284500	Bitter Creek near Garland, Wyo.
22	06258000	Muddy Creek near Shoshoni, Wyo.	72	444524108331801	Whistle Creek near Byron, Wyo.
23	06259000	Wind River below Boysen Reservoir, Wyo.	73	06285100	Shoshone River near Lovell, Wyo.
24	433520108125501	Bighorn River at Wedding of the Waters, near Thermopolis, Wyo.	74	444932108254201	Foster Gulch near Lovell, Wyo.
25	433612108115001	Bighorn River below Buffalo Creek, near Thermopolis, Wyo.	75	06285500	Sage Creek near Lovell, Wyo.
26	06259500	Bighorn River at Thermopolis, Wyo.	76	06286200	Shoshone River at Kane, Wyo.
27	433941108114501	Bighorn River at White Sulfur Springs, near Thermopolis, Wyo.	77	443559107122501	East Fork Big Goose Creek on Forest Service Road 26, near Big Horn, Wyo.

Table 2. *Site information for sampling sites in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000--Continued*

Site map number (figs. 4, 5, 6)	USGS Site No.	Site name	Site map number (figs. 4, 5, 6)	USGS Site No.	Site Name
28	06260000	South Fork Owl Creek near Anchor, Wyo.	78	06301500	West Fork Big Goose Creek near Big Horn, Wyo.
29	434207108281701	Owl Creek at Middleton School, near Hamilton Dome, Wyo.	79	444319107085201	Big Goose Creek below Kane Draw, near Sheridan, Wyo.
30	06264500	Owl Creek near Lucerne, Wyo.	80	443654107110101	Rapid Creek on Forest Service Road 26, near Big Horn, Wyo.
31	06264700	Bighorn River at Lucerne, Wyo.	81	06302200	Big Goose Creek above Park Creek, near Sheridan, Wyo.
32	433653107504501	Kirby Creek on Kirby Creek Road, near Thermopolis, Wyo.	82	444503107061601	Big Goose Creek at County Road 81, near Sheridan, Wyo.
33	434227107541501	Kirby Creek above Lake Creek, near Kirby, Wyo.	83	444550107042601	Big Goose Creek below Beaver Creek, near Sheridan, Wyo.
34	434331107565701	Kirby Creek below Lake Creek, near Kirby, Wyo.	84	444637107014701	Big Goose Creek on Highway 331, near Sheridan, Wyo.
35	06265337	Cottonwood Creek at High Island Ranch, near Hamilton Dome, Wyo.	85	444631107010901	Big Goose Creek three miles west of Sheridan, Wyo.
36	435213108080701	Bighorn River at Hanover Flume, near Winchester, Wyo.	86	444803106574701	Big Goose Creek in Kendrick Park, in Sheridan, Wyo.
37	06266450	Gooseberry Creek at State Highway 431, near Grass Creek, Wyo.	87	443638107070201	Tepee Creek near campground, near Big Horn, Wyo.
38	06267000	Gooseberry Creek at Neiber, Wyo.	88	06303700	Little Goose Creek above Davis Creek, near Big Horn, Wyo.
39	06267050	Bighorn River at Neiber, Wyo.	89	443900107002201	Little Goose Creek at Bradford Brinton Memorial, near Big Horn, Wyo.
40	06267420	Nowater Creek four miles south of Worland, Wyo.	90	444014106593401	Little Goose Creek on County Road 103, near Big Horn, Wyo.
41	440044107584301	Fifteenmile Creek at Worland, Wyo.	91	444101106591501	Little Goose Creek on County Road 28, near Big Horn, Wyo.
42	440045107581401	Sage Creek at mouth, near Worland, Wyo.	92	444246106572801	Little Goose Creek at bridge on Highway 87, near Banner, Wyo.
43	06268600	Bighorn River at Worland, Wyo.	93	444415106565001	Little Goose Creek at Highway 87 bridge below Woodland Park Village, near Sheridan, Wyo.
44	06268640	Slick Creek near Worland, Wyo.	94	444634106565401	Little Goose Creek below Brundage Street bridge, in Sheridan, Wyo.
45	441138107545501	Bighorn River near Rairden, Wyo.	95	06304500	Little Goose Creek at Sheridan, Wyo.
46	06269500	Bighorn River at Manderson, Wyo.	96	444848106573701	Goose Creek at 11th Street, in Sheridan, Wyo.
47	06270000	Nowood River near Tensleep, Wyo.	97	444916107013401	Soldier Creek on County Road 74, near Sheridan, Wyo.
48	440457107183500	Tensleep Creek above Leigh Creek, near Tensleep, Wyo.	98	444911106574601	Soldier Creek near mouth, in Sheridan, Wyo.
49	440959107410301	Nowood River near Big Horn County line, near Hyattville, Wyo.	99	06305500	Goose Creek below Sheridan, Wyo.
50	06273500	Paint Rock Creek near mouth, below Hyattville, Wyo.	100	06305700	Goose Creek near Acme, Wyo.

waters (Dufour, 1984; U.S. Environmental Protection Agency, 1986). The EPA recommends four different limits for *E. coli* concentrations for a single sample, depending on the degree of exposure with the source waters. The recommended limits for *E. coli* for a single sample defined in the EPA study are: 235 col/100 mL for designated beach areas, 298 col/100 mL for moderate use, full-body recreational contact, 406 col/100 mL for light use, full-body recreational contact, and 576 col/100 mL for infrequent use, full-body recreational contact. The *E. coli* limit for designated beach areas was not used in this report because none of the synoptic-study sites were at designated beaches.

In the assessment of fecal-indicator bacteria by basin, the population densities of humans and livestock, which are sources for fecal contamination, were determined. Human population densities for basins were estimated from the 2000 county census data (U.S. Census Bureau, 2002). Livestock population densities (including cattle, cows, milk cows, and breeding sheep) were estimated from the Wyoming Agricultural Statistics Service county data for 2000 (Wyoming Agricultural Statistics Service, 2002). Fremont County data were used to estimate the Wind River Basin, and Hot Springs, Washakie, Bighorn and Park Counties data were used to estimate the Bighorn River Basin. The Goose Creek Basin is about 16 percent of the area of Sheridan County. Human population for the Goose Creek Basin was estimated by using populations for individual towns in the Goose Creek Basin and about 16 percent of the rural population of the basin. For livestock, 16 percent of the county livestock populations were assumed to be in the Goose Creek Basin.

For the purposes of data analysis in this report, land-cover classifications were combined or renamed and a single land-cover attribute was assigned to each sampling site. The forested upland land-cover classification is termed “forested,” shrubland and herbaceous upland natural/semi-natural vegetation land-cover classifications were combined and are termed “rangeland,” the herbaceous planted/cultivated land-cover classification is termed “agricultural,” and the developed land-cover classification is termed “urban.” The urban and recreational grasses, which are classified in the NLCD as herbaceous planted/cultivated land cover, comprised 1 percent or less of the agricultural classification in the Wind and Bighorn River Basins and about 2 percent in the Goose Creek Basin. Although urban and recreational grasses are not actually agricultural cover, they were not considered to be a significant enough component of the land cover to warrant a separate classification.

Land cover for the drainage area upstream from most sampling sites included more than a single land-cover classification. To determine the land-cover designation for each sampling site, a 500-meter buffer was established around each point using a geographic information system. The land cover with the highest percentage of area within the buffer and upstream from the site was assigned as the land-cover attribute for the sampling site. It is important to note that land-cover areas cannot be completely separated, and adjacent upstream land covers may affect the water quality of a downstream reach.

Data in this report are summarized using boxplots and nonparametric statistics. For boxplots, the lower and upper edges of the box indicate the 25th and 75th percentiles, respectively. The median is a line within the box, and whiskers extend to the 10th and 90th percentiles. Values outside the 10th and 90th percentiles are shown as individual points. Nonparametric statistical techniques were used to test for correlations and statistical differences between data sets because the fecal-indicator-bacteria data were not normally distributed. Spearman’s correlation coefficient (Spearman’s Rho) was used to measure the strength and direction of the relation between variables (Helsel and Hirsch, 1995). The coefficient is determined using linear correlation of ranks of the data values instead of actual data values and is resistant to the effects of outliers. Spearman’s Rho values range between –1 and +1; a negative value indicates an inverse relation between the data ranks. Two tests were used for testing statistical differences between data sets. The Wilcoxon rank-sum test was used to compare two groups, and the Kruskal-Wallis test was used for more than two groups. For both tests, data ranks are used rather than actual data values to reduce the effect of outliers. In the most general form, the Wilcoxon rank-sum test determines whether the two distributions of ranked data are similar. Likewise, the Kruskal-Wallis test determines whether three or more groups of ranked data have similar distributions or at least one group differs in its distribution (Helsel and Hirsch, 1995). Statistical significance was determined using a 95 percent confidence level (alpha=0.05) for both tests.

Microbial Source Tracking

A microbial source-tracking method using discriminant analysis of ribotype patterns, performed at the University of Missouri in Columbia, Mo. (Carson and others, 2001), was selected to be tested at two sites from the synoptic-study area where fecal-indicator bacteria were known to exist in the basins. Raw water samples were collected from two sites and shipped on ice overnight to the University of Missouri. At the time of this study, the method was still under development, and the results of this sampling are considered experimental data. In general terms, individual colonies are isolated from the water samples and cultured. DNA is extracted from each isolate culture and the concentration is measured. The DNA is blotted from gels onto nylon membranes. Ribotype patterns are captured for computer analysis by placement on a flatbed scanner, and patterns of bands are converted to a line diagram and DNA-fragment sizes are assigned. Discriminant analysis is performed to compare the presence or absence and number of bands in a given segment. Patterns are compared against a library of patterns for known isolates. A detailed description of the method steps, including the *E. coli* culturing, DNA extraction, southern blot analysis, probe preparation, hybridization, and the statistical analysis, is contained in Parveen and others (1999) and Carson and others (2001).

The discriminant analysis technique used to determine sources can analyze patterns as: 1) human or nonhuman, or as 2) human and individual animal host classes. The average rate of correct classification reported for the method for known human and nonhuman isolates was 97 percent by Carson and others (2001). Rates of correct classification for up to eight individual host classes for known-host sources ranged between 49 and 96 percent (Carson and others, 2001). For this report, isolates were classified as human and nonhuman because of the higher average rate of correct classification. The method testing and average rate of correct classification was performed with known sources for isolates, whereas the synoptic-study samples had unknown sources for isolates.

SYNOPTIC-STUDY RESULTS

The synoptic sampling of 100 sites in the Wind River, Bighorn River, and Goose Creek Basins was conducted during June and July 2000. Fecal-indicator-bacteria concentrations and measurements of other water-quality constituents are presented in table 3. The lowest concentration of fecal coliform for 100 samples was 2 col/100 mL for the (Middle) Popo Agie River below the Sinks, near Lander, Wyo. (site 10) and the Wind River below Boysen Reservoir, Wyo. (site 23) in the Wind River Basin. The highest concentration was 3,000 col/100 mL in a sample from Foster Gulch near Lovell, Wyo. (site 74) in the Bighorn River Basin. The lowest concentration of *E. coli* for 97 samples was 1 col/100 mL for the (Middle) Popo Agie River below the Sinks, near Lander, Wyo. (site 10) and the Wind River below Boysen Reservoir, Wyo. (site 23). The highest *E. coli* concentration was 2,800 col/100 mL in a sample from Foster Gulch near Lovell, Wyo. (site 74).

Sampling Conditions

Because each synoptic sample represents only one point in time for each site, it is important to put the synoptic sampling conditions in some context relative to the hydrologic regime and historical data. In an attempt to reduce the hydrologic variability within the study, samples were collected at the 100 sites during a short period of time, between June 27, 2000 and July 20, 2000. The June-July time period was selected because human exposure to pathogens through recreational contact with water is highest during the summer months.

Hydrographs for the water year and the streamflow at the time of sampling for the terminal sites for the mainstem stream in each of the basins are presented in figure 6. The terminal sites, which represent the lowest site sampled on the mainstem streams are the Wind River above Boysen Reservoir, near Shoshoni, Wyo. (site 17), Bighorn River at Kane, Wyo. (site 68), and Goose Creek near Acme, Wyo. (site 100). The hydrograph for the Wind River above Boysen Reservoir, near Shoshoni, Wyo. (site 17) is shown rather than the hydrograph for the site below the reservoir (site 23) because of the regulated conditions directly below the reservoir. The synoptic sampling was conducted after snowmelt runoff that occurred in late May and early June in each basin had subsided. In the plains, some of the smaller tributaries that experience an earlier runoff were at or near low-flow conditions. Streamflows in the basins may be affected by irrigation diversions, return flows, or reservoirs upstream that alter the natural hydrologic regime.

Table 3. *Streamflow, physical-characteristics, and fecal-indicator-bacteria results for the Wind*

[NTU, nephelometric turbidity units; mm of Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens
>. greater than; E, estimated value; k, count outside

Site map number (figs. 3, 4, 5; tab. 2)	Date sampled	Time sampled	Streamflow, (cubic feet per second)	Turbidity (NTU)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	pH (standard units)
								Wind River
1	07-11-00	0830	155	6.9	591	9.6	111	7.6
2	07-11-00	0900	842	7.2	606	8.7	103	8.3
3	07-11-00	0900	7.1	5.3	619	8.4	103	8.2
4	07-11-00	1330	1650	2.7	597	8.4	112	8.7
5	07-11-00	1430	434	2.5	632	11.8	159	9.1
6	07-11-00	1615	21	3.2	638	7.8	116	8.9
7	07-12-00	0930	169	1.2	610	8.1	96	7.8
8	07-12-00	0900	18	2.2	632	10.1	128	8.3
9	07-12-00	1300	30	6.5	639	--	--	8.6
10	07-10-00	1600	151	4.1	610	11.0	140	7.5
11	07-11-00	1630	7.7	1.2	628	6.4	98	8.6
12	07-11-00	1445	52	2.2	629	7.0	100	8.6
13	07-11-00	1630	108	3.5	632	10.4	149	8.8
14	07-12-00	0835	22	8.6	639	6.3	80	8.0
15	07-12-00	1300	106	4.3	639	6.8	97	8.5
16	07-12-00	1055	162	4.0	643	11.8	161	8.3
17	07-12-00	1620	256	8.5	642	7.2	106	8.6
18	07-13-00	0725	.03	<1.0	629	7.8	--	7.6
19	07-12-00	1500	E279	--	644	--	--	8.6
20	07-13-00	1045	.19	3.1	645	9.0	128	8.2
21	07-12-00	1330	.96	27	635	5.9	95	8.2
22	07-12-00	1700	45	160	644	7.5	109	8.6
23	07-13-00	1500	1350	3.9	645	8.5	110	8.5
								Bighorn River
24	07-14-00	0900	E1320	4.8	653	10.3	128	8.3
25	07-14-00	1030	1670	3.4	--	--	--	8.5
26	07-17-00	1300	1430	5.6	653	13.3	175	8.9
27	07-14-00	1300	E1430	4.0	654	8.2	--	8.7
28	07-14-00	0940	33	3.4	606	8.3	104	8.1
29	07-14-00	1340	.81	3.1	637	7.1	102	8.6
30	07-13-00	1345	5.4	6.6	655	10.4	145	8.7

River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000

per centimeter at 25 degrees Celsius; deg C, degrees Celsius; col/100 mL, colonies per 100 milliliters; <, less than;
acceptable range (non-ideal); --, missing value]

Specific conductance (μS/cm)	Temperature, air (deg C)	Temperature, water (deg C)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3)	Carbonate, dissolved (mg/L as CO_3^{-2})	Fecal coliform (col/100 mL)	*Escherichia coli*, (col/100 ml)	Sediment, suspended (mg/L)
Basin								
160	11.5	10.5	72	88	--	160	130	14
194	25.0	12.5	81	98	--	130	E160k	17
293	19.0	15.0	133	162	--	170	E94k	4
140	26.0	17.0	54	66	1	E20k	E10k	15
211	33.0	20.5	77	81	6	E33k	E23k	16
529	28.5	26.0	150	161	11	38	E30k	6
32	26.5	13.0	13	16	--	E23k	E6k	4
454	21.0	17.5	104	127	--	26	E20k	4
895	35.0	23.5	176	201	7	63	E67k	14
43	22.0	16.0	18	22	--	E2k	E1k	3
478	30.0	27.0	151	177	4	340	450	14
362	32.5	23.0	111	134	--	190	E180k	3
604	32.5	23.5	158	177	7	150	E100k	13
1180	32.0	18.0	217	264	--	240	E130k	70
812	34.0	24.0	174	203	5	32	E46k	27
898	32.0	22.0	179	205	6	E50k	E32k	52
744	35.0	26.0	182	213	5	E48k	E10k	28
4230	--	--	184	225	--	37	33	22
685	35.0	--	156	185	2	300	E400k	241
6160	35.0	23.5	275	336	--	2000	2300	54
4930	34.0	29.5	397	484	--	47	E62k	70
784	35.0	25.5	142	165	4	800	>200	390
595	37.0	19.5	138	162	3	E2k	E1k	5
Basin								
616	23.5	18.0	158	178	7	E10k	E10k	--
615	--	--	136	164	--	E12k	E15k	8
617	30.0	21.0	143	164	5	32	E14k	7
634	--	--	148	167	6	E16k	E25k	--
100	31.0	15.0	46	57	--	240	140	6
2070	33.5	24.0	346	407	8	340	E300	24
1540	--	24.0	236	274	7	1500	620	86

Table 3. *Streamflow, physical-characteristics, and fecal-indicator-bacteria results for the Wind*

Site map number (figs. 3, 4, 5; tab. 2)	Date sampled	Time sampled	Streamflow, (cubic feet per second)	Turbidity (NTU)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	pH (standard units)
								Bighorn River
31	07-14-00	1650	1260	2.0	--	--	--	8.9
32	07-13-00	1100	.06	22	642	9.1	124	8.6
33	07-13-00	1200	.01	21	--	9.0	--	8.7
34	07-13-00	1230	.68	13	652	6.2	89	8.7
35	07-14-00	1115	E.48	5.0	624	11.8	--	9.7
36	07-17-00	1445	742	12	657	8.4	107	8.5
37	07-19-00	1600	.90	3.6	620	7.7	121	8.5
38	07-15-00	0830	.55	5.2	655	--	--	8.2
39	07-16-00	1445	841	12	656	9.3	131	8.7
40	07-15-00	0930	32	66	657	9.0	114	8.3
41	07-16-00	1700	13	88	--	8.1	--	8.6
42	07-17-00	0900	32	83	657	--	--	8.0
43	07-17-00	1030	267	140	660	--	--	8.2
44	07-17-00	1000	27	120	659	8.6	107	8.2
45	07-17-00	1300	471	310	663	7.0	89	8.4
46	07-18-00	0850	608	440	665	8.0	101	8.2
47	07-17-00	1200	106	6.2	649	8.9	112	8.4
48	07-17-00	1000	52	1.1	627	8.3	99	7.6
49	07-17-00	1345	75	14	656	6.6	91	8.4
50	07-17-00	1445	82	8.0	656	8.5	109	8.5
51	07-17-00	1500	136	5.5	663	8.9	120	8.2
52	07-18-00	1150	865	>1000	666	8.2	106	8.2
53	07-19-00	1030	98	3.2	613	9.0	105	8.2
54	07-19-00	1210	638	22	620	8.5	110	8.4
55	07-19-00	1500	582	62	653	8.2	97	8.3
56	07-19-00	1645	85	84	652	7.3	96	8.6
57	07-19-00	1000	112	>1000	669	7.6	94	8.2
58	07-18-00	1515	980	260	663	9.5	126	8.3
59	07-19-00	1445	22	190	653	7.7	105	8.2
60	07-19-00	0845	34	280	671	--	--	8.2

River, Bighorn River, and Goose Creek basins, Wyoming, June-July 2000--Continued

Specific conductance (μS/cm)	Temperature, air (deg C)	Temperature, water (deg C)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3)	Carbonate, dissolved (mg/L as CO_3^{-2})	Fecal coliform (col/100 mL)	*Escherichia coli*, (col/100 ml)	Sediment, suspended (mg/L)
Basin--Continued								
663	--	24.0	139	154	8	35	E77k	19
1100	33.0	22.0	214	255	3	E670k	680	27
3700	39.0	22.0	149	177	2	1900	1700	19
3460	--	25.0	209	244	5	420	550	32
700	32.0	--	166	139	31	E11k	E12k	20
712	22.0	19.5	152	185	--	130	E120k	49
3200	32.0	27.0	332	391	7	260	210	62
3400	24.0	20.0	214	262	--	330	230	5
708	34.0	25.0	150	169	7	110	E47k	40
962	25.0	19.5	206	251	--	1500	670	184
811	--	27.5	163	185	6	1200	1600	423
1030	23.0	17.5	223	272	--	770	550	289
858	27.0	18.5	182	223	--	540	400	235
970	20.0	18.5	221	270	--	1100	800	200
910	20.0	20.0	168	199	3	830	670	380
936	22.0	20.0	196	240	--	1400	E1000k	440
646	23.0	18.5	112	132	2	160	E180k	13
71	24.0	14.5	34	42	--	67	65	4
765	23.0	23.0	143	175	--	55	49	42
591	25.0	20.0	131	159	--	220	E200k	14
758	--	23.0	41	50	--	62	80	10
914	26.0	21.0	166	203	--	E1000	E670	5170
236	20.0	12.5	87	106	--	130	120	10
318	20.0	17.5	94	115	--	58	67	54
336	18.5	16.0	101	123	--	150	E170k	101
392	20.0	21.0	122	139	5	580	E630k	91
860	20.0	19.0	200	244	--	E2200k	E1600	609
947	19.5	22.0	189	230	--	480	540	283
2430	26.0	22.5	230	281	--	>2000	>2000	218
1360	20.0	13.0	261	319	--	2000	E1300	398

Table 3. *Streamflow, physical-characteristics, and fecal-indicator-bacteria results for the Wind*

Site map number (figs. 3, 4, 5; tab. 2)	Date sampled	Time sampled	Streamflow, (cubic feet per second)	Turbidity (NTU)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	pH (standard units)
								Bighorn River
61	07-18-00	0845	90	1.6	580	8.4	97	7.4
62	07-18-00	1000	11	9.7	589	7.8	90	8.4
63	07-18-00	1540	113	6.3	655	9.5	110	8.4
64	07-18-00	1000	8.1	2.7	652	9.1	100	8.0
65	07-18-00	1145	14	6.7	655	7.7	99	8.2
66	07-18-00	1430	27	18	667	8.1	112	8.4
67	07-19-00	0920	.59	710	666	--	--	8.2
68	07-18-00	1400	892	150	670	8.4	114	8.3
69	07-19-00	1045	487	--	612	9.2	107	8.1
70	07-19-00	1200	1160	--	639	9.8	109	8.1
71	07-18-00	1000	304	320	661	8.7	100	8.3
72	07-20-00	0840	47	>1000	657	8.1	98	8.4
73	07-20-00	0800	566	810	667	7.8	92	8.3
74	07-20-00	0900	43	690	666	7.8	92	8.1
75	07-20-00	0930	210	770	669	8.3	99	8.0
76	07-20-00	0800	616	730	669	7.9	91	8.2
								Goose Creek
77	06-27-00	1500	11	4.6	584	8.8	101	7.1
78	06-27-00	1030	E86	1.1	565	8.1	101	6.7
79	06-28-00	1650	72	3.0	658	8.9	102	8.0
80	06-27-00	1330	64	4.8	586	9.1	103	7.2
81	06-28-00	1730	79	5.2	656	8.1	97	7.9
82	06-28-00	1830	95	4.4	658	8.7	106	8.1
83	06-29-00	0730	112	14	656	8.1	91	7.9
84	06-29-00	0800	116	15	664	8.9	99	7.9
85	06-29-00	1010	115	12	666	9.6	109	8.1
86	06-29-00	1000	122	16	663	6.8	80	8.2
87	06-27-00	1200	3.4	3.4	590	7.8	101	--
88	06-27-00	1730	69	2.0	653	9.6	99	7.4
89	06-27-00	1700	21	3.8	666	8.9	96	7.8
90	06-28-00	0850	16	13	658	9.4	99	8.0

River, Bighorn River, and Goose Creek basins, Wyoming, June-July 2000--Continued

Specific conductance (µS/cm)	Temperature, air (deg C)	Temperature, water (deg C)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3^-)	Carbonate, dissolved (mg/L as CO_3^{-2})	Fecal coliform (col/100 mL)	*Escherichia coli*, (col/100 ml)	Sediment, suspended (mg/L)
Basin--Continued								
35	17.5	9.5	19	23	--	130	100	4
241	20.0	10.0	120	147	--	1600	1200	13
188	17.5	15.0	75	92	--	93	74	7
646	21.0	12.5	219	268	--	170	E170k	96
659	22.0	20.0	180	219	--	E680k	E400k	33
1540	29.0	24.5	217	253	6	E630k	600	80
2970	22.0	16.5	340	415	--	200	E170k	703
1000	33.0	24.0	192	234	--	170	E120k	211
84	23.0	12.0	33	40	--	E11k	E7k	9
129	27.5	12.0	47	57	--	E9k	E7k	4
617	28.0	15.5	178	218	--	500	E500k	684
669	17.0	17.0	112	137	--	E2300k	2000	859
703	18.0	16.5	178	217	--	1800	E1200k	676
745	26.0	16.5	194	237	--	E3000k	E2800k	1030
1500	22.5	17.0	220	269	--	E2200k	2000	1030
1010	16.0	15.5	201	246	--	2000	E1200	797
Basin								
37	15.0	9.5	20	24	--	530	580	6
18	6.0	11.5	12	14	--	55	53	7
105	26.0	15.0	34	42	--	23	E15k	8
24	15.0	9.0	16	20	--	130	67	26
124	25.0	16.5	46	56	--	380	260	9
163	26.0	17.5	54	66	--	800	>400	9
241	19.0	13.5	69	84	--	800	--	23
278	20.0	14.0	75	92	--	1100	--	19
283	23.0	15.0	80	98	--	670	E300	21
279	22.0	16.5	75	91	--	560	E430k	24
38	11.0	15.5	19	23	--	360	380	6
51	15.0	10.0	26	32	--	E10k	E4k	9
112	18.0	12.5	51	62	--	97	28	8
197	17.0	11.0	97	119	--	100	E150k	9

Table 3. *Streamflow, physical-characteristics, and fecal-indicator-bacteria results for the Wind*

Site map number (figs. 3, 4, 5; tab. 2)	Date sampled	Time sampled	Streamflow, (cubic feet per second)	Turbidity (NTU)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	pH (standard units)
								Goose Creek
91	06-28-00	0850	23	4.4	664	9.8	102	8.3
92	06-28-00	1120	37	18	667	9.9	109	8.4
93	06-28-00	1300	46	16	664	9.4	109	8.2
94	06-28-00	1430	77	24	665	10.6	132	8.4
95	06-28-00	1320	77	24	670	13.3	160	8.9
96	06-29-00	1215	E224	16	667	9.5	121	8.6
97	06-29-00	1240	19	86	666	8.0	96	8.1
98	06-29-00	1440	14	--	668	7.8	95	8.2
99	06-29-00	1400	224	--	666	9.9	125	8.7
100	06-29-00	1300	190	18	667	11.4	142	8.6

The synoptic approach used in this study for determining the distribution of fecal-indicator bacteria has limitations for data interpretations owing to the variable nature of sources and transport processes of fecal-indicator bacteria. The data from the synoptic study represent only a ‘snapshot’ in time. However, fecal coliform historically have been collected at selected sites within the Wind River Basin (2 sites), Bighorn River Basin (5 sites), and the Goose Creek Basin (3 sites) as part of other monitoring programs. Fecal-coliform concentrations for samples from the synoptic study are summarized with historical data from 1991-2000 to illustrate how the synoptic-study concentrations compare to historical data (fig. 7). The period of record is summarized for each site in table 4.

Fecal-coliform concentrations of synoptic samples generally were between the 50th to 75th percentiles of the historical data (fig. 7). The fecal-coliform concentrations for synoptic samples on the Little Wind River near Riverton, Wyo. (site 16) and the Bighorn River at Lucerne, Wyo. (site 31) were below the historic medians for those sites. For two sites in the Bighorn River Basin, Bighorn River at Basin, Wyo. (site 52) and Bitter Creek near Garland, Wyo. (site 71), the fecal-coliform concentrations for the synoptic samples were greater than the 75th percentile of the historical data for those sites.

Quality-Control Samples

No colonies of fecal coliform or *E. coli* were detected in the eight equipment blanks that were processed for each sampler bottle and nozzle. No bacteria colonies were detected in the 200 membrane-filtration equipment blanks that were processed for fecal coliform or *E. coli*. No colonies were detected in 50 procedure blanks for fecal coliform or *E. coli*.

Seventeen replicate samples are reported for fecal coliform and six are reported for *E. coli*. Fewer *E. coli* replicates are reported because some of the plates for the replicates were unreadable. The RPD for the replicate samples are listed in table 5. The mean and median RPD for fecal-coliform replicates (n=17) were about 13 percent. The mean RPD for *E. coli* replicates (n=6) was 25.4 percent, and the median RPD was 14.5 percent. This indicates that there may be more variability about the *E. coli* replicates than the fecal-coliform replicates; however, the sample size was smaller for the *E. coli* replicates, which can increase apparent variability. The variability in replicate data explains, in part, why the *E. coli* concentration exceeds the fecal-coliform concentration in some samples.

River, Bighorn River, and Goose Creek basins, Wyoming, June-July 2000--Continued

Specific conductance (μS/cm)	Temperature, air (deg C)	Temperature, water (deg C)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3^-)	Carbonate, dissolved (mg/L as CO_3^{-2})	Fecal coliform (col/100 mL)	*Escherichia coli*, (col/100 ml)	Sediment, suspended (mg/L)
Basin--Continued								
251	15.0	11.0	122	149	--	120	90	9
346	17.0	13.5	166	203	--	280	200	20
398	22.0	15.5	187	219	--	270	200	30
376	24.0	19.0	174	180	16	E190k	140	35
410	21.0	18.0	178	188	14	190	150	29
338	30.0	20.5	101	112	6	600	--	23
383	29.0	17.5	121	148	--	1500	E800	134
426	30.0	18.5	151	184	--	1100	E700	184
353	29.0	20.0	124	140	6	380	E240	29
359	29.0	19.5	126	144	5	300	E170	30

Distribution of Fecal-Indicator Bacteria by Basin

Median concentrations of fecal-indicator bacteria varied among basins (fig. 8). The lowest median concentrations of fecal coliform (50 col/100 mL) and *E. coli* (62 col/100 mL) were for samples in the Wind River Basin. The highest median concentrations of fecal coliform (340 col/100 mL) and *E. coli* (300 col/100 mL) were for samples in the Bighorn River Basin. For samples in the Goose Creek Basin, the median concentration of fecal coliform was 330 col/100 mL, and the median concentration of *E. coli* was 200 col/100 mL.

Results of the Kruskal-Wallis test indicate a significant difference in fecal-coliform concentrations (p-value =0.003) and *E. coli* concentrations (p-value =0.001) between basins at a 95 percent confidence level. A Wilcoxon rank-sum test was run between each pair of basins to determine which distributions were different. The fecal-coliform (p-value =0.35) and the *E. coli* (p-value =0.193) concentrations in the Bighorn River and Goose Creek Basins were not significantly different from each other. The concentrations of fecal-indicator bacteria in the Wind River Basin were statistically different from those in the Bighorn River (p-value for fecal coliform =0.002; p-value for *E. coli* =0.001) and Goose Creek Basins (p-value for fecal coliform =0.008; p-value for *E. coli* =0.014). Most samples in the Wind River Basin had fecal-indicator-bacteria concentrations that were less than the median concentrations in the Bighorn River or Goose Creek Basins (fig. 8).

Because the synoptic samples represent the conditions at only one point in time, the reason for the lower concentrations in the Wind River Basin during this study could not be determined. In 2000, stream reaches in the Bighorn River and Goose Creek Basins were listed by the State of Wyoming for fecal-coliform impairments, whereas reaches in the Wind River Basin were not listed (Wyoming Department of Environmental Quality, 2000). The variation in fecal-indicator bacteria between basins is not directly related to the populations of livestock and humans in the basins. The population densities of humans and livestock were not higher in the Bighorn River Basin when compared to the Wind River Basin (table 6). Human and livestock population densities were substantially higher in the Goose Creek Basin than in the other two basins. The overall basin density does not take into account, however, the distribution of people and livestock relative to their actual proximity to riparian areas.

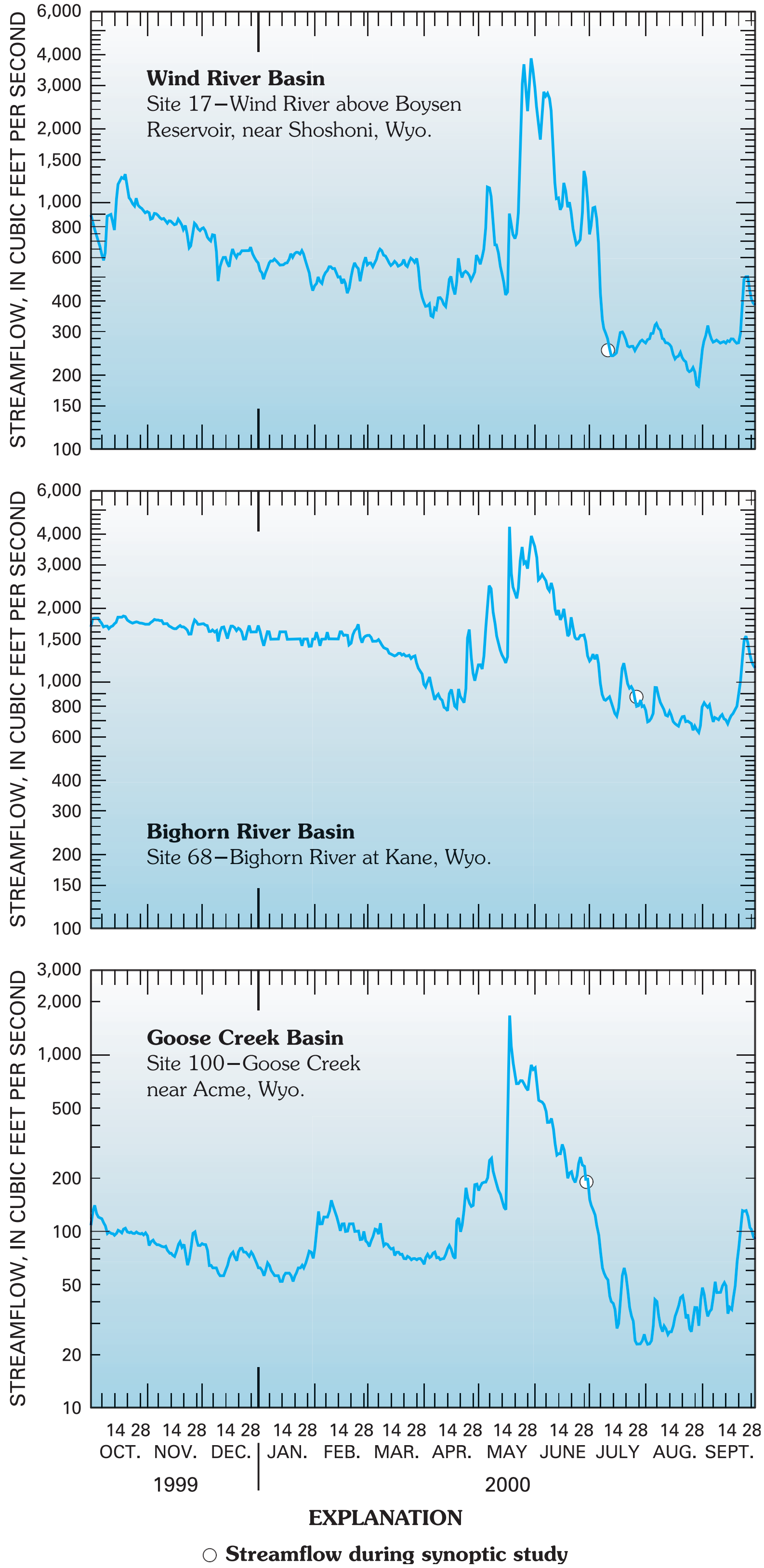
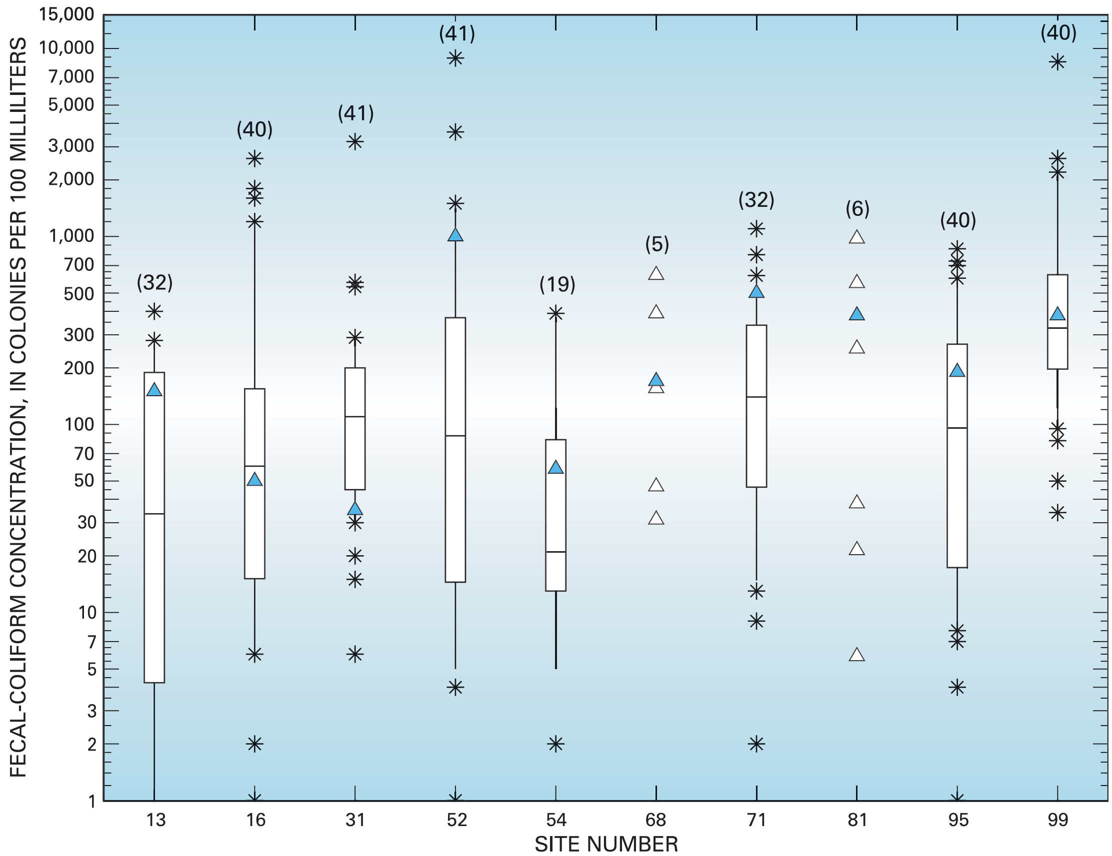


Figure 6. Annual hydrographs and streamflows for terminal sites during a synoptic study in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, 2000.



EXPLANATION

Fecal-coliform samples, 1991-2000

(32) Number of observations

✳ Data values outside the 10th and 90th percentiles

90th percentile
75th percentile
Median
25th percentile
10th percentile

△ Individual sample point

▲ Synoptic-study sample

Figure 7. Historical and synoptic-study fecal-coliform concentrations for selected sites in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, 1991-2000.

Table 4. *Period of record for fecal-coliform concentrations for selected sites in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, 1991-2000.*

Site map number (figs. 4, 5, 6; tab. 2)	Basin	Period of record (water years)
13	Wind River	1993-2000
16	Wind River	1991-2000
31	Bighorn River	1991-2000
52	Bighorn River	1991-2000
54	Bighorn River	1996-2000
68	Bighorn River	2000
71	Bighorn River	1993-2000
81	Goose Creek	1999-2000
95	Goose Creek	1991-2000
99	Goose Creek	1991-2000

Table 5. *Concentrations and relative percent difference of replicate quality-control samples of fecal-indicator bacteria in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.*

[col/100 mL, colonies per 100 milliliters; RPD, relative percent difference; --, not applicable]

Site map number (figs. 3, 4, 5; tab. 2)	Fecal coliform regular sample (col/100 mL)	Fecal coliform replicate sample (col/100 mL)	RPD	*Escherichia coli* regular sample (col/100 mL)	*Escherichia coli* replicate sample (col/100 mL)	RPD
6	38	41	7.6	--	--	--
8	26	30	14.3	20	10	66.7
16	50	38	27.3	32	32	0.0
18	37	30	20.9	33	28	16.4
26	32	28	13.3	--	--	--
31	35	40	13.3	--	--	--
33	1900	1600	17.1	1700	1000	51.9
38	330	360	8.7	--	--	--
52	1000	900	10.5	--	--	--
57	2200	2000	9.5	--	--	--
72	2300	2200	4.4	2000	2100	4.9
73	1800	1700	5.7	--	--	--
76	2000	1900	5.1	--	--	--
80	130	110	16.7	67	59	12.7
85	670	650	3.0	--	--	--
86	560	460	19.6	--	--	--
91	120	160	28.6	--	--	--

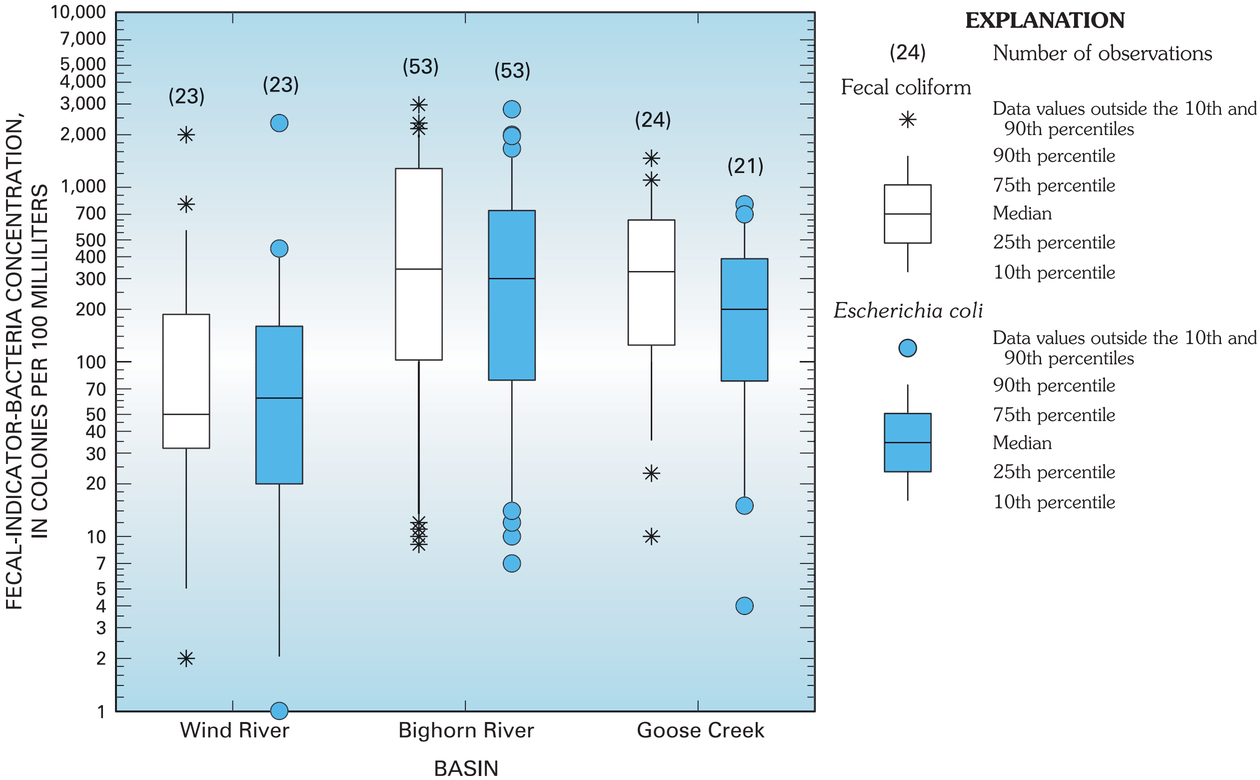


Figure 8. Fecal-indicator-bacteria concentrations for the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.

Table 6. *Estimated human and livestock population densities for the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, 2000.*

Basin	Human population density, in persons per square kilometer	Livestock population density, in animals per square kilometer
Wind River	1.8	10
Bighorn River	1.0	6.6
Goose Creek	16	25

Fecal-indicator-bacteria concentrations exceeded the EPA's recommended limits for a single sample for recreational contact with water for a percentage of samples collected from all three basins (table 7). The Bighorn River Basin had the highest percentage of samples (49.1 percent) with fecal-coliform concentrations higher than the recommended limit of 400 col/100 mL. Concentrations of fecal coliform in the Goose Creek Basin exceeded the recommended limit in 37.5 percent of the samples. Concentrations of fecal coliform in the Wind River Basin exceeded the recommended limit in 8.7 percent of the samples. In this report, the EPA recommended limit of 400 col/100 mL for fecal coliform is used for comparison purposes, but does not necessarily represent a violation of the State of Wyoming water-quality criteria.

E. coli concentrations exceeded the EPA recommended limit for a single sample for moderate use, full-body recreational contact of 298 col/100 mL in 50.9 percent of the samples from the Bighorn River Basin compared to 33.3 percent in the Goose Creek Basin and 13.0 percent in the Wind River Basin. In the Bighorn River Basin, *E. coli* concentrations exceeded the EPA recommended limit for a single sample for infrequent use, full-body recreational contact of 576 col/100 mL in 37.7 percent of samples compared to 14.3 percent in the Goose Creek Basin and 4.3 percent in the Wind River Basin. *E. coli* concentrations of the synoptic-study samples are compared to the EPA recommended limits, but do not represent violations of water-quality criteria because the *E. coli* limits had not been adopted by the State of Wyoming as of 2000.

Wind River Basin

The synoptic sampling of the 23 sites in the Wind River Basin was conducted July 10-13, 2000. Seven sites on the mainstem of the Wind River and 16 tributary sites were sampled (fig. 9). Fecal-coliform concentrations for 23 samples ranged from 2 col/100 mL for the (Middle) Popo Agie River below the Sinks, near Lander, Wyo. (site 10) and the Wind River below Boysen Reservoir, Wyo. (site 23) to 2,000 col/100 mL for Poison Creek near Shoshoni, Wyo. (site 20). *E. coli* concentrations for 23 samples ranged from 1 col/100 mL (site 10 and site 23) to 2,300 col/100 mL (site 20) (fig. 9).

Fecal-coliform concentrations for the seven sites on the mainstem of the Wind River ranged from 2 col/100 mL below Boysen Reservoir, Wyo. (site 23) to 160 col/100 mL near Dubois, Wyo. (site 1). Bottom deposits in lakes or reservoirs can serve as a sink for fecal-indicator bacteria and prevent the bacteria from being transported in the overlying material (Geldreich, 1970). However, the fecal-coliform concentration was relatively low (48 col/100 mL) in a sample from the Wind River above Boysen Reservoir, near Shoshoni, Wyo. (site 17) as well. *E. coli* concentrations ranged from 1 col/100 mL below Boysen Reservoir, Wyo. (site 23) to 160 col/100 mL on the Wind River above Red Creek, near Dubois, Wyo. (site 2).

Table 7. *Fecal-indicator-bacteria concentrations exceeding the U.S. Environmental Protection Agency's recommended limits for a single sample for recreational contact with water for samples in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.*

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

Basin	Sample size (n) Fecal coliform/ *Escherichia coli*	Fecal coliform	*Escherichia coli*		
		Percent >400 col/100 mL	Percent >298 col/100 mL (Moderate use, full-body contact)	Percent >406 col/100 mL (Light use, full-body contact)	Percent >576 col/100 mL (Infrequent use, full-body contact)
Wind River	23/23	8.7	13.0	8.7	4.3
Bighorn River	53/53	49.1	50.9	45.3	37.7
Goose Creek	24/21	37.5	33.3	19.0	14.3
All samples	100/97	37.0	38.1	30.9	24.7

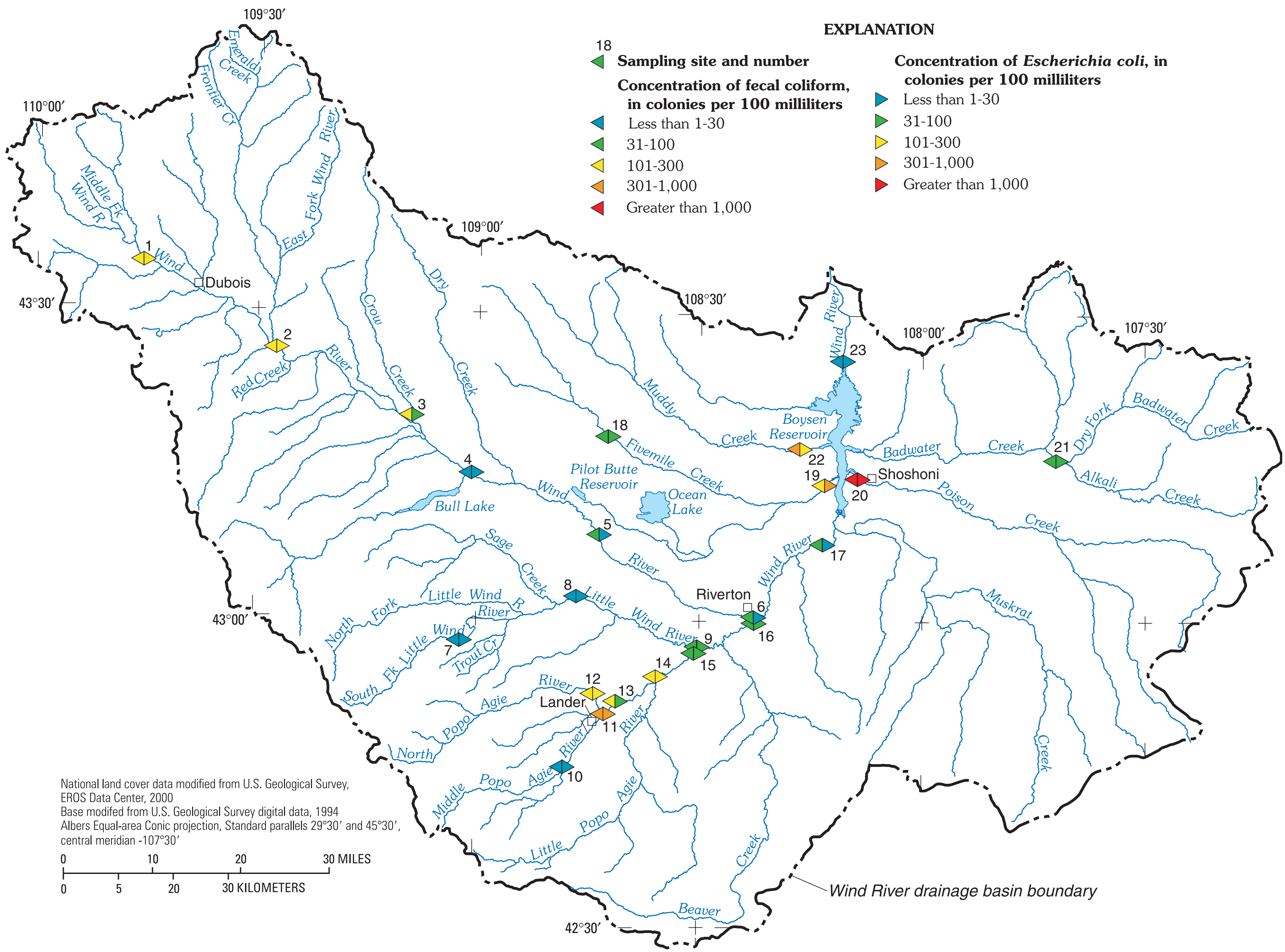


Figure 9. Fecal-indicator-bacteria concentrations for samples collected in the Wind River Basin, Wyoming, July 2000.

Tributaries sampled in the Wind River Basin included: Crow Creek, South Fork of the Little Wind River, Little Wind River (3 sites), Middle Popo Agie River (2 sites), North Fork Popo Agie River, Little Popo Agie River, Popo Agie River (2 sites), Fivemile Creek (2 sites), Poison Creek , Badwater Creek, and Muddy Creek. For the 16 tributary sites, the lowest fecal-coliform concentration (2 col/100 mL) and *E. coli* concentration (1 col/100 mL) occurred in a sample from the (Middle) Popo Agie River below the Sinks, near Lander, Wyo. (site 10). The highest concentration of fecal coli-form (2,000 col/100 mL) and *E. coli* (2,300 col/100 mL) for the tributary sites occurred in a sample from Poison Creek near Shoshoni, Wyo. (site 20).

Sites in the Wind River Basin where concentrations exceeded at least one of the EPA's recommended limits for a single sample for recreational contact with water are listed in table 8. All of the fecal coliform and *E. coli* concentrations on the mainstem of the Wind River were below the EPA recommended limits for recreational contact with water. Tributary sites that had concentrations exceeding at least one of the EPA's recommended limits for recreational contact with water include: Middle Popo Agie River in Lander, Wyo. (site 11), Fivemile Creek near Shoshoni, Wyo. (site 19), Poison Creek near Shoshoni, Wyo. (site 20), and Muddy Creek near Shoshoni, Wyo. (site 22).

Bighorn River Basin

The synoptic sampling of the 53 sites in the Bighorn River Basin was conducted July 13-20, 2000. Thirteen sites on the mainstem of the Bighorn River and 40 tributary sites were sampled, including 3 sites on the mainstem of the Shoshone River (fig. 10). Fecal-coliform concentrations for 53 samples ranged from 9 col/100 mL for the Shoshone River above Demaris-Springs, near Cody, Wyo. (site 70) to 3,000 col/100 mL for Foster Gulch near Lovell, Wyo. (site 74). *E. coli* concentrations for 53 samples ranged from 7 col/100 mL (sites 69 and 70) to 2,800 col/100 mL (site 74).

Fecal-coliform concentrations for the 13 sites on the mainstem of the Bighorn River ranged from 10 col/100 mL at the "Wedding of the Waters" near Thermopolis, Wyo. (site 24) to 1,400 col/100 mL at Manderson, Wyo. (site 46). *E. coli* concentrations ranged from 10 col/100 mL at the "Wedding of the Waters" near Thermopolis, Wyo. (site 24) to 1,000 col/100 mL at Manderson, Wyo. (site 46). The fecal-coliform concentration (170 col/100 mL) and *E. coli* concentration (120 col/100 mL) were lower at the terminal site on the Bighorn River at Kane, Wyo. (site 68) compared to the mid-basin Bighorn River sites.

Tributaries to the Bighorn River above Kane, Wyo. that were sampled during the synoptic study include: South Fork Owl Creek, Owl Creek (2 sites), Kirby Creek (3 sites), Cottonwood Creek, Gooseberry Creek (2 sites), Nowater Creek, Fifteenmile Creek, Sage Creek, Slick Creek, Nowood River (3 sites), Tensleep Creek, Paint Rock Creek, Wood River, Greybull River (4 sites), Dry Creek (2 sites), Shell Creek (3 sites), Granite Creek, Trapper Creek, Beaver Creek, and Crystal Creek. For these 32 tributary sites, the lowest concentrations of fecal coliform (11 col/100 mL) and *E. coli* (12 col/100 mL) were from the site on Cottonwood Creek at High Island Ranch near Hamilton Dome, Wyo. (site 35). The highest concentration of fecal coliform

Table 8. *Sites where sample concentrations of fecal-indicator bacteria exceeded the U.S. Environmental Protection Agency's recommended limits for a single sample for recreational contact with water in the Wind River Basin, Wyoming, July 2000.*

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

Fecal coliform	*Escherichia coli*		
>400 col/100 mL	>298 col/100 mL (Moderate use, full-body contact)	>406 col/100 mL (Light use, full-body contact)	>576 col/100 mL (Infrequent use, full-body contact)
Poison Creek (site 20)	Fivemile Creek (site 19)	Middle Popo Agie River (site 11)	Poison Creek (site 20)
Muddy Creek (site 22)			

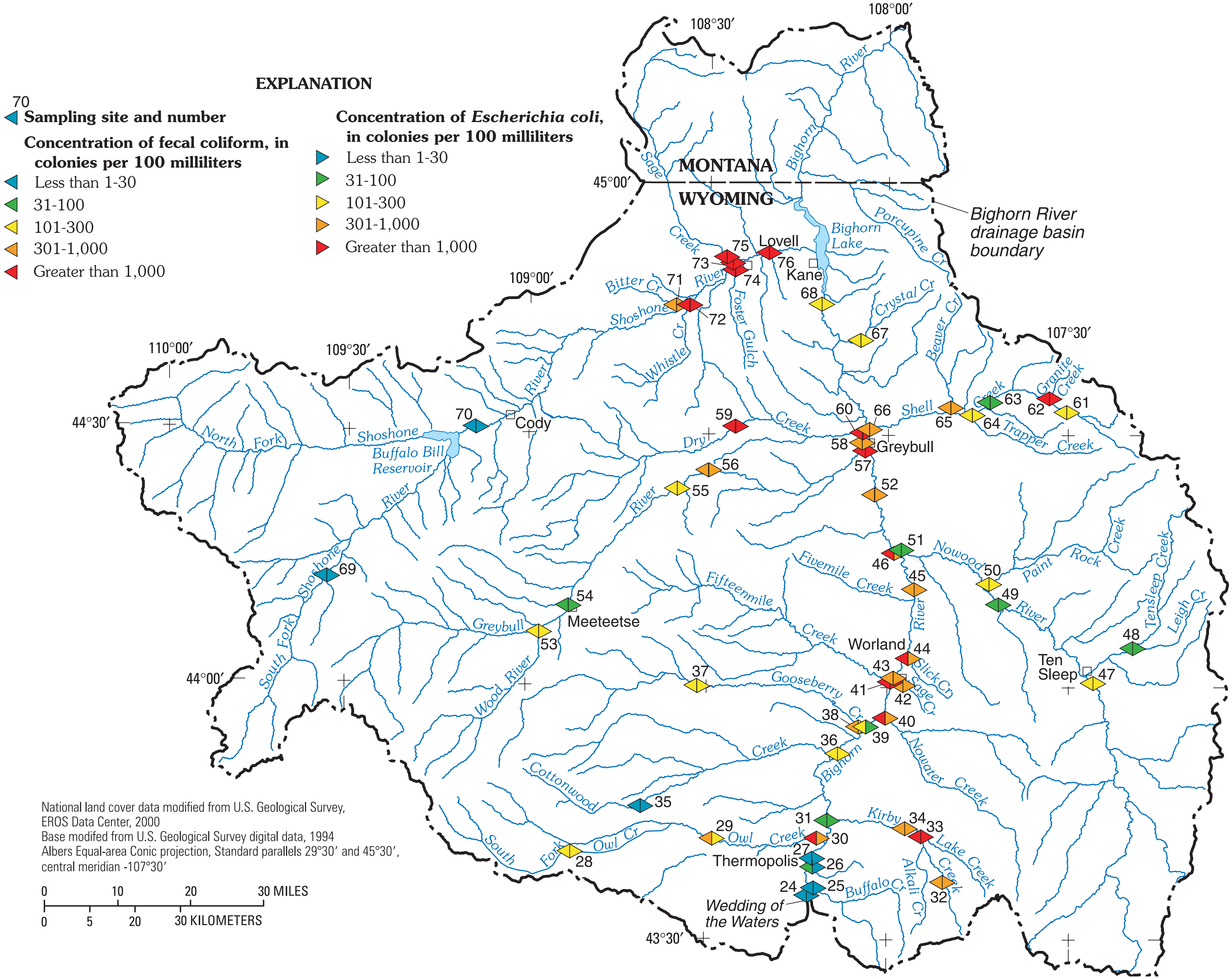


Figure 10. Fecal-indicator-bacteria concentrations for samples collected in the Bighorn River Basin Wyoming, July 2000.

(2,200 col/100 mL) was in a sample from the Greybull River at its mouth at Greybull, Wyo. (site 57). A fecal-coliform concentration greater than 2,000 col/100 mL and the highest concentration of *E. coli* (greater than 2,000 col/100 mL) were in a sample from Dry Creek near Emblem, Wyo. (site 59).

Eight of the tributary sites in the Bighorn River Basin were in the Shoshone River Basin above Bighorn Lake. Tributaries sampled included: the South Fork Shoshone River, Shoshone River (3 sites), Bitter Creek, Whistle Creek, Foster Gulch, and Sage Creek. For these eight sites, the lowest concentrations of fecal coliform (9 col/100 mL) and *E. coli* (7 col/100 mL) were in a sample from the Shoshone River above Demaris Springs, near Cody, Wyo. (site 70). The sample from South Fork Shoshone River near Valley, Wyo. (site 69) also had an *E. coli* concentration of 7 col/100 mL. The highest concentrations of fecal coliform (3,000 col/100 mL) and *E. coli* (2,800 col/100 mL) in the Shoshone River Basin were in a sample from Foster Gulch near Lovell, Wyo. (site 74).

Sites in the Bighorn River Basin where concentrations exceeded at least one of the EPA's recommended limits for a single sample for recreational contact with water are listed in table 9. Concentrations of fecal coliform and *E. coli* exceeded the EPA recommended limits for recreational contact with water at 5 of the 13 sites on the mainstem of the Bighorn River in the reach from Worland, Wyo. (site 43) to Greybull, Wyo. (site 58). Concentrations of fecal coliform or *E. coli* exceeded the EPA's recommended limits for recreational contact with water in samples from 16 of the 26 tributaries sampled, including the mainstem of the Shoshone River (site 73 and site 76).

Goose Creek Basin

Synoptic sampling of the 24 sites in the Goose Creek Basin was conducted during June 27-29, 2000. Seven sites on Big Goose Creek, 8 sites on Little Goose Creek, 3 sites on Goose Creek, and 6 tributary sites were sampled. Fecal-coliform concentrations for 24 samples ranged from 10 col/100 mL for Little Goose Creek above Davis Creek, near Bighorn, Wyo. (site 88) to 1,500 col/100 mL for Soldier Creek on County Road 74, near Sheridan, Wyo. (site 97). *E. coli* concentrations for 21 samples ranged from 4 col/100 mL (site 88) to 800 col/100 mL (site 97) (fig. 11).

Data for Big Goose Creek and Little Goose Creek are discussed with the mainstem of Goose Creek because their drainage areas represent a large part of the Goose Creek Basin. Big Goose Creek and Little Goose Creek form Goose Creek at their confluence in Sheridan, Wyo. Fecal-coliform concentrations on Big Goose Creek ranged from 23 col/100 mL at the upstream-most site (site 79) to 1,100 col/100 mL upstream from the Sheridan, Wyo. urban area on Highway 331 (site 84), and *E. coli* concentrations ranged from 15 col/100 mL (site 79) to 430 col/100 mL at Kendrick Park in Sheridan, Wyo. (site 86). Fecal-coliform concentrations on Little Goose Creek ranged from 10 col/100 mL above Davis Creek, near Big Horn, Wyo. (site 88) to 280 col/100 mL on Highway 87 near Banner, Wyo. (site 92), and *E. coli* concentrations ranged from 4 col/100 mL (site 88) to 200 col/100 mL at two sites on Highway 87 (site 92 and site 93). Fecal-coliform concentrations on Goose Creek ranged from 600 col/100 mL at 11th Street in Sheridan, Wyo. (site 96) to 300 col/100 mL near Acme, Wyo. (site 100). The *E. coli* concentration was 240 col/100 mL in a sample collected below Sheridan, Wyo. (site 99) and 170 col/100 mL in the sample collected near Acme, Wyo. (site 100).

Six tributary sites were sampled in the Goose Creek Basin. Tributaries sampled in the forested, upper Goose Creek Basin included West Fork Big Goose Creek, East Fork Big Goose Creek and Rapid Creek, which are tributary to Big Goose Creek, and Tepee Creek, which is tributary to Little Goose Creek. Fecal-coliform concentrations in the upper basin tributaries ranged from 55 col/100 mL for the sample from West Fork Big Goose Creek near Big Horn, Wyo. (site 78) to 530 col/100 mL for the sample from East Fork Big Goose Creek on Forest Service Road 26 near Big Horn, Wyo. (site 77). *E. coli* concentrations in the upper basin tributaries ranged from 53 col/100 mL for the sample from West Fork Big Goose Creek near Big Horn, Wyo. (site 78) to 580 col/100 mL for the sample from East Fork Big Goose Creek on Forest Service Road 26 near Big Horn, Wyo. (site 77). A light to moderate rain fell during the sampling of sites in the upper basin and may have contributed to the high fecal-indicator bacteria at East Fork Big Goose Creek. Two sites on Soldier Creek, which is tributary to Goose Creek, were sampled. Fecal coliform (1,500 col/100 mL) and *E. coli* concentrations (800 col/100 mL) were higher at the upstream site on County Road 74, near Sheridan, Wyo. (site 97) than the downstream site in Sheridan, Wyo. (site 98).

Table 9. *Sites where sample concentrations of fecal-indicator bacteria exceeded the U.S. Environmental Protection Agency's recommended limits for a single sample for recreational contact with water in the Bighorn River Basin, Wyoming, July 2000.*

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

Fecal coliform	*Escherichia coli*		
>400 col/100 mL	>298 col/100 mL (Moderate use, full-body contact)	>406 col/100 mL (Light use, full-body contact)	>576 col/100 mL (Infrequent use, full-body contact)
Owl Creek (site 30)	Owl Creek (site 29)	Kirby Creek (site 34)	Owl Creek (site 30)
Kirby Creek (site 32, site 33, and site 34)	Bighorn River (site 43)	Sage Creek (site 42)	Kirby Creek (site 32 and site 33)
Nowater Creek (site 40)	Beaver Creek (site 65)	Bighorn River (site 58)	Nowater Creek (site 40)
Fifteenmile Creek (site 41)		Bitter Creek (site 71)	Fifteenmile Creek (site 41)
Sage Creek (site 42)			Slick Creek (site 44)
Bighorn River (site 43, site 45, site 46, site 52, and site 58)			Bighorn River (site 45, site 46, and site 52)
Slick Creek (site 44)			Greybull River (site 56 and site 57)
Greybull River (site 56 and site 57)			Dry Creek (site 59 and site 60)
Dry Creek (site 59 and site 60)			Granite Creek (site 62)
Granite Creek (site 62)			Shell Creek (site 66)
Beaver Creek (site 65)			Whistle Creek (site 72)
Shell Creek (site 66)			Shoshone River (site 73 and site 76)
Bitter Creek (site 71)			Foster Gulch (site 74)
Whistle Creek (site 72)			Sage Creek (site 75)
Shoshone River (site 73 and site 76)			
Foster Gulch (site 74)			
Sage Creek (site 75)			

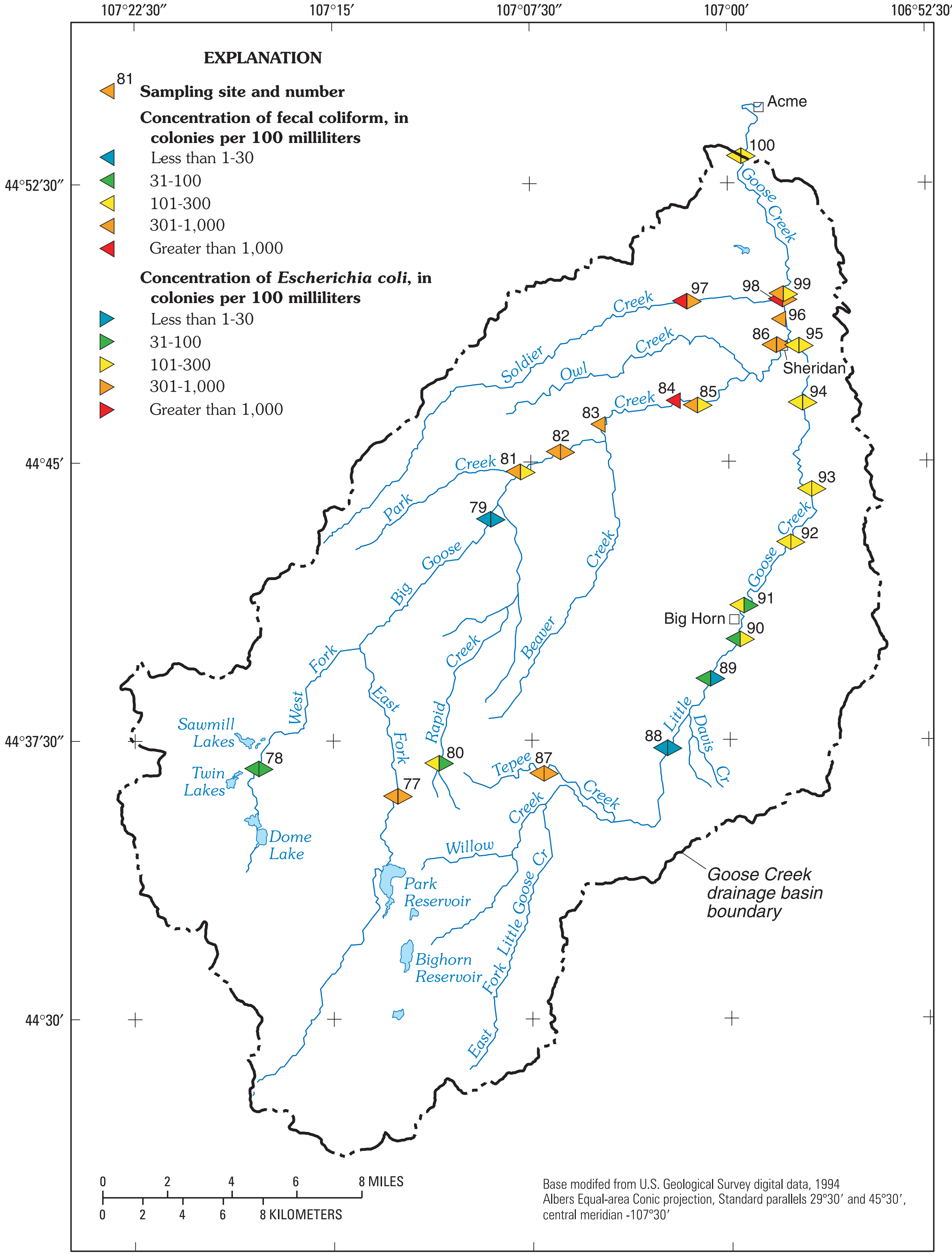


Figure 11. Fecal-indicator-bacteria concentrations for samples collected in the Goose Creek Basin, Wyoming, June 2000.

Samples from all of the sites on Big Goose Creek except the two upstream most sites (site 79 and site 81) exceeded at least one of the EPA's recommended limits for a single sample for recreational contact with water for fecal coliform or *E. coli* (table 10). None of the samples for the synoptic study collected on Little Goose Creek exceeded the EPA's recommended limits for recreational contact with water (table 3). Tributary sites that had concentrations exceeding at least one of the EPA's recommended limits for recreational contact with water include East Fork Big Goose (site 77), Tepee Creek (site 87), and Soldier Creek (site 97 and site 98). The Wyoming Department of Environmental Quality (2000) has listed Big Goose Creek, Little Goose Creek, Goose Creek, and Soldier Creek as impaired by fecal coliform in the 305(b) report for 2000.

Distribution of Fecal-Indicator Bacteria by Land Cover

Synoptic-sampling sites were located in various land-cover settings of the YRB to assess the distribution of fecal-indicator bacteria as it related to land cover in the Wind River, Bighorn River, and Goose Creek Basins. Land-cover classes for the synoptic-study sites include: forested, rangeland, agricultural, and urban. The distribution of the land cover by basin is summarized in table 11. The fewest sites were in the forested land-cover classification because several of the sites initially selected to represent forested land-cover were actually classified in the NLCD as shrubland or herbaceous upland natural/semi-natural vegetation. Also, road conditions and driving times to remote forested areas made sampling sites in these areas prohibitive.

Table 10. *Sites where sample concentrations of fecal-indicator bacteria exceeded the U.S. Environmental Protection Agency's recommended limits for a single sample for recreational contact with water in the Goose Creek Basin, Wyoming, June 2000.*

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

Fecal coliform	*Escherichia coli*		
>400 col/100 mL	>298 col/100 mL (Moderate use, full-body contact)	>406 col/100 mL (Light use, full-body contact)	>576 col/100 mL (Infrequent use, full-body contact)
East Fork Big Goose Creek (site 77)	Tepee Creek (site 87)	Big Goose Creek (site 86)	East Fork Big Goose Creek (site 77)
Big Goose Creek (site 82, site 83, site 84, site 85, and site 86)	Big Goose Creek (site 82 and site 85)		Soldier Creek (site 97 and site 98)
Goose Creek (site 96)			
Soldier Creek (site 97 and site 98)			

Table 11. *Sampling sites by land cover in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.*

Basin	Total number of sampling sites (n)	Land-cover classification: Forested	Rangeland	Agricultural	Urban
Wind River	23	1	19	1	2
Bighorn River	53	2	34	13	4
Goose Creek	24	4	7	8	5
Total	100	7	60	22	11

Boxplots summarizing the statistical distribution of fecal-indicator-bacteria concentrations for each land cover are presented in figure 12. The highest median concentrations of fecal coliform (540 col/100 mL) and *E. coli* (420 col/100 mL) for all samples were for sites with an urban land cover. The maximum concentrations of fecal coliform (3,000 col/100 mL) and *E. coli* (2,800 col/100 mL) for all samples were from sites with an agricultural land cover. The lowest median concentrations of fecal coliform (130 col/100 mL) and *E. coli* (67 col/100 mL) were for samples from sites with a forested land cover.

Results of a Kruskal-Wallis test indicate that the fecal-indicator-bacteria concentrations were not significantly different between land covers at a 95 percent confidence level for fecal-coliform concentrations (*p*-value =0.08) or *E. coli* concentrations (*p*-value=0.19). The median concentrations for sites with the forested and rangeland land cover were 2 to 3 times lower than the median concentrations for sites with agricultural and urban land covers; however, the variance of the fecal-indicator-bacteria concentrations was fairly wide for each land-cover classification. This indicates that while streams in agricultural and urban areas may be more likely to have elevated fecal-indicator-bacteria, low and high concentrations may occur for any of the land-cover areas in these basins. In this study, the forested sites were located in basins with multiple uses, including recreational use and grazing, which are typical for Wyoming's forested basins. In 1974, a study in a forested basin in southern Wyoming found fecal-coliform concentrations were higher in basins with multiple uses compared to natural areas without these uses (Skinner and others, 1974).

Relation of *Esherichia coli* to Fecal Coliform

The concentrations of fecal coliform and *E. coli* in samples during the synoptic study were comparable, indicating that historical fecal-coliform data generally will be a useful indicator of *E. coli* presence when the State of Wyoming transitions to *E. coli* criteria for water-quality monitoring in 2003 (C. Harnish, Wyoming Department of Environmental Quality, oral commun., 2002). Relations between fecal coliform and *E. coli* for the Wind River, Bighorn River, and Goose Creek Basins, and for the combined data set are presented in figure 13. Spearman's rank correlation shows a strong and positive correlation in each basin between fecal coliform and *E. coli*—varying only slightly between the basins. Spearman's Rho was 0.938 in the Wind River Basin, 0.981 in the Bighorn River Basin, 0.961 in the Goose Creek Basin, and 0.976 for the combined data set. For this analysis, data from sites on tributaries and mainstems were grouped together within a basin because site-specific relations could not be determined with only one sample per site. The strong correlation between fecal coliform and *E. coli* for the pooled data sets does not ensure that the relation between them is the same for individual streams. Studies have found that regression equations derived to predict *E. coli* based on fecal coliform differ from site to site, due in part to differences in sources of bacteria (Francy and others, 1993).

The lines on the scatter plots in figure 13 indicate where samples with an *E. coli* to fecal-coliform ratio of 0.5 and 1.0 would plot and where 50 to 100 percent of the fecal coliform would be in the form of *E. coli*. Most of the data plot between these lines, indicating that the majority of the fecal coliform were *E. coli* in the samples collected during the synoptic study. Data points that plot above the 1.0 line represent *E. coli* concentrations greater than the fecal-coliform concentrations. Because *E. coli* is a subset of fecal-coliform bacteria, these data reflect some of the variability about the fecal-indicator-bacteria concentrations seen in quality-assurance replicate samples. *E. coli* concentrations also may exceed fecal-coliform concentrations owing to differences in the processing method—the *E. coli* method uses a smaller filter pore size and has a resuscitation step that the fecal-coliform method does not have.

Relation of Fecal-Indicator Bacteria to Water-Quality Characteristics

Environmental conditions such as water characteristics affect the survival rate of fecal-indicator bacteria once they leave the digestive tract of warm-blooded animals. Selected physical water-quality characteristics were measured in the field and sediment samples were collected for analysis during the synoptic sampling in the Wind River, Bighorn River, and Goose Creek Basins to provide data on the environmental conditions. A wide range of stream settings was selected for the synoptic study, including large perennial streams that originate from mountainous sources and small intermittent streams that originate in the plains. The wide range of settings of the streams sampled for this study is reflected in the wide range of field measurement values (table 3).

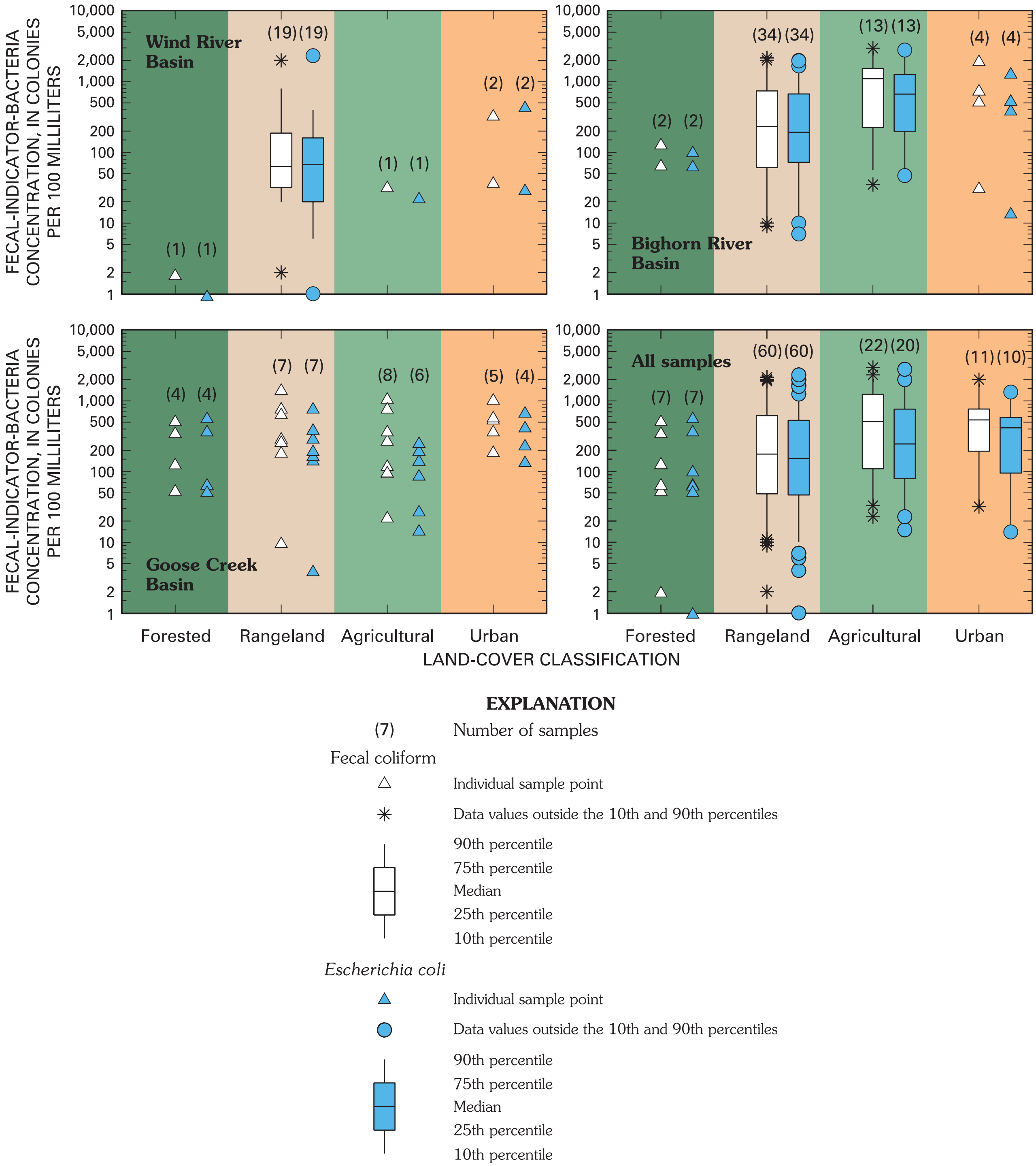


Figure 12. Fecal-indicator-bacteria concentrations by land-cover classification in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.

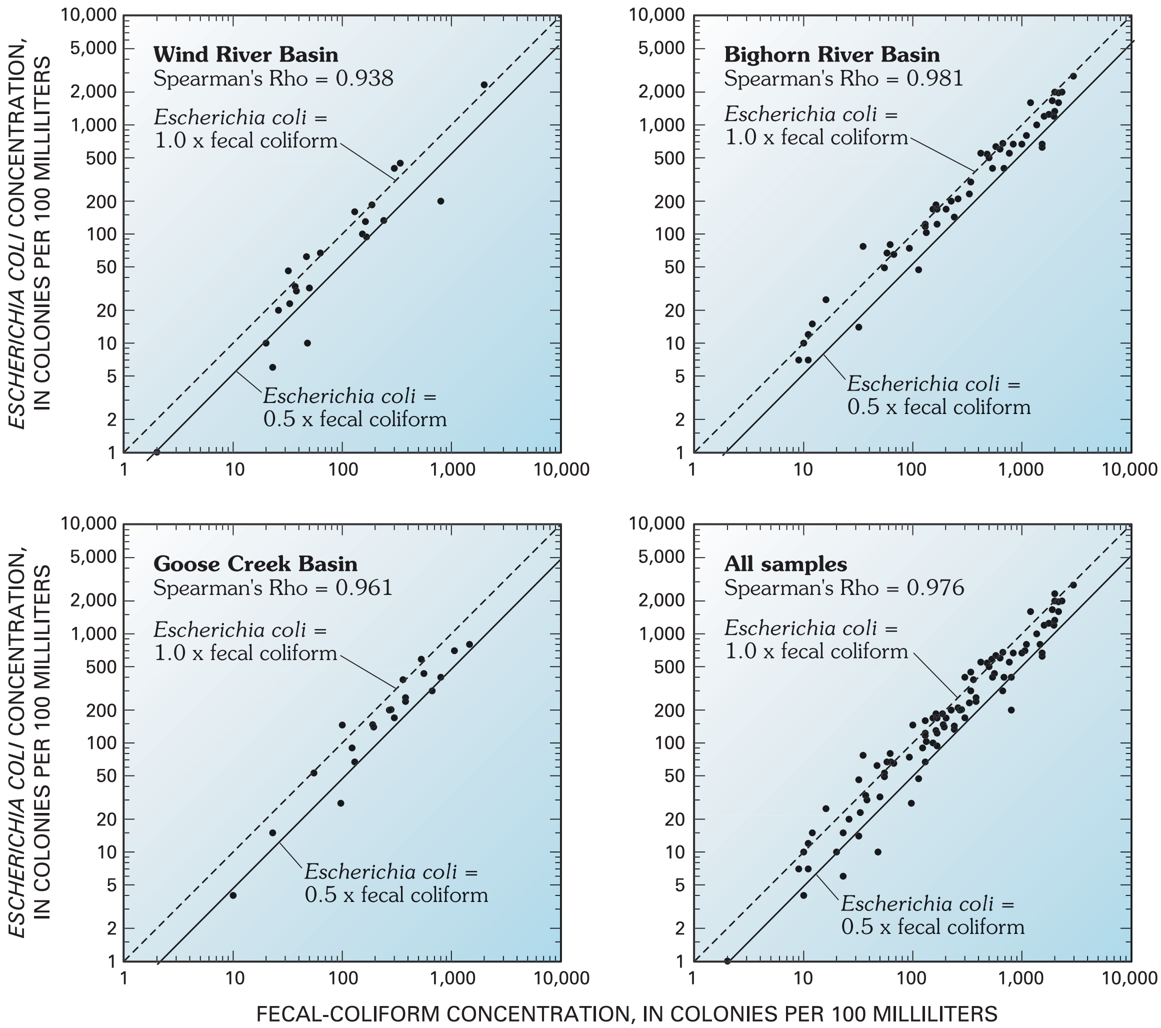


Figure 13. Fecal-coliform and *Escherichia coli* relations in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.

Spearman's rank correlation coefficient was used to determine the strength of the relation between the fecal-indicator bacteria and selected water-quality constituents for the pooled dataset of all samples (table 12) because site-specific relations were not possible with one data point. Fecal-indicator bacteria were poorly related to streamflow, water temperature, dissolved oxygen, pH, specific conductance, and alkalinity. The weak correlations for the pooled dataset probably are the result of the wide range of stream settings that were sampled. Other studies have shown that streamflow, in particular, can be an important factor controlling fecal-indicator-bacteria concentrations at a stream site as bacteria can be carried to the stream with overland flow (Stephenson and Street, 1978; Elder, 1987; Hunter and others, 1992; Barbe´ and Francis, 1995; Myers and others, 1998; Baudart and others, 2000).

Fecal-indicator bacteria and turbidity (Spearman's Rho values of 0.662 and 0.640 for fecal coliform and *E. coli*, respectively) and sediment (Spearman's Rho values of 0.628 and 0.636 for fecal coliform and *E. coli*, respectively) had moderate correlations, even given the wide range of stream settings that were sampled. The

Table 12. *Spearman's rank correlation coefficients between fecal-indicator bacteria and water-quality constituents in the Wind River, Bighorn River, and Goose Creek Basins, Wyoming, June-July 2000.*

Water-quality constituent	Spearman's rank correlation coefficient	
	Fecal coliform	*Escherichia coli*
Streamflow	-0.286	-0.313
Water temperature	.102	.140
Dissolved Oxygen	-.308	-.340
pH	-.076	-.026
Specific conductance	.384	.436
Alkalinity	.407	.455
Turbidity	.662	.640
Sediment	.628	.636

positive correlation of bacteria and solid particles can-result from overland flow carrying bacteria-laden sediment to streams (Hunter and others, 1992) or resuspension of sediment from the stream bottom, either by increased flows or human or animal traffic in the stream. Bacteria that are deposited with stream sediments can survive for extended periods in the protective environment of the sediment (Sherer and others, 1992). Fecal-coliform concentrations that were 100 to 1,000 times greater than concentrations in the water column have been found in the associated sediments (Van Donsel and Geldreich, 1971). No major storms producing significant amounts of overland flow on a large scale occurred during the synoptic study; however, isolated short storms locally may have contributed to fecal-indicator bacteria and turbidity or sediment concentrations at some sites.

Microbial Source Tracking

Determining the sources of fecal contamination in a basin can assist water managers in developing waste-load allocations, establishing best management practices, and assessing health risk presented by the contamination. Fecal-indicator bacteria are nearly always present at some level in Wyoming streams because sources for the bacteria exist in the basins. The presence of *E. coli* indicates the presence of fecal contamination from warm-blooded animals, but does not differentiate between host sources.

The two sites selected to test the DNA method using discriminant analysis of ribotypes for *E. coli* isolates were the Bighorn River at Basin, Wyo. (site 52) and Bitter Creek near Garland, Wyo. (site 71). Historical data from these sites include high fecal-indicator-bacteria concentrations. Both sites were listed as being impaired by fecal coliform for contact recreation in the Wyoming 305(b) water-quality assessment for 2000 (Wyoming Department of Environmental Quality, 2000). Eight *E. coli* isolates were cultured for the Bighorn River at Basin, Wyo. (site 52) and seven isolates were cultured for Bitter Creek near Garland, Wyo. (site 71).

Source classifications for the isolates for the sample from the Bighorn River at Basin, Wyo. (site 52) and Bitter Creek near Garland, Wyo. (site 71) are presented in figure 14. The source classification determinations are presented using three different confidence levels—70 percent, 80 percent, and 90 percent. The confidence level of 70 percent represents the case where there is a 30 percent probability that a classification determination is incorrect. The confidence level of 90 percent represents the case where there is a 10 percent probability that a classification determination is incorrect. Using the lower confidence levels results in fewer unknown determinations, but increases the chance of an incorrect classification.

Using a confidence level of 70 percent for the Bighorn River at Basin, Wyo. (site 52), 2 isolates were classified as human, 5 isolates as nonhuman, and 1 isolate as unknown. Using a confidence level of 90 percent for site 52, 1 isolate was classified as human, 3 isolates as nonhuman, and 4 isolates as unknown. Using a confidence level of 70 percent for Bitter Creek near Garland, Wyo. (site 71), 1 isolate was classified as human and 6 isolates as nonhuman. Using a confidence level of 90 percent for site 71, 1 isolate was classified as human, 4 isolates as nonhuman, and 2 isolates as unknown. These data indicate that both human and nonhuman sources contribute *E. coli* to the Bighorn River and Bitter Creek, and a higher percentage of the known isolates are from nonhuman sources. Whether the nonhuman sources are pets, agricultural animals, or wildlife was not determined for this study.

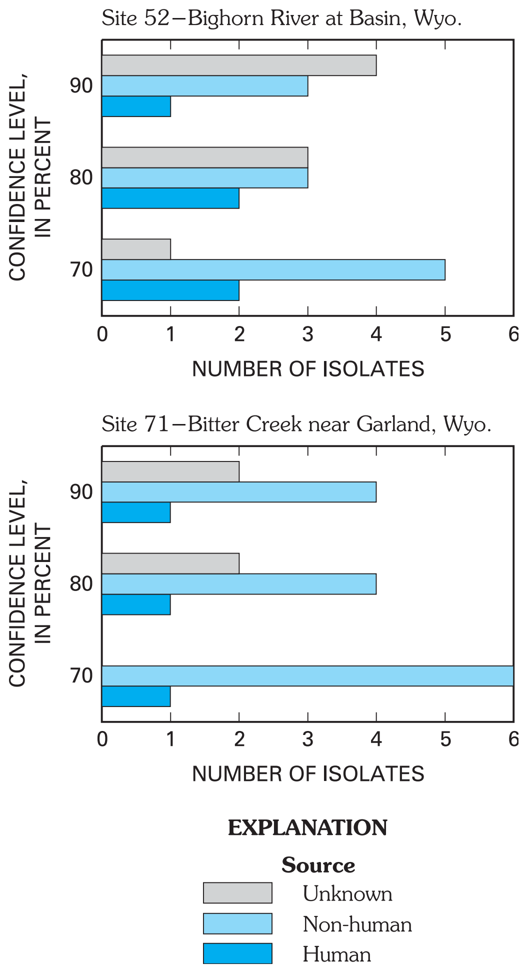


Figure 14. Source determinations of *Escherichia coli* isolates for samples from the Bighorn River at Basin, Wyoming (site 52) and Bitter Creek near Garland, Wyoming (site 71) in the Bighorn River Basin, Wyoming, July 2000.

SUMMARY

A synoptic study of fecal-indicator bacteria was conducted during June and July 2000 in the Wind River, Bighorn River, and Goose Creek Basins in Wyoming as part of the U.S. Geological Survey's National Water-Quality Assessment Program for the Yellowstone River Basin. Twenty-three sites were in the Wind River Basin, 53 sites were in the Bighorn River Basin, and 24 sites were in the Goose Creek Basin. Samples were collected in the summer when human exposure to pathogens through recreational contact with water typically is the highest. Fecal-coliform concentrations for 100 samples ranged from 2 to 3,000 col/100 mL (colonies per 100 milliliters). *Escherichia coli* (*E. coli*) concentrations for 97 samples ranged from 1 to 2,800 col/100 mL.

Fecal-indicator-bacteria concentrations varied significantly by basin. Samples from the Bighorn River Basin had the highest median concentrations for fecal coliform of 340 col/100 mL and for *E. coli* of 300 col/100 mL. Samples from the Goose Creek Basin had median concentrations for fecal coliform of 330 col/100 mL and for *E. coli* of 200 col/100 mL. Samples from the Wind River Basin had the lowest median concentrations for fecal coliform of 50 col/100 mL and for *E. coli* of 62 col/100 mL. The lower concentrations in the Wind River Basin were not directly related to the population densities of livestock and humans in the basins.

The Bighorn River Basin had the highest percentage of samples (49.1 percent) with fecal-coliform concentrations higher than EPA's recommended limit for a single sample for recreational contact with water of 400 col/100 mL. Concentrations of fecal coliform in the Goose Creek Basin exceeded the recommended limit in 37.5 percent of the samples. Concentrations of fecal coliform in the Wind River Basin exceeded the recommended limit in 8.7 percent of the samples. In the Bighorn River Basin, 50.9 percent of the samples for *E. coli* exceeded the EPA recommended limit for a single sample for moderate use, full-body recreational contact of 298 col/100 mL, compared to 33.3 percent in the Goose Creek Basin and 13.0 percent in the Wind River Basin. In the Bighorn River Basin, 37.7 percent of the samples of *E. coli* exceeded the EPA recommended limit for infrequent use, full-body recreational contact of 576 col/100 mL, compared to 14.3 percent in the Goose Creek Basin and 4.3 percent in the Wind River Basin.

The distribution of fecal-indicator-bacteria concentrations by land cover was determined relative to the dominant land cover 500 meters upstream of each sample site. The highest median concentrations for fecal coliform of 540 col/100 mL and for *E. coli* of 420 col/100 mL were for samples from sites with an urban land cover. The maximum concentrations for fecal coliform of 3,000 col/100 mL and for *E. coli* of 2,800 col/100 mL were in samples from sites with an agricultural land cover. The lowest median concentrations for fecal coliform of 130 col/100 mL and for *E. coli* of 67 col/100 mL were for samples from sites with a forested land cover. Although the median concentrations for sites with the forested and rangeland land cover were 2 to 3 times lower than the median concentrations for sites with agricultural and urban land covers, the results of a Kruskal-Wallis test indicated the fecal-indicator-bacteria concentrations were not statistically different between land covers.

Relations between fecal coliform and *E. coli* for the Wind River, Bighorn River, and Goose Creek Basins were strong and positive. Spearman's Rho was 0.938 in the Wind River Basin, 0.981 in the Bighorn River Basin, and 0.961 in the Goose Creek Basin. These results indicate that the distribution of fecal coliform and *E. coli* in Wyoming streams is comparable and historical fecal-coliform data generally will be a useful indicator of *E. coli* presence when the State of Wyoming transitions to using *E. coli* for water-quality criteria in 2003.

Fecal-indicator bacteria were not corelated with the field constituents of streamflow, pH, specific conductance, dissolved oxygen, water temperature, and alkalinity. Fecal-indicator bacteria were moderately correlated with turbidity (Spearman's Rho values of 0.662 and 0.640 for fecal coliform and *E. coli*, respectively) and sediment (Spearman's Rho values of 0.628 and 0.636 for fecal coliform and *E. coli*, respectively).

A microbial source-tracking method was tested as part of the synoptic study. *E. coli* isolates in samples from the Bighorn River at Basin, Wyo. and Bitter Creek near Garland, Wyo. were analyzed using discriminant analysis of ribotype patterns. Using a confidence level of 90 percent for the Bighorn River at Basin, Wyo., 1 isolate was classified as human, 3 isolates as nonhuman, and 4 isolates as unknown. Using a confidence level of 90 percent for Bitter Creek near Garland, Wyo., 1 isolate was classified as human, 4 isolates as nonhuman, and 2 isolates as unknown. These data indicate that human and nonhuman sources contribute *E. coli* to stream waters in both basins, and a higher percentage of the known isolates are from nonhuman sources.

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