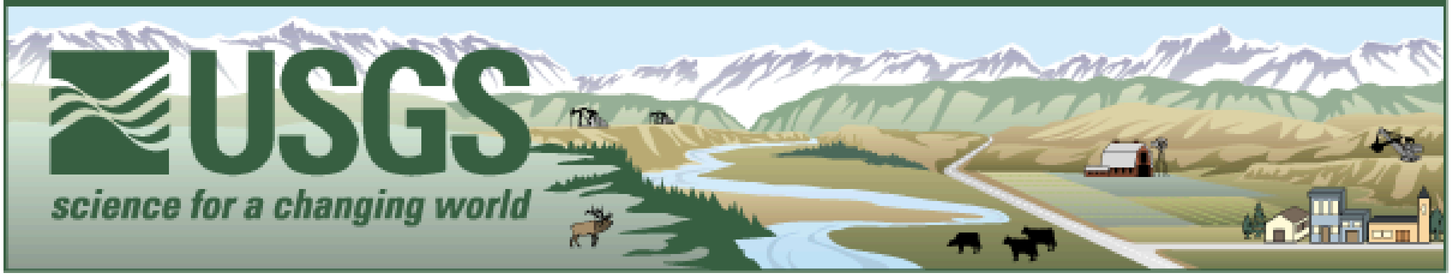
National Water-Quality Assessment   Yellowstone River Basin



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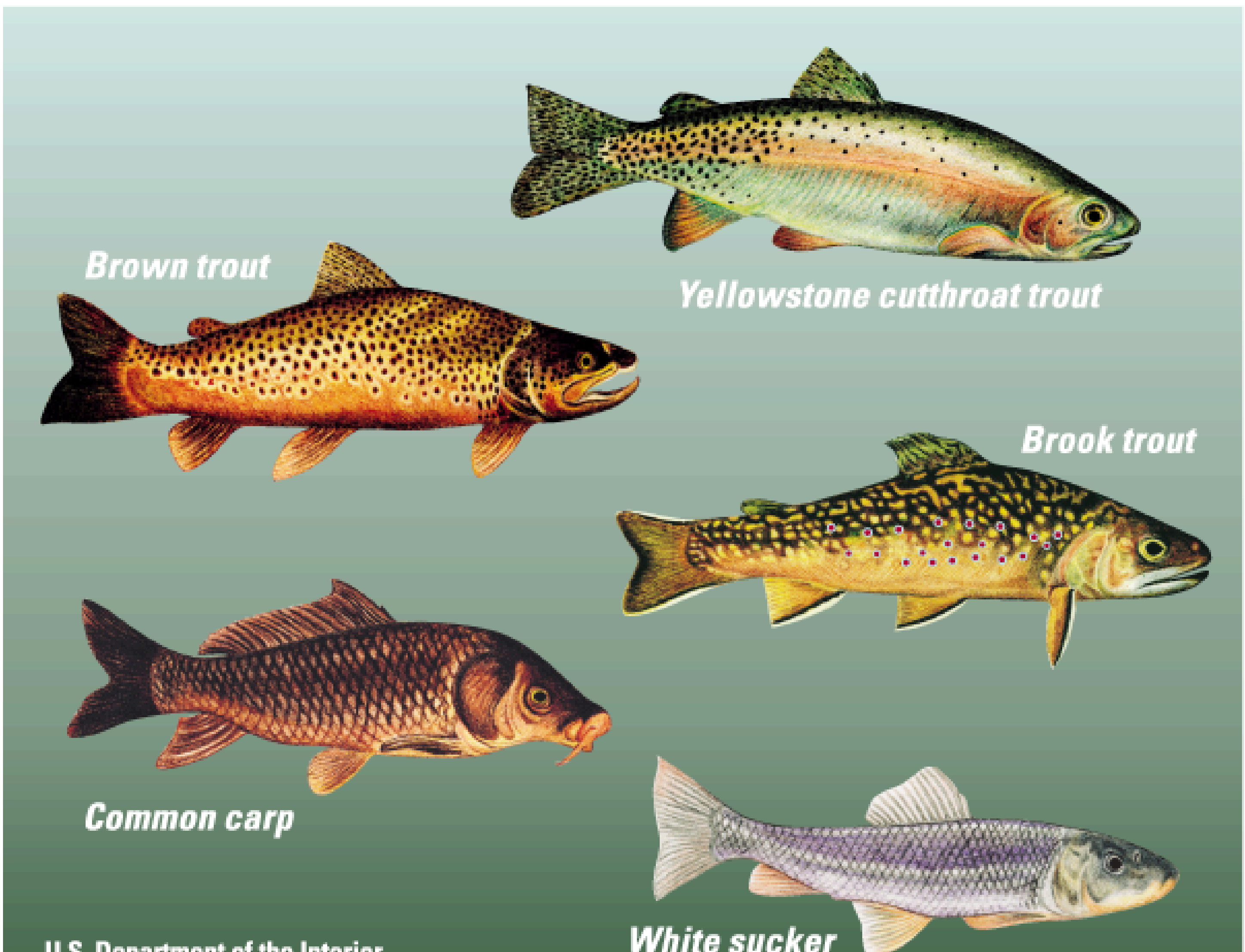
Water-Resources Investigations Report 00-4190



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Organic Compounds and Trace Elements in Fish Tissue and Bed Sediment from Streams in the Yellowstone River Basin, Montana and Wyoming, 1998

By David A. Peterson and Gregory K. Boughton

Water-Resources Investigations Report 00-4190

Prepared as part of the

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Cheyenne, Wyoming
2000

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, Tribal, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, Tribal, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society, we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, Tribal, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, Tribal, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of more than 50 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the study units, and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas, and will identify changes and trends and their causes. The current topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, trace elements, and aquatic ecology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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By David A. Peterson and Gregory K. Boughton

ABSTRACT

A comprehensive water-quality investigation of the Yellowstone River Basin began in 1997, under the National Water-Quality Assessment (NAWQA) Program. Twenty-four sampling sites were selected for sampling of fish tissue and bed sediment during 1998. Organic compounds analyzed included organochlorine insecticides and their metabolites and total polychlorinated biphenyls (PCBs) from fish-tissue and bed-sediment samples, and semivolatile organic compounds from bed-sediment samples. A broad suite of trace elements was analyzed from both fish-tissue and bed-sediment samples, and a special study related to mercury also was conducted.

Of the 12 organochlorine insecticides and metabolites detected in the fish-tissue samples, the most compounds per site were detected in samples from integrator sites which represent a mixture of land uses. The presence of DDT, and its metabolites DDD and DDE, in fish collected in the Yellowstone Park area likely reflects long-term residual effects from historical DDT-spraying programs for spruce budworm. Dieldrin, chlordane, and other organic compounds also were detected in the fish-tissue samples. The compound p, p′-DDE was detected at 71 percent of the sampling sites, more than any other compound. The concentrations of total DDT in fish samples were low, however, compared to concentrations from historical data from the study area, other NAWQA studies in the Rocky Mountains, and national baseline concentrations.

Only 2 of the 27 organochlorine insecticides and metabolites and total PCBs analyzed in bed sediment were detected. Given that 12 of the compounds were detected in fish-tissue samples, fish appeared to be more sensitive indicators of contamination than bed sediment.

Concentrations of some trace elements in fish and bed sediment were higher at sites in mineralized areas than at other sites. Concentrations of selenium in fish tissue from some sites were above background levels. Concentrations of arsenic, chromium, copper, and lead in some of the bed-sediment samples potentially exceeded criteria for the protection of aquatic life.

INTRODUCTION

The Yellowstone River Basin (YELL) was selected as one of more than 50 study units in the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. The scope and objectives of the NAWQA program are described briefly in the foreword to this report and in more detail by Hirsch and others (1988) and Gilliom and others (1995). The NAWQA study units were divided across the United States into three groups on a rotational schedule, with one group of studies beginning in 1991, a second group beginning in 1994, and a third group beginning in 1997. The YELL was among the group of study-unit investigations that began in 1997.

The surface-water component of the NAWQA program requires an integrated approach (physical, chemical, and biological) to aid in interpreting and assessing changes in stream quality (Gurtz, 1994). One element of this integrated approach is describing the occurrence and distribution of organic compounds and trace elements in fish tissue and bed sediment.

Purpose and Scope

The purpose of this report is to describe the occurrence and distribution of organic compounds and trace elements in fish tissue and bed sediment from selected streams in the YELL. Development of a biological and sediment database provides a baseline for assessment of long-term trends and is useful for comparing land-use inputs (Crawford and Luoma, 1993, p. 4). The fish-tissue and bed-sediment data are compared to data from other investigations in the United States and Canada, regional, statewide, and site-specific investigations, and results of studies related to potential adverse effects on aquatic biota or human health.

Fish-tissue and bed-sediment analyses and related data from samples collected for the YELL NAWQA during the summer and fall of 1998 are presented in this report. The data also are available from the USGS National Water Information System (NWIS) database, a report by Swanson and others (2000), and the Internet, at ***http://wy.water.usgs.gov/YELL/html/data.htm***.

Bed-sediment samples were collected at 24 sites, and fish-tissue samples were collected at 21 of those sites. Fish-tissue and bed-sediment data are included from 5 sites that were co-sampled as part of a USGS national mercury investigation.

Description of the Study Unit

The Yellowstone River is the largest tributary of the Missouri River and drains an area of approximately 70,000 mi^2 (square miles) in Montana, North Dakota, and Wyoming (fig. 1). The annual mean discharge of the Yellowstone River near its mouth is 12,830 cubic feet per second (Shields and others, 1998, p. 302). Major tributaries to the Yellowstone River include the Clarks Fork Yellowstone River, the Wind/Bighorn River, the Tongue River, and the Powder River.

Mean annual precipitation in the YELL ranges from about 5.9 inches in the central parts of the Bighorn and Wind River Basins to more than 59 inches at high elevations in the mountains near Yellowstone National Park (Oregon Climate Service, 1995a, 1995b). Snowfall composes a substantial part of annual precipitation in most years, with average annual snowfall ranging from less than 12 inches in parts of the Bighorn Basin to more than 200 inches near Yellowstone National Park (Western Regional Climate Center, 1997).

The environmental setting of the Yellowstone River Basin has been described by Zelt and others (1999); the following discussion is condensed from that report. Four ecoregions occur in the YELL (fig. 2). The ecoregions are based on integrated patterns of factors including land use, morphology, potential natural vegetation, and soil (Omernik, 1987). Approximately 55 percent of the study unit lies in the Northwestern Great Plains ecoregion (Zelt and others, 1999). This ecoregion has plains with open hills of varying height and tablelands of moderate relief; predominant land cover is subhumid grass used for grazing (Omernik, 1987). The Middle Rocky Mountains and Wyoming Basin ecoregions each contain about 21 percent of the study unit. The Middle Rocky Mountains ecoregion features high mountains and plateaus covered by Douglas fir, western spruce-fir forests, and alpine meadows; land use includes grazing, recreation, and silviculture. The Wyoming Basin ecoregion has plains with hills or low mountains, some irrigated agriculture, and the potential natural vegetation is shrub steppe, desert shrubland, and juniper-pinyon woodland. The Montana Valley and Foothill Prairies ecoregion contains the remaining 3 percent of the study unit. The Montana Valley and Foothill Prairies ecoregion is characterized as subhumid grassland used for grazing, and some irrigated land. Additional details describing the study unit can be found in Zelt and others (1999) and Peterson and Zelt (1999).

Environmental setting and site type were the primary factors in selection of the sampling sites (table 1). The environmental setting of the study unit can be stratified by identifying sub-areas (not necessarily contiguous) that have relatively homogeneous combinations of those natural and anthropogenic features believed to be relevant to water quality (Gilliom and

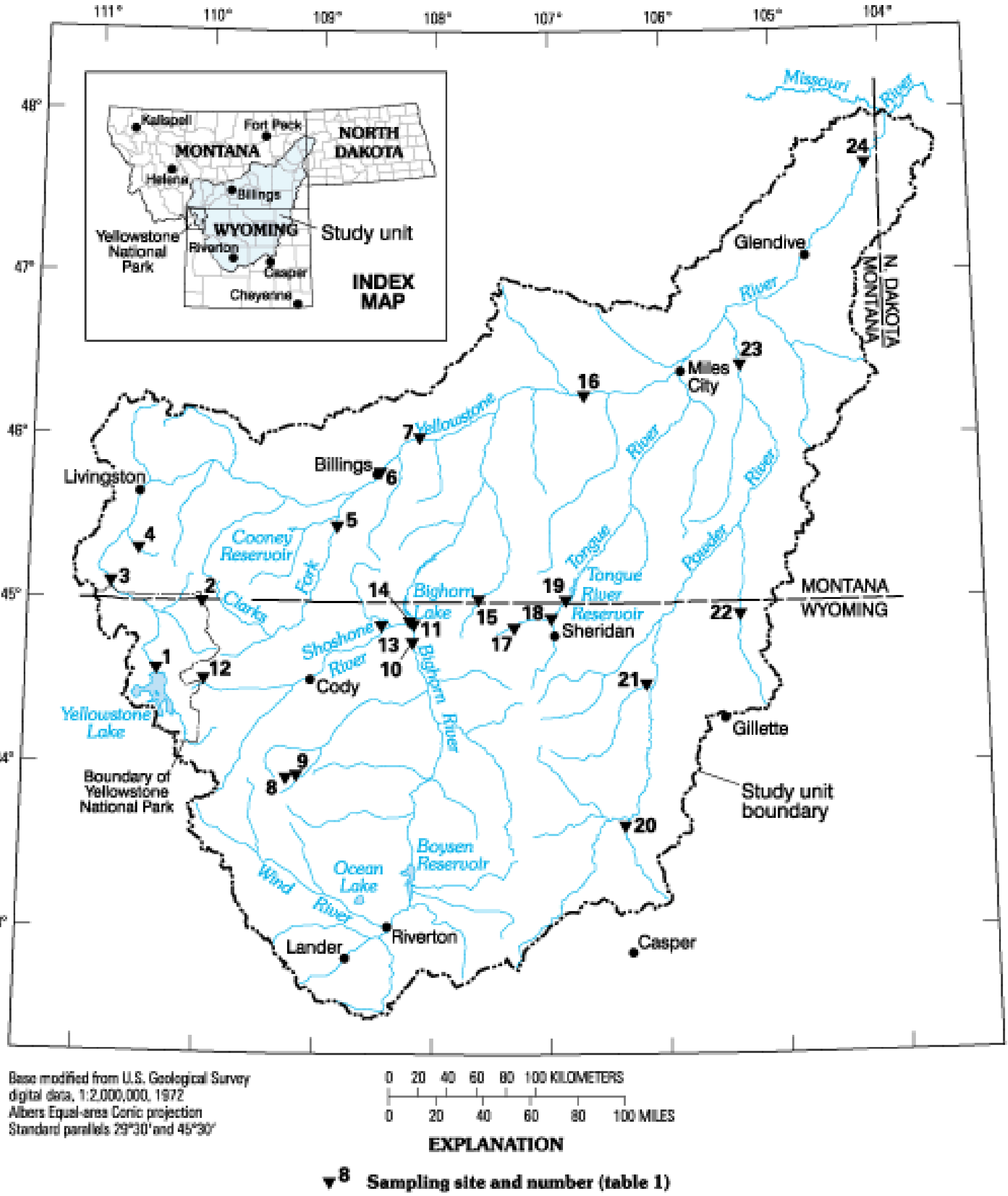
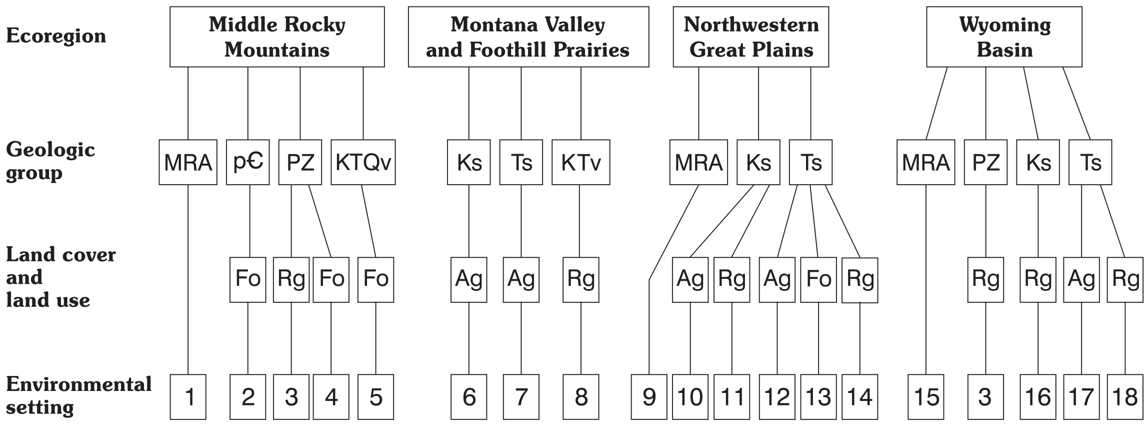


Figure 1. Location of fish-tissue and bed-sediment sampling sites in the the Yellowstone River Basin NAWQA study unit, Montana, North Dakota, and Wyoming.

A



EXPLANATION

Geologic group

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

Land cover and land use

Ag	Agricultural
Fo	Forest
Rg	Range

Figure 2. Environmental settings in the Yellowstone River Basin (modified from Zelt and others, 1999).

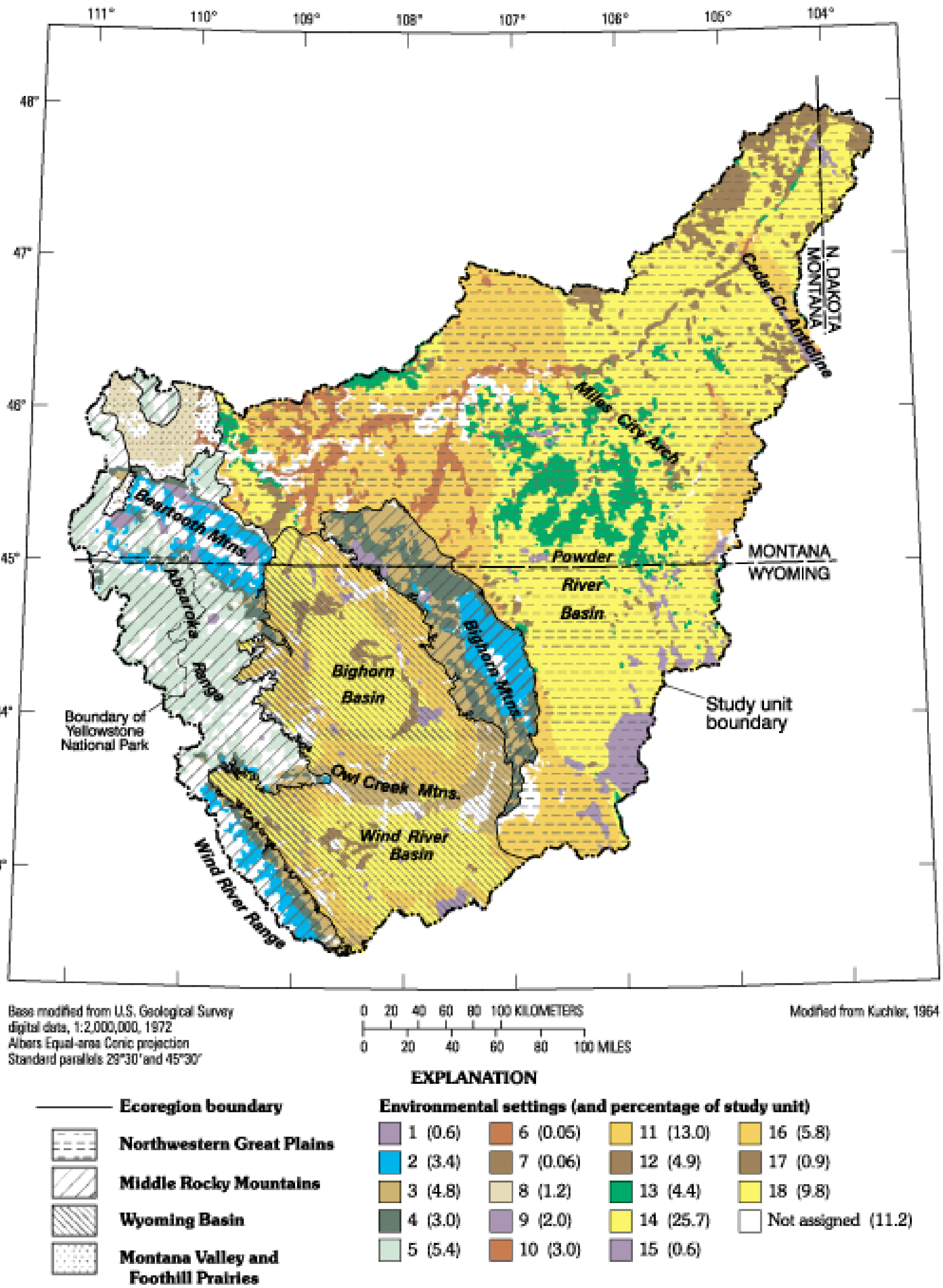


Figure 2. Continued.

Table 1. *Fish-tissue and bed-sediment sampling sites, Yellowstone River Basin*

[mi^2, square miles. Site type: int, integrator; ind, indicator; min, mineralized area; ag, agriculture; ref, reference for mineralized area; og, oil and gas; for, forested; rg, range. Ecoregion: MR, Middle Rocky Mountains; NWGP, Northwestern Great Plains; WB, Wyoming Basin]

Site number (fig. 1)	USGS station number	Station name	Drainage area (mi^2)	Site type	Ecoregion	Major land use and land cover (percent of drainage area)		
1	06186500	Yellowstone River at lake outlet	1,006	int	MR	forest (64)	water (14)	tundra (14)
2	06187915	Soda Butte Creek at Park boundary	31.2	ind - min	MR	forest (66)	tundra (28)	range (5)
3	06191500	Yellowstone River at Corwin Springs	2,623	int	MR	forest (67)	range (9)	water (5)
4	451753110334301	West Fork Mill Creek near Pray	40.2	ind - min	MR	forest (67)	tundra (33)	
5	06208500	Clarks Fork Yellowstone River at Edgar	2,032	int	NWGP	forest (37)	range (45)	tundra (8)
6	06214500	Yellowstone River at Billings	11,795	int	NWGP	forest (41)	range (36)	agric (10)
7	455905108081301	Arrow Creek near Worden	56.7	ind - ag	NWGP	agric (50)	range (49)	urban (1)
8	435440109152501	Wood River below Galena Creek	21.3	ind - min	MR	tundra (79)	forest (21)	
9	435602109095301	Wood River above Middle Fork Wood River	44.9	ind - min	MR	tundra (79)	forest (27)	range (3)
10	06279500	Bighorn River at Kane	15,765	int	WB	range (73)	forest (16)	agric (5)
11	445110108102901	Bighorn Lake at Highway 14A	15,846	int	WB	range (73)	forest (16)	agric (5)
12	06279795	Crow Creek at mouth, near Pahaska	19.1	ind - ref	MR	forest (80)	tundra (20)	
13	06285500	Sage Creek at Lovell	381	ind - og	WB	range (62)	forest (22)	agric (16)
14	445221108122601	Shoshone River at mouth near Kane	2,977	int	WB	range (45)	forest (33)	agric (11)
15	06289000	Little Bighorn River at State line	193	ind - for	MR	forest (83)	range (17)	
16	06295000	Yellowstone River at Forsyth	40,339	int	NWGP	range (58)	forest (25)	agric (9)
17	06298000	Tongue River near Dayton	204	ind - for	MR	forest (74)	range (26)	
18	06305700	Goose Creek near Acme	411	int	NWGP	forest (47)	range (35)	agric (12)
19	06306300	Tongue River at State line	1,477	int	NWGP	range (56)	forest (32)	agric (10)
20	06313400	Salt Creek near Sussex	769	ind - og	NWGP	range (96)	forest (3)	agric (1)
21	06316400	Crazy Woman Creek near Arvada	945	ind - rg	NWGP	range (79)	forest (18)	agric (2)
22	06324970	Little Powder River near State line	1,235	ind - rg	NWGP	range (84)	forest (8)	agric (7)
23	06326500	Powder River near Locate	13,189	int	NWGP	range (82)	forest (12)	agric (5)
24	06329500	Yellowstone River near Sidney	69,103	int	NWGP	range (65)	forest (20)	agric (10)

others, 1995). Eighteen environmental settings in the YELL (fig. 2) were identified on the basis of primary stratification by ecoregion, geology, land use, and land-cover, and secondary stratification by coal lease areas, metallic mineral deposits, and oil and gas fields (Zelt and others, 1999, p. 75-80). Sampling sites also can be classified as either indicator or integrator sites. Indicator sites represent relatively small, homogeneous basins associated with environmental settings, such as a specific land use that is considered to be important for understanding water quality in the study unit. Integrator sites are established at downstream points in large drainage basins that are relatively heterogeneous and incorporate complex combinations of environmental settings.

Physical conditions at the sampling sites varied widely. Streams in the Middle Rocky Mountains ecoregion tended to be small, wadeable streams, with specific conductance less than 200 µS/cm (microsiemens per centimeter at 25 degrees Celsius) at the time of sampling (table 2). In contrast, streams in the Northwestern Great Plains ecoregion also were wadeable, but specific conductance was higher, reaching a maximum of 2,010 µS/cm. The sampling sites on the main stem of the Yellowstone River and the Bighorn River were not wadeable. Specific conductance on the main stem of the Yellowstone River was relatively low, ranging from 83 µS/cm at the lake outlet (site 1) to 433 µS/cm near the mouth (site 24). Dissolved oxygen concentrations were near saturation (typically 8-10 mg/L (milligrams per liter)) at all of the sites. The water at the sampling sites tended to be slightly alkaline, as indicated by the pH range of 7.4 to 8.6.

Sample Collection and Analysis

The length of the sampling reach was determined by multiplying the mean wetted channel width by 20, in order to encompass habitat types such as pools, runs, and riffles, with regard to the minimum and maximum reach lengths specified by Fitzpatrick and others (1998). At wadeable sites, the sampling reach ranged from 150 to 300 meters long. At non-wadeable sites, the sample reach generally was about 1,000 meters long. Samples were collected during late July to October 1998.

Fish were collected by electrofishing (fig. 3), netting, and seining following procedures outlined by Meador and others (1993) and Crawford and Luoma (1993). The nationally consistent target taxa were common carp (*Cyprinus carpio*) and brown trout (*Salmo trutta*); white sucker (*Catostomus commersoni*) was the designated alternate species. Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) and brook trout (*Salvelinus fontinalis*) were collected at a few sites where target taxa were not available. No fish-tissue samples were collected from sampling sites 8, 20, and 23 because no target taxa or suitable alternate species were found.

At each site, tissue from 5 to 9 adult fish of the same species and similar size were composited to form a sample. External anomalies including deformities, eroded fins, lesions, tumors, and parasites were recorded. Whole-body fish were analyzed for organic compounds, and fish livers were analyzed for trace elements (Crawford and Luoma, 1993), with two exceptions. At site 9, whole body brook trout were collected for analysis of trace elements because the fish were too small to yield adequate mass of liver tissue. Both whole-body and liver samples of brook trout were collected at site 12 for analysis of trace elements. At seven of the sites, liver tissue was removed for trace element analysis and the remainder of the whole-body tissue was sent for analysis of organic compounds because of inadequate numbers of fish to do separate analyses. Fish-tissue samples were kept frozen prior to analysis at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado.

Bed-sediment samples were collected from multiple depositional areas at each sampling reach and composited for analysis according to guidelines established by Shelton and Capel (1994). A Teflon coring device was used to collect sediment from the upper 2.5 cm (centimeters) of the streambed from 20 to 25 places in undisturbed depositional areas along the reach. Sediments were homogenized, and a subsample of about 500 mL (milliliters) was wet sieved through a 2-mm (millimeter) stainless-steel sieve into a precleaned 500 mL glass jar for analysis of organic compounds. Each sediment sample for analysis of trace elements was sieved through a cleaned 0.062-mm nylon sieve cloth stretched over a frame and funnel into a clean, acid-rinsed plastic jar.

Twenty-eight organic compounds and lipid content in fish-tissue samples and 114 organic compounds in bed-sediment samples were analyzed (table 3). Both fish-tissue and bed-sediment samples were analyzed for organochlorine insecticides and their metabolites,

Table 2. *Physical measurements at sampling sites, Yellowstone River Basin, July-September 1998*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per cubic centimeter at 25°Celsius; C, Celsius; mg/L, milligrams per liter; NA, not available; E, estimated]

Site number (fig. 1)	Date	Discharge, instantaneous (ft^3/s)	Percent of annual mean discharge	Specific conductance (µS/cm)	pH (standard units)	Water temperature (degrees C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)
1	9/4/98	1,580	118	83	8.4	17.5	8.3	111
2	9/3/98	NA	NA	172	8.4	15.0	8.0	104
3	8/27/98	3,280	105	170	7.6	14.5	8.7	103
4	8/27/98	35	NA	123	7.8	10.5	9.1	98
5	8/26/98	531	51	612	8.1	17.0	8.6	102
6	8/25/98	4,740	67	301	8.4	21.0	9.6	123
7	9/25/98	NA	NA	519	7.8	20.2	7.5	NA
8	8/3/98	E70	NA	155	7.5	10.0	9.0	104
9	8/6/98	NA	NA	161	7.8	11.5	8.8	106
10	8/31/98	2,720	122	676	8.4	22.0	6.7	89
11	9/2/98	NA	NA	NA	NA	NA	NA	NA
12	8/5/98	E30	NA	66	7.4	12.5	8.6	103
13	9/1/98	NA	NA	1130	8.1	20.0	8.0	102
14	9/2/98	NA	NA	878	8.1	14.5	9.0	102
15	9/22/98	130	87	320	8.2	8.4	9.9	99
16	7/27/98	12,990	118	401	8.6	24.5	7.8	104
17	9/23/98	110	60	207	8.2	9.4	9.5	97
18	9/21/98	276	169	452	8.1	13.4	9.1	98
19	9/24/98	290	62	483	8.5	15.5	10.4	120
20	8/1/98	E12	27	2010	7.9	22.0	6.7	91
21	7/31/98	NA	NA	1180	8.3	20.5	7.5	97
22	7/30/98	6.4	27	1930	8.2	22.0	8.1	105
23	7/29/98	E60	10	1940	8.3	23.0	7.5	96
24	7/28/98	11,300	88	433	8.6	24.5	6.8	89

and total polychlorinated biphenyls (PCBs). Bed-sediment samples also were analyzed for a variety of semivolatile organic compounds (SVOCs). Methods used to analyze organic compounds in fish-tissue and sediment are described by Leiker and others (1995) and Foreman and others (1995). Fish-tissue samples were analyzed for trace elements using inductively coupled plasma atomic emission spectrophotometry, inductively coupled plasma mass spectrometry, and cold vapor atomic absorption (Hoffman, 1996) at the USGS NWQL in Denver, Colorado. Bed-sediment samples were analyzed for trace elements using a strong acid digestion followed by inductively coupled plasma atomic emission spectroscopy and various forms of atomic absorption spectrophotometry, including cold vapor, graphite furnace, and hydride generation at the USGS Branch of Geochemistry, Analytical Services Group Laboratory in Denver, Colorado (Arbogast, 1990). Percent organic carbon was determined by heating a sample in an inductive furnace and measuring the amount of carbon dioxide by thermal conductivity (Wershaw and others, 1987). Method reporting limits are listed in table 3, but actual reporting limits for some samples are higher because of matrix effects. In other cases, as indicated by an "E" prefix in tables 4 and 5, concentrations below the method reporting limit are estimated.

Figure 3. Electrofishing on the Bighorn River at Kane, Wyoming, September 1998

Additional fish and sediment samples were collected at five sites for the USGS National Mercury Project. Olson and DeWild (1999) describe the analytical techniques used for low levels of mercury and speciation in water, sediment, and biota. The water and bed-sediment samples were analyzed at the USGS laboratory in Madison, Wisconsin. The fish-tissue fillet samples were analyzed at the USGS laboratory in Columbia, Missouri.

Quality Assurance

Paired primary and replicate composite whole-body fish samples for analysis of organic compounds were collected at site 6 (white sucker) and at site 10 (common carp). The organic compound p,p′-DDE was the only one detected in both the primary and replicate samples. The primary sample of white sucker had a concentration of 6.7 µg/kg (micrograms per kilogram) p,p′-DDE, and 4.9 percent lipids, and the replicate sample had 13 µg/kg p,p′-DDE and 2.7 percent lipid. Concentrations of p,p′-DDE in whole-body carp from site 10 were 38.8 µg/kg in the primary sample and 25.4 µg/kg in the replicate sample; lipid contents were 4.05 percent and 2.75 percent, respectively. Triplicate samples of composite white sucker liver (primary and two replicates) were collected from site 6 for analysis of trace elements. The relative percent difference in element concentrations among the three samples ranged from 0 to 84 percent and averaged 26 percent. The element concentrations were not consistently higher or lower from one sample to another.

Laboratory quality control consisted of laboratory blanks and surrogate and reagent spike recoveries. Laboratory blanks indicated that samples were not contaminated during laboratory processing. Surrogate and reagent spike recoveries were within acceptable levels according to method performance standards outlined in reports by Leiker and others (1995) and Foreman and others (1995). Results were not adjusted to account for percent recovery.

The NWQL participated in several fish-tissue interlaboratory studies sponsored by the U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency (Leiker and others, 1995). Results of these studies validated the fish-tissue methodology used by the NWQL. About 80 percent of all data were within 1 standard deviation and 100 percent were within 2 standard deviations for all compounds analyzed.

Acknowledgments

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ORGANIC COMPOUNDS

The organochlorine insecticides and metabolites, and total PCBs analyzed in the fish-tissue and bed-sediment samples are manmade organic compounds.

Table 3. *Organic compounds analyzed and reporting limits for fish-tissue and bed-sediment analyses*

[MRL, method reporting limit; concentrations in micrograms per kilogram (µg/kg) unless expressed otherwise; NA, not analyzed; unsp, unspecified]

Compound	Fish tissue MRL	Bed sediment MRL	Compound	Fish tissue MRL	Bed sediment MRL
cis-Chlordane	5	1	Dieldrin	5	1
trans-Chlordane	5	1	Endrin	5	2
Heptachlor	5	1	Hexachlorobenzene	5	1
Heptachlor epoxide	5	1	alpha-BHC	5	1
cis-Nonachlor	5	1	beta-BHC	5	1
trans-Nonachlor	5	1	delta-BHC	5	NA
Oxychlordane	5	1	Lindane (gamma-BHC)	5	1
o,p′-DDD	5	1	o,p′-Methoxychlor	5	5
p,p′-DDD	5	1	p,p′-Methoxychlor	5	5
o,p′-DDE	5	1	Mirex	5	1
p,p′-DDE	5	1	Pentachloroanisole	5	1
o,p′-DDT	5	2	Toxaphene	200	200
p,p′-DDT	5	2	Total PCB	50	50
Aldrin	5	1	Lipids (percent)	0.5	NA
Dacthal (DCPA)	5	5			
Compounds analyzed only in bed sediment					
Chloroneb		5	4-Chlorophenyl phenyl ether		50
Endosulfan I		1	4-Nitrophenol		unsp
Isodrin		1	4H-cyclopenta[def]phenanthrene		50
cis-Permethrin		5	Acenaphthene		50
trans-Permethrin		5	Acenaphthylene		50
1,2,4-Trichlorobenzene		50	Acridine		50
1,2-Dichlorobenzene		50	Anthracene		50
1,2-Dimethylnaphthalene		50	Anthraquinone		50
1,3-Dichlorobenzene		50	Azobenzene		50
1,4-Dichlorobenzene		50	Benz[a]anthracene		50
1,6-Dimethylnaphthalene		50	Benzo[a]pyrene		50
1-Methyl-9H-fluorene		50	Benzo[b]fluoranthene		50
1-Methylphenanthrene		50	Benzo[c]cinnoline		50
1-Methylpyrene		50	Benzo[ghi]perylene		50
2,2′-Biquinoline		50	Benzo[k]fluoranthene		50
2,3,5,6-Tetramethylphenol		50	Phenanthridine		50
2,3,6-Trimethylnaphthalene		50	Phenol		50
2,4,6-Trichlorophenol		unsp	Pyrene		50
2,4,6-Trimethylphenol		unsp	Bis(2-ethylhexyl)phthalate		50
2,4-Dichlorophenol		unsp	Butybenzyl phthalate		50
2,4-Dinitrophenol		unsp	C8-Alkylphenol		50
2,4-Dinitrotoluene		50	Carbazole		50
2,6-Dimethylnaphthalene		50	Chrysene		50

Table 3. *Organic compounds analyzed and reporting limits for fish-tissue and bed-sediment--Continued*

Compound	Fish tissue MRL	Bed sediment MRL	Compound	Fish tissue MRL	Bed sediment MRL
2,6-Dinitrotoluene		50	Di-n-butyl-phthlate		50
2-Chloronaphthalene		50	Di-n-octyl phthlate		50
2-Chlorophenol		50	Dibenz[a,h]anthracene		50
2-Ethylnaphthalene		50	Dibenzothiophene		50
2-Methylanthracene		50	Diethyl phthalate		50
2-Nitrophenol		unsp	Dimethyl phthalate		50
3,5-Dimethylphenol		50	Fluoranthene		50
4,6-Dinitro-2-methylphenol		unsp	Fluorene		50
4-Bromophenylphenylether		50	Hexachlorobenzene		50
4-Chloro-3-methylphenol		50	Hexachlorobutadiene		unsp
Isophorone		50	Hexachlorocyclopentadiene		unsp
Isoquinoline		50	Hexachloroethane		unsp
N-Nitrosodi-n-propylamine		50	Indeno[1,2,3-cd]pyrene		50
N-Nitrosodiphenylamine		50	Quinoline		50
Naphthalene		50	bis(2-Chloroethoxy)methane		50
Nitrobenzene		50	bis(2-Chloroethyl)ether		50
Pentachloroanisole		50	bis(2-Chloroisopropyl) ether		unsp
Pentachloronitrobenzene		50	p-Cresol		50
Pentachlorophenol		unsp	Inorganic carbon (grams per kg)		0.2
Phenanthrene		50	Organic carbon (grams per kg)		0.2

Although those compounds are known to be lipophilic (Hebert and Keenleyside, 1995), analysis of the YELL fish data indicated virtually no correlation between lipid content and contaminant concentration. Therefore, the fish-tissue contaminant concentrations were not adjusted for lipid content. There were too few detections in the bed-sediment data to determine if contaminant concentrations in bed sediment were correlated with the organic carbon concentration in the sediment.

Fish Tissue

Of the 12 organic compounds detected in the fish-tissue samples, the most compounds per site were detected at integrator sites (fig. 4, table 4) which reflect multiple environmental settings. Five or six compounds, including dieldrin, chlordane and metabolites, and metabolites of DDT were detected in common carp from site 10 on the Bighorn River, site 11 on Bighorn Lake, and site 14 on the Shoshone River. Four compounds were detected in the carp from site 18 on Goose Creek and in the cutthroat trout from site 1 on the Yellowstone River at the outlet of Yellowstone Lake. The Goose Creek site reflects mixed environmental settings, including forest, rangeland, agriculture, and urban development. The Yellowstone River at site 1 drains an area of primarily undeveloped land in Yellowstone National Park and surrounding wilderness areas (fig. 1). At the other integrator sites on the main stem of the Yellowstone River (sites 3, 6, 16, and 24), p,p′-DDE was the only compound detected in the fish samples. The fish sample from the agricultural indicator site on Arrow Creek (site 7) contained dieldrin and two metabolites of DDT at relatively low concentrations. No organic compounds were detected in the fish samples from rangeland indicator sites 21 and 22, from forest indicator sites 15 and 17, mineralized indicator site 9, or from reference site 12.

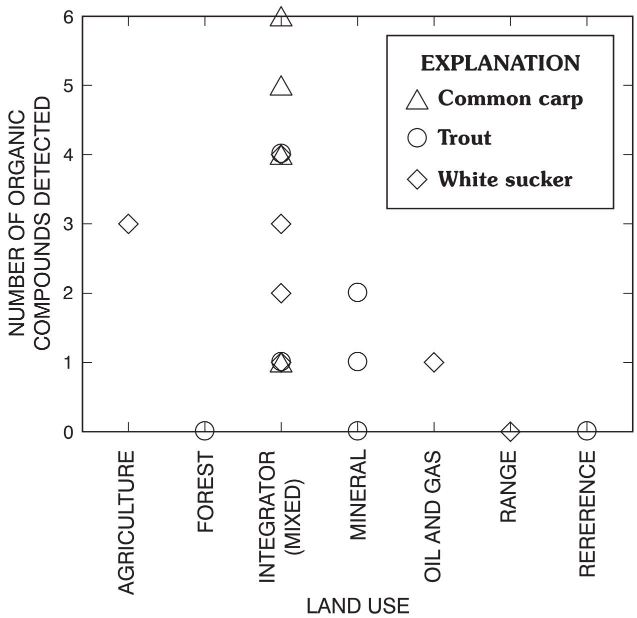


Figure 4. Relation between land use and number of organic compounds detected in fish-tissue samples from the Yellowstone River Basin, 1998.

The organic compound most frequently detected in the fish-tissue samples was p,p′-DDE, which is a metabolite of the organochlorine insecticide DDT. The compound p,p′-DDE was detected at 15 of 21, or 71 percent, of the sampling sites (fig. 5). The largest concentrations of p,p′-DDE were 58 μg/kg wet weight in common carp from Goose Creek (site 18) and 51.3 μg/kg in cutthroat trout from the Yellowstone River at the outlet of Yellowstone Lake (site 1). The parent compound, p,p′-DDT, was detected in cutthroat trout from the Yellowstone River (site 1) and West Fork Mill Creek (site 4).

The presence of DDT, DDD, and DDE in fish-tissue samples from sites in the area of Yellowstone National Park probably reflects the historical spraying of DDT to control spruce budworm. For example, DDT was sprayed on 71,678 acres in the northern part of Yellowstone National Park during 1957 (Cope, 1961). Samples collected in conjunction with the 1957 spraying indicated the presence of DDT in fish tissue from within the sprayed area, downstream of the sprayed area, and in a control sample from Pelican Creek in the Park but well outside of the sprayed area (Cope, 1961). The presence of DDT or its metabolites in fish tissue from sampling sites 1, 2, 3, and 4 and Pelican Creek, which are well outside of the documented spray area, might result from either a historically more extensive application program for DDT than that documented by Cope (1961) or from environmental transport in the more than 40 years since the documented spraying. DDT application was banned in the United States in 1972 due to its persistence in the environment, but is still used in other parts of the world.

Organic compounds including DDT are transported atmospherically on a global scale (Nowell and others, 1999, p. 199), and deposition can increase with altitude (Blais and others, 1998). Global atmospheric deposition probably is not the primary source of DDT in fish-tissue samples from sites in the area of Yellowstone National Park, however, considering the poor correlation of the fish-tissue concentrations of DDT and metabolites with either altitude or precipitation.

Comparison of data from this study to historical data indicates concentrations of DDT in fish tissue have declined with time in the study area. Both this study and Cope (1961) analyzed whole-body brown trout from the Yellowstone River at Corwin Springs (site 3). Cope reported concentrations of 1,100 μg/kg DDT and 500 μg/kg DDE in brown trout collected on August 3, 1957, and 1,200 μg/kg DDT and 900 μg/kg DDE in brown trout collected on August 11, 1957. The brown trout from the same site on August 27, 1998 contained 19 μg/kg p,p′-DDE; the DDT concentration was less than the reporting limit of 5 μg/kg. The concentrations of total DDT (sum of DDT and metabolites of DDT) in brown trout from site 3 were about two orders of magnitude less in 1998 than in 1957.

The concentration of total DDT in fish also appears to have decreased over time in the Yellowstone River near Sidney (site 24, table 4). Two samples of common carp collected there during 1984, as part of the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (NCBP) nationwide sampling, contained 40 μg/kg and 50 μg/kg total DDT, respectively (Schmitt and others, 1990). The common carp collected on July 28, 1998, from the Yellowstone River near Sidney contained 13 μg/kg total DDT, all in the form of the metabolite p,p′-DDE. The predominance of DDE and DDD relative to DDT (fig. 5) in the 1998 samples is consistent with the environmental degradation of the parent DDT to its metabolites, as described by Nowell and others (1999).

Table 4. *Organic compounds detected in fish-tissue samples, Yellowstone River Basin, 1998*

[All concentrations in micrograms per kilograms wet weight, unless expressed otherwise; mm, millimeter; g, gram; <, less than; E, estimated concentration. Concentrations of total chlordane and total DDT are calculated values, and are listed as zero, if all of the respective compounds are less than the reporting limit. Total chlordane includes cis-chlordane, trans-chlordane, trans-nonachlor, and oxychlordane. Total DDT includes o,p′-DDD, p,p′-DDD, p,p′-DDE, and p,p′-DDT.]

Site number (fig. 1)	Station name	Fish species	Number of fish in sample	Mean total length (mm)	Mean weight (g)	Percent of fish with anomalies	Lipids (percent)	Cis-chlordane	Trans-chlordane	Trans-nonachlor	Oxy-chlordane	Total chlordane
1	Yellowstone River at lake outlet	cutthroat trout	5	418	641	40	6.3	5.3	<5	<5	<5	5.3
2	Soda Butte Creek at Park boundary	cutthroat trout	7	270	244	0	6.2	<5	<5	<5	<5	0
3	Yellowstone River at Corwin Springs	brown trout	5	392	657	40	6.0	<5	<5	<5	<5	0
4	West Fork Mill Creek	cutthroat trout	7	210	134	0	6.3	<5	<5	<5	<5	0
5	Clarks Fork Yellowstone River	white sucker	8	279	266	50	8.5	<5	<5	<7.7	<5	0
6	Yellowstone River at Billings	white sucker	6	309	331	67	4.9	<5	<5	<5	<5	0
7	Arrow Creek near Worden	white sucker	7	284	284	0	5.5	<5	<5	<5	<5	0
9	Wood River above Middle Fork Wood River	brook trout	8	189	85	38	7.2	<5	<5	<5	<5	0
10	Bighorn River at Kane	carp	5	484	1680	20	4.05	<5	5.1	<5	<5	5.1
11	Bighorn Lake at Highway 14A	carp	5	449	1134	0	5.9	<5	<5	6.4	5.3	11.7
12	Crow Creek near Pahaska	brook trout	7	191	71	0	4.2	<5	<5	<5	<5	0
13	Sage Creek near Lovell	white sucker	6	261	186	0	1.3	<5	<5	<5	<5	0
14	Shoshone River at mouth	carp	5	494	1498	20	4.95	5.2	<5	6.7	<47	11.9
15	Little Bighorn River at State line	brown trout	8	284	243	0	4.6	<5	<5	<5	<5	0
16	Yellowstone River at Forsyth	carp	8	509	1919	0	7.5	<5	<5	<5	<5	0
17	Tongue River near Dayton	brown trout	8	279	228	0	4.2	<5	<5	<5	<5	0
18	Goose Creek near Acme	carp	5	600	3180	80	4.8	<5	<5	5.9	<5	5.9
18	Goose Creek near Acme	white sucker	8	327	395	38	6.1	<5	<5	5.4	<5	5.4
19	Tongue River at State line	white sucker	5	379	630	20	7.9	<5	<5	<5	<5	0
21	Crazy Woman Creek	white sucker	9	230	126	0	1.9	<5	<5	<5	<5	0
22	Little Powder River	white sucker	5	288	253	20	2.4	<5	<5	<5	<5	0
24	Yellowstone River near Sidney	carp	6	478	1542	0	8.5	<5	<5	<5	<5	0

Table 4. *Organic compounds detected in fish-tissue samples, Yellowstone River Basin, 1998--Continued*

Site number (fig. 1)	Station name	Fish species	o,p′-DDD	p,p′-DDD	p,p′-DDE	p,p′-DDT	Total DDT	Dieldrin	p,p′-Meth-oxychlor	Pentchlor-anisol	Total PCB	Number of compounds detected
1	Yellowstone River at lake outlet	cutthroat trout	<12	6.9	51.3	6.3	64.5	<5	<5	<5	<50	4
2	Soda Butte Creek at park boundary	cutthroat trout	<5	<5	7.4	<5	7.4	<5	<5	<5	<50	1
3	Yellowstone River at Corwin Springs	brown trout	<5	<5	19	<5	19	<5	<5	<5	<50	1
4	West Fork Mill Creek	cutthroat trout	<5	<5	35	5.7	40.7	<5	<5	<5	<50	2
5	Clarks Fork Yellowstone River	white sucker	<5	5.4	24	<5	29.4	10	<5	5 E	<50	4
6	Yellowstone River at Billings	white sucker	<5	<5	6.7	<5	6.7	<5	<5	<5	<50	1
7	Arrow Creek near Worden	white sucker	<5	5.7	7.8	<5	13.5	11	<5	<5	<50	3
9	Wood River above Middle Fork Wood River	brook trout	<5	<5	<5	<5	0	<5	<5	<5	<50	0
10	Bighorn River at Kane	carp	6.6	<5	38.8	<5	45.4	8.8	8.4	<5	<50	5
11	Bighorn Lake at Highway 14A	carp	<5	7.2	43	<5	50.2	7.6	<5	<5	<50	5
12	Crow Creek near Pahaska	brook trout	<5	<5	<5	<5	0	<5	<5	<5	<50	0
13	Sage Creek near Lovell	white sucker	<5	<5	10	<5	10	<5	<5	<5	<50	1
14	Shoshone River at mouth	carp	<5	5.8	50.7	<5	56.5	16.7	6.2	<5	<50	6
15	Little Bighorn River at State line	brown trout	<5	<5	<5	<5	0	<5	<5	<5	<50	0
16	Yellowstone River at Forsyth	carp	<5	<5	17	<5	17	<5	<5	<5	<50	1
17	Tongue River near Dayton	brown trout	<5	<5	<5	<5	0	<5	<5	<5	<50	0
18	Goose Creek near Acme	carp	<5	8.6	58	<5	66.6	<5	<5	<5	190	4
18	Goose Creek near Acme	white sucker	<5	<5	13	<5	13	<5	<5	<5	50	3
19	Tongue River at State line	white sucker	<5	<5	11	<5	11	<5	<5	<5	56	2
21	Crazy Woman Creek	white sucker	<5	<5	<5	<5	0	<5	<5	<5	<50	0
22	Little Powder River	white sucker	<5	<5	<5	<5	0	<5	<5	<5	<50	0
24	Yellowstone River near Sidney	carp	<5	<5	13 E	<5	13 E	<5	<5	<5	<50	1

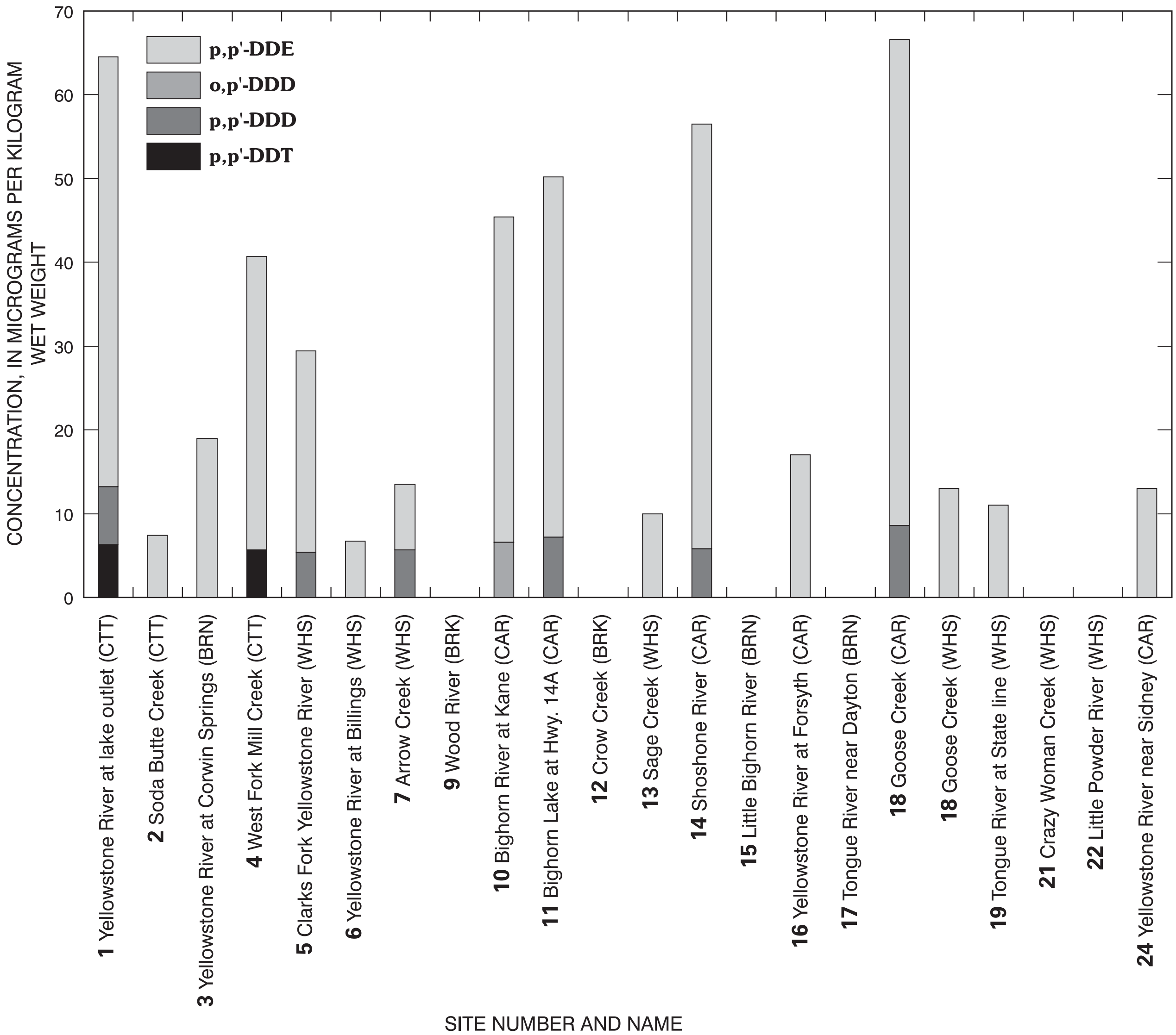


Figure 5. Concentrations of DDT and metabolites of DDT in fish-tissue samples, Yellowstone River Basin, 1998 (fish species abbreviations: CTT, cutthroat trout; BRN, brown trout; WHS, white sucker; BRK, brook trout; CAR, carp).

Concentrations of total DDT in fish from the YELL also were low compared to the geometric mean concentration of 260 µg/kg total DDT in NCBP samples from across the United States in 1984 (Schmitt and others, 1990). The median concentration of total DDT in the YELL samples was 13 µg/kg; the maximum was 66.6 µg/kg. Median concentrations of total DDT in fish-tissue samples from other NAWQA studies in the Rocky Mountain region were 92 µg/kg in the South Platte River Basin (Tate and Heiny, 1996), 69 µg/kg in the Upper Snake River Basin (Maret and Ott, 1997), and 9.6 µg/kg in the upper Colorado River Basin (Stephens and Deacon, 1998). In an investigation of an irrigation drainage project near Riverton, Wyoming (fig. 1), Peterson and others (1991) reported concentrations of 10 to 20 µg/kg total DDT in rainbow trout and 100 to 200 µg/kg total DDT in common carp.

Fish samples from Goose Creek (site 18) and the Tongue River at State line (site 19) contained PCBs. The concentrations of total PCBs were 190 µg/kg in carp from Goose Creek, 50 µg/kg in white sucker from Goose Creek, and 56 µg/kg in white sucker from the Tongue River at site 19. The source of the PCBs in the Tongue River might be the tributary inflow from Goose Creek. PCBs are synthetic compounds that have been banned in the United States since 1979 because of high bioconcentration factors, but they were widely used as plasticizers, lubricants, and in heat-transfer systems such as capacitors (Smith and others, 1988, p. 26-35). As noted earlier, Goose Creek receives drainage from multiple land uses, including urban development.

Data from other NAWQA study units in the northern and middle Rocky Mountain region indicate the occurrence and distribution of PCBs is related to land use. In the upper Snake River basin, PCBs were detected in 39 percent of the fish-tissue samples, but at only mixed and agricultural land use sites, at concentrations ranging from 50 to 1,900 µg/kg (Maret and Ott, 1997, p. 9, 15). In the South Platte River basin, PCBs were detected in 67 percent of the fish-tissue samples at concentrations ranging from 56 to 1,000 µg/kg and were largest in urban and mixed land-use settings (Tate and Heiny, 1996). In contrast, PCBs were detected at only one site in the upper Colorado River Basin (Stephens and Deacon, 1998). The nationwide average concentration of PCBs in fish tissue from the NCBP was 390 µg/kg in 1984 (Schmitt and others, 1990). The PCB concentrations from an irrigation drainage investigation near Riverton, Wyoming were less than the reporting limit for rainbow trout samples and ranged from 100 to 150 µg/kg wet weight in common carp samples (Peterson and others, 1991). Concentrations of total PCBs, total DDT, and other organochlorine insecticides in fish tissue from the YELL were low compared to concentrations from 20 NAWQA study units across the United States as reported in Wong and others (2000).

Concentrations of organochlorine compounds in fish samples from the YELL were less than the concentrations recommended for the protection of wildlife that eat fish: total chlordane and dieldrin, 100 µg/kg; total DDT, 1,000 µg/kg; and PCBs, 500 µg/kg (National Academy of Sciences and National Academy of Engineering, 1973). Samples of fish fillets from Bighorn Lake, Cooney Reservoir, and Tongue River Reservoir in the Montana portion of the YELL were analyzed for PCBs and no fish consumption advisories were issued (Montana Department of Public Health and Human Services, 1995).

A species comparison conducted at one site indicated higher concentrations of some organic compounds in common carp than in white sucker. Concentrations of total PCBs and p,p′-DDE were about 4 times as large in common carp as in white sucker collected from Goose Creek (table 4). Tate and Heiny (1996, p. 70) also found that PCB concentrations were higher in common carp than white sucker among fish collected at the same sites in the South Platte River basin.

Bed Sediment

Two of the 27 organochlorine insecticides and metabolites and total PCBs that were analyzed in bed-sediment samples were detected. Comparison of organic compounds analyzed in both fish-tissue and bed-sediment samples indicates that of the 12 pesticides detected in fish tissue, only trans-chlordane and p,p′-DDT were detected in bed-sediment samples. The only sample that had detectable concentrations was from Goose Creek (site 18), which had 1.6 µg/kg trans-chlordane and 2.2 µg/kg p,p′-DDT (table 5). The more extensive occurrence of organochlorine insecticides and PCBs in the fish samples probably results from the lipophilic nature of the compounds, chemical partitioning, and bioaccumulation. The data suggest that fish are more sensitive indicators of insecticide and PCB contamination than bed sediment, when the method reporting limits are similar to each other (table 3).

Table 5. *Organic compounds detected in bed-sediment samples, Yellowstone River Basin, 1998*

[All concentrations in micrograms per kilogram dry weight, unless expressed otherwise; g/kg, grams per kilogram; <, less than; E, estimated concentration; NA, not analyzed; *, less than concentration in blank samples (Gilliom and others, 1998)]

Site number	trans-Chlordane	p,p′-DDT	Acenaphthene	Anthracene	Benz [a] anthracene	Dibenz [a,h] anthracene	2-Methyl-anthracene	Chrysene	Dibenzo-thiophene	Fluoranthene
1	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
2	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
3	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
4	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
5	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
6	<1.0	<2.0	<50	E12	E22	<50	<50	E17	<50	E31
7	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	E.6
9	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
10	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
11	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
12	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
13	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
14	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
15	<3	<6	<100	<100	<100	<100	<100	<100	<100	<100
16	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
17	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
18	1.6	2.2	E5	E43	75	E19	E2	110	<50	210
19	<1.0	<2.0	<50	<50	<50	<50	<50	E.3	55	E.007
20	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
21	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
22	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
23	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50
24	<1.0	<2.0	<50	<50	<50	<50	<50	<50	<50	<50

Table 5. *Organic compounds detected in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

Site number	Benzo [b] fluoranthene	Benzo [k] fluoranthene	1-Methyl-9H-fluorene	Naphthalene	1,6-Dimethyl-naphthalene	2,6-Dimethyl-naphthalene	2-Ethyl-naphthalene	Benzo [ghi] perylene	Phenan-threne	1-Methyl-phenan-threne
1	<50	<50	<50	<50	<50	E18	<50	<50	<50	<50
2	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
3	<50	<50	<50	<50	E2	E15	<50	<50	<50	<50
4	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
5	<50	<50	<50	<50	<50	E46	<50	<50	<50	<50
6	E26	E24	<50	<50	E8	E24	E10	E24	E7	<50
7	E5	<50	<50	E4	E7	52	<50	E7	E6	<50
9	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
10	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
11	<50	<50	<50	<50	<50	E13	<50	<50	<50	<50
12	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
13	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
14	<50	<50	<50	<50	<50	E12	<50	<50	<50	<50
15	<100	<100	<100	<100	E13	190	<100	<100	<100	<100
16	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
17	<50	<50	<50	<50	<50	E50	<50	<50	<50	<50
18	120	E41	E10	E20	<50	110	<50	52	120	E10
19	E8	<50	<50	<50	E5	78	<50	E10	E.6	<50
20	E9	E11	<50	<50	<50	<50	<50	<50	<50	<50
21	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
22	<50	<50	<50	<50	<50	E27	<50	<50	<50	<50
23	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
24	<50	<50	<50	<50	<50	<50	E1	<50	<50	<50

Table 5. *Organic compounds detected in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

Site number	4H-cyclopenta [def]phenan-threne	Pyrene	Benzo [a] pyrene	Indeno [1,2,3-cd] pyrene	Sum of PAHs (ug/kg sediment)	Sum of PAHs (μg/g organic carbon)	Acridine	9,10-Anthra-quinone	Carbazole	p-Cresol	Pentachloro-phenol
1	<50	<50	<50	<50	18	2.6	<50	<50	<50	150	E150
2	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
3	<50	<50	<50	<50	17	4.4	<50	<50	<50	120	NA
4	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
5	<50	<50	<50	<50	46	4.6	<50	<50	<50	E39	NA
6	<50	E31	E27	E27	290	56.9	<50	<50	<50	390	NA
7	<50	E4	E2	<50	88	4.4	<50	<50	<50	140	NA
9	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
10	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
11	<50	<50	<50	<50	13	2.9	<50	<50	<50	<50	NA
12	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
13	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
14	<50	<50	<50	<50	12	3.2	<50	<50	<50	<50	NA
15	<100	<100	<100	<100	203	6.8	<100	<100	<100	7400	NA
16	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
17	<50	<50	E1	<50	51	2.7	<50	<50	<50	1,200	NA
18	E8	170	79	E47	1251	62.6	E2	E42	E10	2,600	NA
19	<50	E4	E5	E12	178	8.5	<50	<50	<50	2,600	NA
20	<50	<50	<50	<50	20	2.9	<50	<50	<50	<50	NA
21	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
22	<50	<50	<50	<50	27	2.8	<50	<50	<50	<50	NA
23	<50	<50	<50	<50	0	0.0	<50	<50	<50	<50	NA
24	<50	<50	<50	<50	1	0.2	<50	<50	<50	<50	NA

Table 5. *Organic compounds detected in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

Site number	Phenol	4,6-Dinitro-2-methyl-phenol	Bis (2-ethylhexyl) phthalate	Butylbenzyl phthalate	Diethyl phthalate	Di-n-butyl phthalate	Di-n-octyl phthalate	3,5-Xylenol	Carbon, organic (g/kg)	Percent finer than 0.062 mm	Percent 0.062 to 2 mm
1	E15*	NA	E31*	<50	<50	E36*	<50	<50	6.9	22	78
2	E23*	NA	E25*	<50	<50	E30*	<50	<50	5.2	44	56
3	E4*	NA	E21*	E14*	E29	E35*	<50	<50	3.9	20	80
4	<50	NA	<50	<50	E31	<50	<50	<50	8.5	23	77
5	E15*	NA	<50	<50	E14*	<50	<50	<50	10	63	37
6	E9*	NA	E28*	E17*	E39	E37*	<50	<50	5.1	26	74
7	E22*	NA	E27*	E13*	<50	E28*	E20	<50	20	36	64
9	<50	NA	E20*	E16*	<50	E20*	<50	<50	1.2	17	83
10	<50	NA	E21*	<50	<50	E29*	<50	<50	4.7	57	43
11	<50	NA	E29*	E18*	<50	E39*	<50	<50	4.5	100	0
12	E4*	NA	E17*	E19*	<50	E44*	<50	<50	2.9	12	88
13	<50	NA	E18*	<50	<50	E24*	<50	<50	1.5	46	54
14	<50	E150	E25*	<50	<50	E29*	<50	<50	3.8	42	58
15	140	NA	E60*	E37*	<100	110	<100	<100	30	65	35
16	<50	NA	E29*	E26*	<50	E43*	<50	<50	4.4	36	64
17	E39	NA	E29*	E19*	E2*	E36*	<50	E29	19	22	78
18	92	NA	95*	E23*	E.6*	E35*	E28	E13	20	36	64
19	86	NA	E39*	E18*	E.6*	E33*	<50	<50	21	69	31
20	<50	NA	E38*	E18*	<50	E38*	<50	<50	6.8	69	31
21	E8*	NA	67*	E27*	<50	E37*	<50	<50	14	54	46
22	<50	NA	E42*	E36*	<50	66	<50	<50	9.6	69	31
23	<50	NA	E35*	E15*	<50	E18*	<50	<50	3.1	8	92
24	<50	NA	E30*	E24*	<50	E37*	<50	<50	6.2	46	54

The other organic compounds detected in bed sediment are semivolatile organic compounds (SVOCs) that can be loosely grouped into two categories based on occurrence and distribution. The first category contains a broad array of SVOCs detected primarily in two specific areas of the study unit. The second category contains a few SVOCs, such as p-cresol, detected in many areas.

About 20 polynuclear aromatic hydrocarbon (PAH) compounds occurred in bed-sediment samples from the Yellowstone River at Billings (site 6, table 5) and Goose Creek (site 18). The maximum concentrations of PAHs also occurred at these two sites, which are integrator sites (fig. 6) located near urban areas. Major sources of PAHs to aquatic systems nationwide include atmospheric deposition, urban sources, industrial discharges, and municipal discharges (U.S. Environmental Protection Agency, 1997). Any or all of the major sources identified by the EPA could be contributing PAHs to the bed sediment at sites 6 and 18. Some of the same PAHs detected at sites 6 and 18 also were detected, generally at lower concentrations, in the samples from site 7 on Arrow Creek and site 19 on the Tongue River. The occurrence of PAHs at Arrow Creek could reflect either an atmospheric source common to both sites 6 and 7, or contamination of water and sediment diverted from the Yellowstone River and used to irrigate lands in the Arrow Creek area. The occurrence of PAHs at the Tongue River site might be a reflection of inflow from Goose Creek.

Concentrations of PAHs in the YELL bed-sediment samples were less than the criteria for protection of aquatic life. After adjusting for organic carbon content of the sediment, the concentrations of individual PAHs in the YELL samples, such as benzo (a) pyrene, benz (a) anthracene, chrysene, fluoranthene, and phenanthrene, were less than the criteria summarized by Gilliom and others (1998, p. 25). The sum of the PAHs in each of the YELL samples also was less than the threshold effect concentration of 290 µg PAH/g organic carbon calculated by Swartz (1999, p. 783) (fig. 6).

P-cresol, phthalates, and phenol were detected in many of the samples, often at estimated concentrations below the normal method reporting limit (table 5). One or more PAHs were detected in bed-sediment samples from 14 of 23 sites. Sources of cresols include auto and diesel exhaust, petroleum refining, and other manufacturing; small quantities originate from natural sources (Howard,1989, p. 189-216). P-cresol was

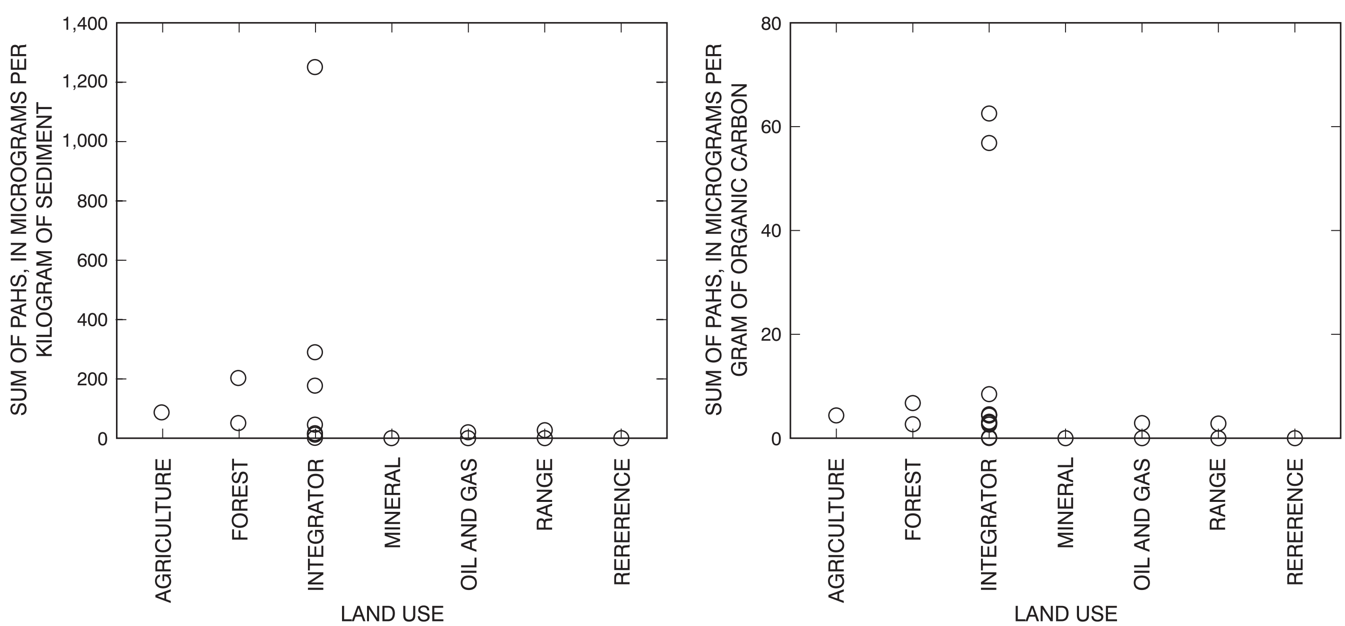


Figure 6. Relation between land use and concentrations of polynuclear aromatic hydrocarbons (PAHs) in bed-sediment samples from the Yellowstone River Basin, 1998.

detected at nine sites, reaching a maximum concentration of 7,400 µg/kg, which occurred in the bed-sediment sample from the Little Bighorn River (site 15). The maximum concentration of phenol, 140 µg/kg, also was from the Little Bighorn River. Many of the phenol concentrations and nearly all of the phthalate concentrations reported from the YELL bed-sediment samples were less than the 95th percentile concentration in laboratory blanks (Gilliom and others, 1998). For comparing SVOC concentrations in bed sediment from NAWQA study units across the United States, Gilliom and others (1998, p. 13) corrected for laboratory contamination by subtracting the following concentrations from the measured concentration in each environmental sample:

Bis(2-Ethylhexyl) phthalate	100 µg/kg
Di-n-butyl phthalate	54 µg/kg
Butylbenzyl phthalate	64 µg/kg
Phenol	27 µg/kg
Diethyl phthalate	25 µg/kg

Correction factors are not available specifically for the YELL data, but the reader should be aware that the data for phthalates and phenol likely are influenced by laboratory contamination.

TRACE ELEMENTS

The discussion of trace elements is focused on selected elements, as determined from comparison with historical concentrations and criteria, and potential adverse effects to either aquatic life or human health.

Fish Tissue

Trace elements are normally present in fish tissue, and many are required micronutrients such as copper and selenium (Sorenson, 1991). In excessive concentrations, however, trace elements can negatively affect growth, reproduction, and other biological functions. Concentrations of trace elements in fish tissue vary between fish species because of physiological, environmental, and other factors (Sorenson, 1991). All of the trace element concentrations discussed below are expressed in µg/g dry weight in liver-tissue samples unless noted otherwise.

The highest concentrations of copper and selenium were in trout samples from forested and mineralized indicator sites (fig. 7), and integrator sites located in forested areas. The maximum concentrations of copper, selenium, and arsenic occurred in the brown-trout sample from a forested indicator site on the Little Bighorn River (site 15, table 6).

Concentrations of cadmium, chromium, manganese, molybdenum, selenium, and vanadium were higher in the sample from the mineralized area indicator site on Soda Butte Creek (site 2) than concentrations from the other two sites where cutthroat trout were sampled, including the mineralized area indicator site on West Fork Mill Creek (site 4, table 6). Mining in the Soda Butte Creek drainage has caused elevated concentrations of copper in cutthroat trout collected upstream of site 2 (Nimmo and others, 1998). The concentration of copper in the sample of cutthroat trout from site 2 on Soda Butte Creek, 207 µg/g, was below the range of copper concentrations of 265-605 µg/g dry weight in cutthroat trout livers reported by Nimmo and others (1998).

Volcanic and geothermal areas are generally known as sources of mercury (Eisler, 1987, p. 4-6), which might be responsible for the relatively high mercury concentration in the cutthroat-trout sample from the Yellowstone River at the outlet of Yellowstone Lake (site 1). The mercury concentration was 0.54 µg/g and notably higher than in any other trout samples. Yellowstone Lake lies within an ancient caldera with numerous geothermal features, and the drainage upstream of and surrounding the lake is underlain by volcanic rocks of Quaternary, Tertiary, and Cretaceous age.

The selenium concentration in many of the fish samples was higher than the background range of 2 to 8 µg/g in liver cited by the U.S. Department of the Interior (1998) (fig. 7). None of the white sucker or carp samples from the YELL exceeded the 25-30 µg/g threshold selenium concentration associated with sublethal effects in field studies of warm-water fish (U.S. Department of the Interior, 1998). None of the YELL trout samples exceeded the 51 µg/g selenium concentration in rainbow trout liver associated with substantial changes in blood chemistry (Lemly, 1996). Potentially seleniferous areas are widespread in Wyoming (Case and Cannia, 1988), and elevated concentrations of selenium in water, the aquatic food chain, and other media also have been described (See and others, 1992; Peterson and others, 1991).

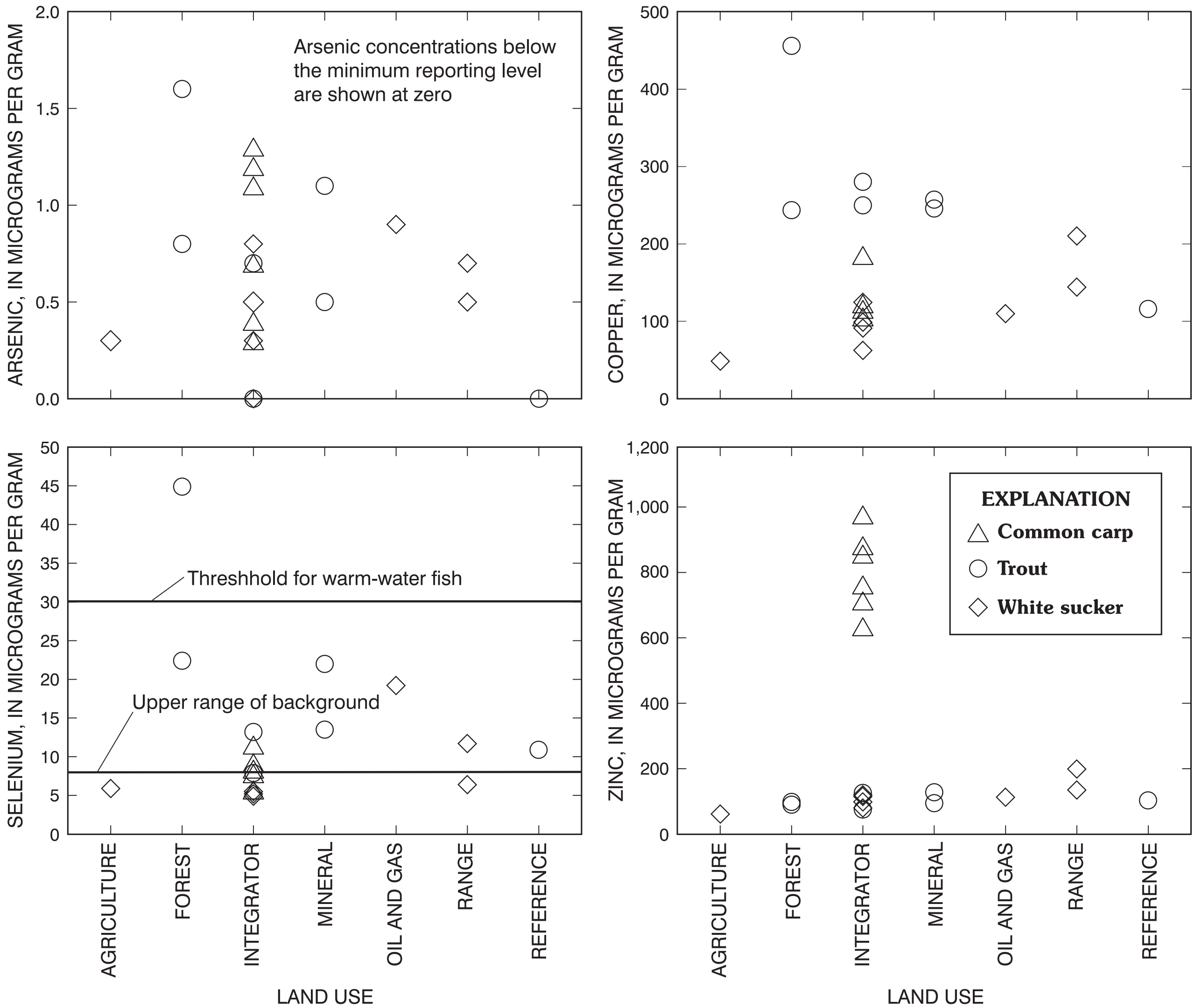


Figure 7. Relation between land use and concentrations of selected trace elements in fish-tissue samples from the Yellowstone River Basin, 1998. Upper range of background selenium concentration, 8 micrograms per gram, and upper range of threshhold concentration, 30 micrograms per gram, associated with sublethal effects in field studies of warm-water fish are from U.S. Department of the Interior (1998).

Table 6. *Trace-element concentrations in fish-liver samples, Yellowstone River Basin, 1998*

[mm, millimeter; g, gram; element concentrations are in micrograms per gram dry weight; <, less than]

Site number	Fish species	Number of fish in sample	Mean total length (mm)	Mean weight (g)	Percent of fish with anomalies	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt
1	cutthroat trout	8	416	655	38	6.6	<.2	0.7	3.4	<.2	0.3	0.5	0.7	<.2
2	cutthroat trout	7	286	290	0	4.6	<.3	1.1	3.4	<.3	0.7	1.2	1.1	0.6
3	brown trout	5	224	134	0	3.3	<.4	<.4	<.1	<.4	0.6	<.4	<.5	<.4
4	cutthroat trout	7	215	131	0	1.2	<.4	0.5	<.1	<.4	0.6	0.6	0.7	<.4
5	white sucker	8	279	266	50	14.1	<.3	<.3	0.3	<.3	0.5	<.3	<.5	0.3
6	white sucker	7	286	270	86	7.9	<.3	0.8	0.3	<.3	0.9	<.3	0.6	<.3
7	white sucker	8	292	295	25	18.3	<.3	0.3	0.2	<.3	0.9	<.3	0.6	<.3
10	common carp	8	503	1744	12	11.7	<.2	1.1	0.3	<.2	<.2	41.2	<.5	0.3
11	common carp	5	449	1134	0	8.9	<.1	1.3	0.2	<.1	0.3	6.3	<.5	0.3
12	brook trout	7	190	73	0	7.4	<.6	<.6	<.1	<.6	2.3	<.6	0.9	0.8
13	white sucker	6	261	186	0	40.3	<.2	0.9	0.8	<.2	0.9	<.2	0.6	0.3
14	common carp	5	494	1498	20	14.8	<.2	0.7	0.2	<.2	0.5	12.0	<.5	0.3
15	brown trout	8	311	332	25	1.4	<.2	1.6	<.1	<.2	0.6	0.3	0.6	0.4
16	common carp	8	493	1794	25	15.8	<.2	1.2	0.3	<.2	0.4	7.6	<.5	0.3
17	brown trout	8	276	237	0	3.3	<.2	0.8	<.1	<.2	0.9	<.2	0.6	0.3
18	white sucker	8	347	482	75	23.4	<.2	0.3	0.3	<.2	0.6	<.2	<.5	<.2
18	common carp	5	600	3180	80	15.0	<.2	0.5	0.1	<.2	0.5	2.2	<.5	0.4
19	white sucker	6	335	446	0	1.5	<.1	0.5	0.1	<.1	0.6	0.2	0.7	0.3
21	white sucker	9	230	126	0	35.1	<.4	0.7	1.0	<.4	1.2	1.0	0.6	<.4
22	white sucker	5	288	253	20	60.3	<.1	0.5	0.4	<.1	0.5	0.2	0.8	0.3
24	common carp	7	477	1614	0	43.1	<.1	0.4	1.4	<.1	0.3	4.6	<.5	0.2

Table 6. *Trace-element concentrations in fish-liver samples, Yellowstone River Basin, 1998--Continued*

Site number	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Uranium	Vanadium	Zinc	Water (percent)
1	229	889	<.2	5.7	0.54	0.9	<.2	7.9	0.6	0.5	<.2	1.1	126	79.1
2	207	757	<.3	9.5	0.09	1.3	<.3	22.0	0.3	0.3	<.3	1.6	128	79.8
3	200	295	<.4	2.3	0.1	0.7	<.4	13.2	<.4	0.4	<.4	<.4	75.5	70.6
4	196	537	<.4	4.8	<.080	0.8	<.4	13.5	<.4	0.4	<.4	<.4	94.6	77.0
5	20.6	677	<.3	7.2	0.3	0.7	<.3	5.2	0.3	1.0	<.3	0.5	80.0	76.9
6	80.1	782	<.3	9.2	<.4	0.9	<.3	5.5	0.5	1.2	<.3	0.4	120	80.5
7	7.4	1000	<.3	4.4	<.3	0.3	<.3	5.9	<.3	0.8	<.3	0.5	61.2	80.1
10	138	1300	0.2	4.6	0.77	1.7	<.2	11.5	0.3	2.1	<.2	2.9	882	74.2
11	62.2	457	<.1	4.7	0.47	1.5	<.1	7.8	0.2	0.7	<.1	2.2	856	69.9
12	71.9	878	<.6	3.9	<.6	0.9	<.6	10.9	<.6	0.5	<.6	0.7	103	76.7
13	66.1	638	<.2	16.0	<.2	0.7	0.2	19.2	0.7	3.2	<.2	0.6	113	79.3
14	71.3	892	<.2	4.7	0.71	1.8	<.2	9.2	0.3	0.8	<.2	3.4	762	72.5
15	397	489	<.2	3.7	0.13	0.9	<.2	44.9	1.6	<.1	<.2	0.4	90.2	76.4
16	78.2	677	<.2	6.6	0.29	1.4	0.2	7.8	0.6	1.4	<.2	1.2	976	67.2
17	194	450	<.2	6.5	0.14	0.8	<.2	22.4	2.3	<.1	<.2	0.3	98.5	77.1
18	48.2	344	<.2	10.8	0.08	0.9	<.2	4.9	0.7	0.5	<.2	0.5	98.7	76.2
18	62.5	369	<.2	5.7	0.33	1.6	<.2	8.4	0.5	0.5	<.2	1.8	634	75.8
19	55.5	212	<.1	9.1	<.1	0.9	<.1	6.7	0.3	0.8	<.1	0.3	115	76.5
21	162	1080	<.4	12.4	<.4	1.3	<.4	11.7	1.0	2.1	<.4	0.7	199	82.2
22	98.8	358	<.1	7.4	0.2	0.7	<.1	6.4	0.6	1.6	<.1	0.4	135	79.6
24	62.0	660	0.2	4.7	0.14	0.7	0.3	5.7	0.3	1.0	<.1	0.8	713	65.6

Comparison of white sucker to common carp sampled on the same date from Goose Creek indicated concentrations of arsenic, cadmium, cobalt, mercury, molybdenum, selenium, vanadium, and zinc were higher in the common carp than in the white sucker (table 6). Elevated concentrations of cadmium and zinc in common carp relative to other fish species have been noted by Schmitt and Brumbaugh (1990) and Heiny and Tate (1997).

Whole-body composite samples of brook trout were collected from the Wood River (site 9) and Crow Creek (site 12) (table 7). Concentrations of arsenic, copper, mercury and zinc in samples from the two sites are less than no-effect levels or within the range of background concentrations for whole-body fish, but selenium concentrations are within the level of concern of 2 to 4 µg/g described by the U.S. Department of the Interior (1998). The concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in the whole-body trout from sites 9 and 12 were near or less than the NCBP 85th percentile concentrations for the United States (Schmitt and Brumbaugh, 1990) and also were within the range of concentrations in whole-body fish from the Bighorn River and Wind River (Ramirez and Armstrong, 1992).

Bed Sediment

The concentrations of trace elements in natural waters are often much lower than would be expected on the basis of either equilibrium solubility calculations or of supply to the water from various sources. The most common reason for the low concentrations is adsorption of the element onto a solid phase (Drever, 1997) because bed sediment can serve as a sink for trace elements. Organic matter generally interacts strongly with trace metals; however, statistical analysis of selected trace elements indicated the concentrations were not correlated with the organic carbon concentration in the YELL samples.

Table 7. *Trace-element concentrations in whole-body brook trout samples, Yellowstone River Basin, 1998*

[mm, millimeter; g, gram. Element concentrations in micrograms per gram dry weight]

Site number	Number of fish in sample	Mean total length (mm)	Mean weight (g)	Percent of fish with anomalies	Aluminum	Antimony	Arsenic	Barium	Beryllium
9	8	180	67	0	57.0	<.2	<.2	3.6	<.2
12	6	177	77	0	147	<.2	0.3	3.7	<.2

Site number	Boron	Cadium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury
9	0.3	<.2	1.6	0.5	5.3	138	<.2	5.8	0.01
12	0.6	<.2	2.3	0.4	4.0	437	<.2	12.5	0.04

Site number	Molybdenum	Nickel	Selenium	Silver	Strontium	Uranium	Vanadium	Zinc	Water (percent)
9	<.2	0.4	2.8	<.2	52.0	<.2	0.3	66.2	74.1
12	<.2	0.5	2.9	<.2	39.1	<.2	1.5	60.7	73.2

Forty-four trace elements were analyzed in streambed sediment (table 8) at sites in the Yellowstone River Basin. Concentrations of four of these elements potentially exceeded criteria for the protection of aquatic biota. Because of their elevated concentrations and their toxicity in the aquatic ecosystem, arsenic, chromium, copper, and lead were selected for detailed presentation in this section.

The concentrations of the four selected trace elements at sites representing the different land-use categories in the YELL study unit are shown in figure 8. Median copper and lead concentrations were highest at mineralized sites. Median arsenic concentration was highest at the single agriculture site. Median chromium concentration was highest at the single reference site.

The concentrations of the four selected trace elements in relation to the different geologic units on which sites are located in the YELL study unit are shown in figure 9. Median concentrations of chromium, copper, and lead were highest at the sites located in Tertiary and Cretaceous volcanic rocks. Median arsenic concentration was highest at the sites located in the Cretaceous sedimentary rocks.

For comparative purposes, sediment criteria for protection of aquatic life are shown in figure 8 and historical concentrations for the YELL are shown in figure 9. There are no State guidelines for evaluating trace elements in sediment in Wyoming or Montana. The sediment quality guidelines for trace elements considered most toxic to aquatic life from the Canadian Council of Ministers of the Environment (2000) are used for reference with the YELL data. The Canadian guidelines have two levels: a lower value, referred to as an interim sediment quality guideline (ISQG), and an upper value, referred to as the probable effect level (PEL). Concentrations below the ISQGs are not expected to be associated with any adverse biological effects, whereas concentrations above the PELs are expected to be frequently associated with adverse biological effects. Concentrations between ISQGs and PELs represent the range in which effects are occasionally observed. Historical concentrations for trace elements in sediment for the YELL were calculated by Peterson and Zelt (1999), from data collected for the National Uranium Resource Evaluation (NURE) program. The NURE data consisted of about 13,000 samples collected in the YELL study unit area during 1974-79 as part of a nationwide, systematic study of uranium resources. Summary statistics for NURE trace element data from eight geologic units were compiled by Peterson and Zelt (1999); the 50th and 95th percentile data are used as historical data for this report. The NURE samples were sieved through 150 µm mesh, whereas the Canadian guidelines are based on the concentrations of elements in bulk sediment, and the YELL samples were sieved through 62 µm mesh. The differences in size fraction might cause the YELL samples to be biased high relative to the NURE data and the bulk sediment guidelines, because trace metal concentrations commonly are inversely related to sediment grain size (Horowitz, 1991, p. 16-22).

Arsenic exceeded the ISQG of 5.9 µg/g at 17 sites. The highest concentration (41 µg/g) occurred at Yellowstone River at Corwin Springs (site 3), which was the only site that exceeded the PEL of 17 µg/g. Historical arsenic concentrations for the YELL were not available from the NURE data.

Chromium exceeded the ISQG of 37.3 µg/g at all 24 sites. The PEL of 90 µg/g was exceeded at nine sites with a maximum concentration of 180 µg/g at Yellowstone River at Corwin Springs (site 3). None of the chromium concentrations exceeded the 95th percentile historical concentration (fig. 9).

Copper exceeded the ISQG of 35.7 µg/g at eight sites, with a maximum concentration of 67 µg/g at Arrow Creek near Worden (site 7). None of the samples approached the PEL of 197 µg/g (fig. 8). The copper concentration in two samples exceeded the 95th percentile YELL historical concentration for Tertiary and Cretaceous volcanic rocks; and one copper concentration exceeded the 95th percentile historical concentration for Tertiary sedimentary rocks (fig. 9).

Lead exceeded the ISQG of 35 µg/g at two sites: West Fork Mill Creek, site 4 (37 µg/g) and Wood River, site 8 (36 µg/g). The PEL of lead is 91.3 µg/g (fig. 8). Several of the lead concentrations also exceeded the 95th percentile NURE historical concentration (fig. 9).

Selected trace-element concentrations in bed sediment from the YELL were compared to those from the South Platte (SPLT) and Upper Colorado (UCOL) NAWQA study units (fig. 10). These three study units are all located in the Rocky Mountains with similar land uses and geology. The Kruskall-Wallis rank sum statistical test (Helsel and Hirsch, 1992) was performed on the streambed sediment data to determine if the differences in the trace element concentrations among the three study units were significant. Significant differ-

Table 8. *Trace-element concentrations in bed-sediment samples, Yellowstone River Basin, 1998*

[Values in micrograms per gram dry weight unless expressed as percentage (%); --, no data]

Site number	Aluminum (%)	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Calcium (%)	Cerium	Chromium	Cobalt	Copper
1	6.5	0.9	15	1100	2	<1	0.1	2.2	78	130	11	17
2	9.2	.2	2.3	1400	1	<1	.2	4.7	61	170	28	43
3	6.8	1.0	41	1000	2	<1	.3	3.0	88	180	24	39
4	7.1	.5	7.0	1200	2	<1	.4	2.0	79	100	18	39
5	6.9	.5	6.0	640	2	<1	.3	3.3	68	78	17	42
6	6.6	.7	15	800	2	<1	.3	2.7	67	100	14	36
7	7.1	.5	12	730	1	<1	.3	2.1	58	83	11	23
8	8.3	.1	3.6	1500	2	<1	.2	3.0	110	120	20	64
9	7.8	.2	7.4	1400	2	<1	.2	2.9	96	130	21	67
10	5.2	.6	6.1	690	1	<1	.2	1.9	65	63	7	18
11	9.7	.8	6.7	590	2	<1	.5	1.7	81	86	12	22
12	7.6	.2	3.6	1200	2	<1	.1	3.2	69	160	23	38
13	5.6	.6	8.6	700	2	<1	.2	2.9	68	66	8	18
14	5.6	.5	7.5	610	2	<1	.2	2.7	63	68	9	21
15	5.1	.2	4.3	370	1	<1	.2	11	71	55	8	11
16	6.0	.5	11	780	2	<1	.2	2.8	70	93	11	23
17	5.4	.2	4.3	640	1	<1	.2	5.1	120	62	9	14
18	5.8	.5	5.2	530	1	<1	.4	3.3	72	54	9	17
19	6.3	.5	6.1	560	2	<1	.3	3.5	72	56	10	17
20	7.5	.9	7.8	650	3	<1	.3	2.0	63	74	10	22
21	5.7	.8	7.6	650	2	<1	.4	1.9	70	53	8	19
22	8.4	.8	4.9	510	2	<1	.3	2.0	60	73	9	20
23	6.0	.7	8.0	720	2	<1	.3	3.7	70	68	8	19
24	5.7	.6	8.8	810	2	<1	.2	2.7	69	74	10	20

Table 8. *Trace-element concentrations in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

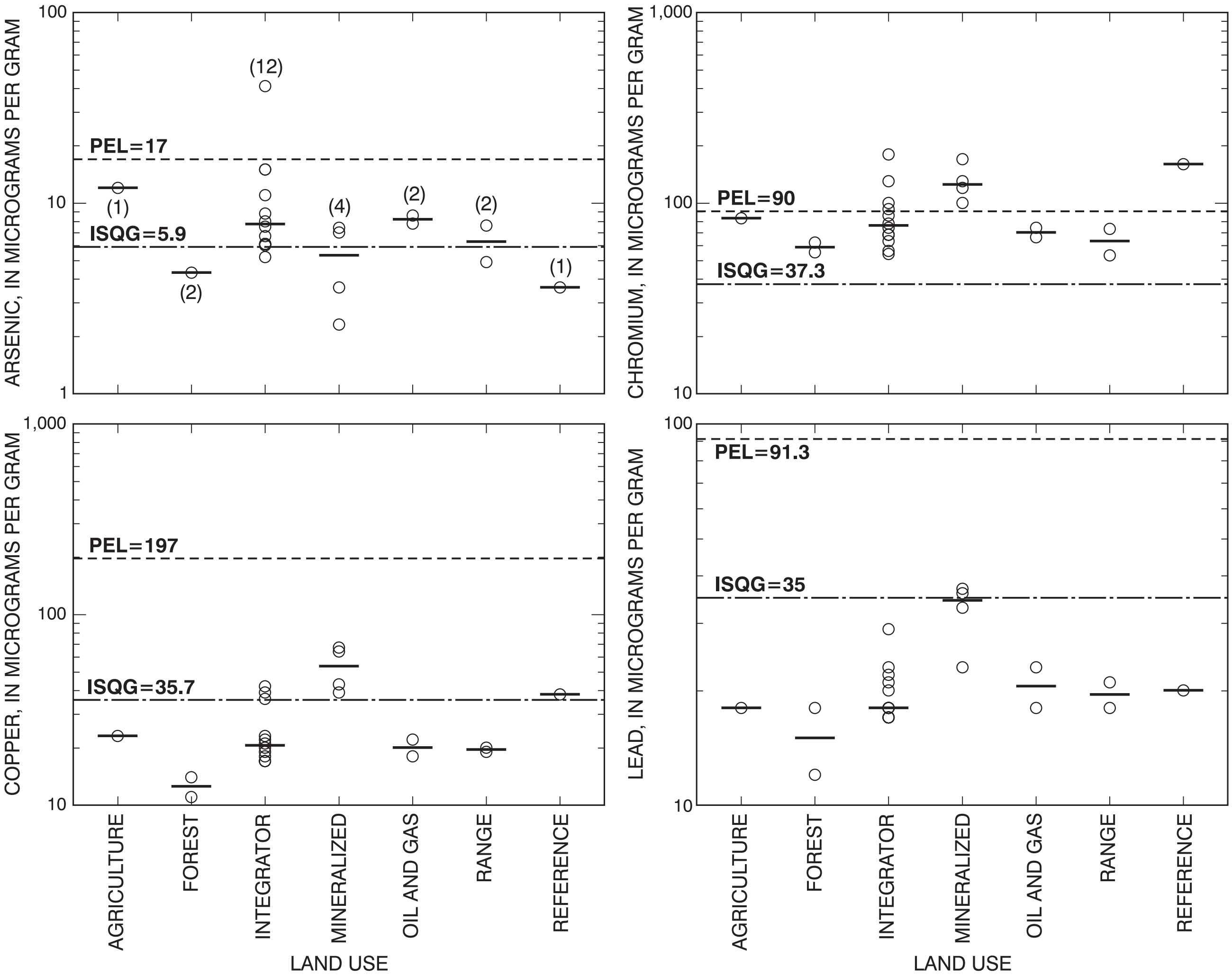
Site number	Europium	Gallium	Gold	Holmium	Iron (%)	Lanthanum	Lead	Lithium	Magnesium (%)	Manganese	Mercury	Molybdenum
1	1	16	<1	1	2.4	48	22	20	1.2	370	0.05	1.0
2	1	14	<1	<1	5.2	32	23	20	4.0	920	.02	<.5
3	1	17	<1	1	5.5	53	21	20	2.1	720	.20	1.0
4	2	18	<1	<1	4.6	46	37	20	1.1	710	.09	1.0
5	1	17	<1	<1	4.2	38	18	30	2.2	550	.06	.9
6	1	15	<1	1	3.6	40	29	30	1.8	630	.04	.9
7	1	14	<1	1	3.0	37	18	30	1.5	490	.04	.9
8	2	19	<1	<1	3.6	65	36	20	2.2	670	<.02	1.0
9	2	18	<1	<1	3.9	59	33	20	2.3	670	.02	.9
10	1	12	<1	1	2.0	39	17	30	.97	350	.02	.6
11	1	21	<1	1	3.3	46	23	50	1.6	350	.04	1.0
12	1	18	<1	<1	4.8	42	20	20	2.4	830	.03	.5
13	1	13	<1	1	2.4	40	18	30	1.5	380	.03	.9
14	1	13	<1	1	2.5	37	18	30	1.3	470	.03	.8
15	<1	10	<1	1	2.2	37	12	30	2.3	460	.02	.7
16	1	14	<1	<1	2.9	41	18	30	1.5	470	.03	.6
17	2	11	<1	2	2.7	74	18	30	1.8	410	.03	<.5
18	1	12	<1	1	2.3	39	20	30	1.6	760	.04	.7
19	1	13	<1	1	2.7	40	17	30	1.6	770	.05	.9
20	1	18	<1	<1	2.9	39	23	40	1.5	350	.04	.8
21	1	13	<1	<1	2.3	41	18	30	1.2	380	.03	1.0
22	1	20	<1	<1	2.4	36	21	40	.92	400	.06	.9
23	1	14	<1	<1	2.5	42	18	40	1.2	370	.03	1.0
24	1	13	<1	<1	2.5	41	17	20	1.4	420	.03	.7

Table 8. *Trace-element concentrations in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

Site number	Neodymium	Nickel	Niobium	Phosphorus (%)	Potassium (%)	Scandium	Selenium	Silver	Sodium (%)	Strontium	Sulfur (%)	Tantalum
1	34	41	20	0.094	1.7	7	0.1	0.69	1.8	600	0.06	1
2	25	88	7	.10	1.7	19	.1	.7	2.2	760	<.05	<1
3	38	51	19	.10	1.6	14	.4	.67	1.5	560	.25	1
4	35	39	10	.15	1.9	12	.7	<1	1.4	380	.05	1
5	34	38	10	.10	2.1	12	.5	<1	.67	310	.05	1
6	31	36	14	.10	1.9	10	.7	.54	.95	320	.16	1
7	30	27	11	.11	1.8	9	.7	<.1	1.1	320	.19	<1
8	44	58	10	.16	1.7	12	.1	.56	1.9	740	<.05	1
9	39	60	10	.14	1.6	12	.2	.5	1.8	680	<.05	2
10	30	21	14	.074	1.7	6	.4	.51	.49	170	<.05	<1
11	37	31	17	.081	2.0	11	.5	<.1	.29	170	<.05	1
12	30	52	7	.16	1.4	14	.4	.4	1.7	660	<.05	<1
13	31	23	15	.090	1.8	6	.6	.5	.67	200	<.05	<1
14	29	25	14	.085	1.8	7	.6	.51	.52	180	.05	<1
15	31	26	10	.11	2.0	7	.8	<.1	.19	150	.06	<1
16	32	38	8	.10	1.7	10	.5	.74	.92	280	.09	1
17	62	21	12	.14	2.0	8	1.1	<.1	.51	150	.11	<1
18	33	21	11	.11	1.6	7	.8	<.1	.37	160	.17	<1
19	32	22	12	.10	1.7	7	.6	.1	.35	170	.11	<1
20	30	25	11	.068	2.1	11	.6	.58	.38	190	.07	1
21	33	20	10	.079	1.9	8	.6	.55	.34	120	.08	1
22	26	20	12	.042	1.6	11	.5	.6	.26	190	.24	1
23	33	22	10	.085	1.8	9	.7	.66	.44	190	.12	1
24	33	24	9	.092	1.8	9	.4	.48	.77	210	.06	1

Table 8. *Trace-element concentrations in bed-sediment samples, Yellowstone River Basin, 1998--Continued*

Site number	Thallium	Thorium	Tin	Titanium (%)	Uranium	Vanadium	Ytterbium	Yttrium	Zinc	Inorganic carbon (%)	Total carbon (%)
1	<1	9.0	2	0.30	2.0	69	2	22	65	0.01	1.90
2	<1	3.6	1	.50	.85	140	1	8	76	.07	.7
3	<1	9.4	2	.51	1.7	190	2	23	100	.12	1.27
4	<1	9.3	2	.41	3.6	90	2	19	120	.02	3.16
5	<1	10	2	.33	3.0	110	2	20	100	.70	1.70
6	<1	9.6	2	.35	2.5	130	2	21	100	.62	1.93
7	<1	10	2	.32	2.7	100	3	21	86	.37	1.67
8	<1	11	1	.43	2.3	98	1	14	80	.1	.35
9	<1	9.9	1	.44	2.3	110	1	13	83	.05	.59
10	<1	11	1	.29	2.7	88	2	20	71	.58	1.05
11	<1	14	4	.39	4.0	140	3	26	110	.37	.91
12	<1	6.6	1	.47	2.1	150	1	14	88	.01	1.98
13	<1	11	2	.27	2.7	100	2	22	76	1.14	1.44
14	<1	10	2	.28	2.6	96	2	21	80	.98	1.52
15	<1	12	2	.27	2.3	49	3	24	53	3.63	6.71
16	<1	12	2	.36	3.0	110	2	20	75	.71	1.43
17	<1	22	2	.34	3.8	62	5	34	53	1.73	5.19
18	<1	12	3	.28	2.8	75	3	22	93	1.19	3.56
19	<1	12	3	.25	2.7	78	3	20	75	1.23	3.19
20	<1	12	3	.32	3.7	120	2	20	96	.65	1.29
21	<1	13	2	.32	3.6	86	2	21	68	.65	1.42
22	<1	12	3	.39	3.6	110	2	17	87	.53	1.47
23	<1	13	2	.32	4.0	100	2	22	76	1.23	2.01
24	<1	11	2	.34	3.3	92	2	20	67	.83	1.52



EXPLANATION

- - - - - - - **Canadian probable effect level (PEL)**

—·—·— **Canadian interim sediment quality guideline (ISQG)**

—— **Median concentration**

(1) **Number of samples**

Figure 8. Relation between land use and concentrations of selected trace elements in bed-sediment samples, Yellowstone River Basin,1998.

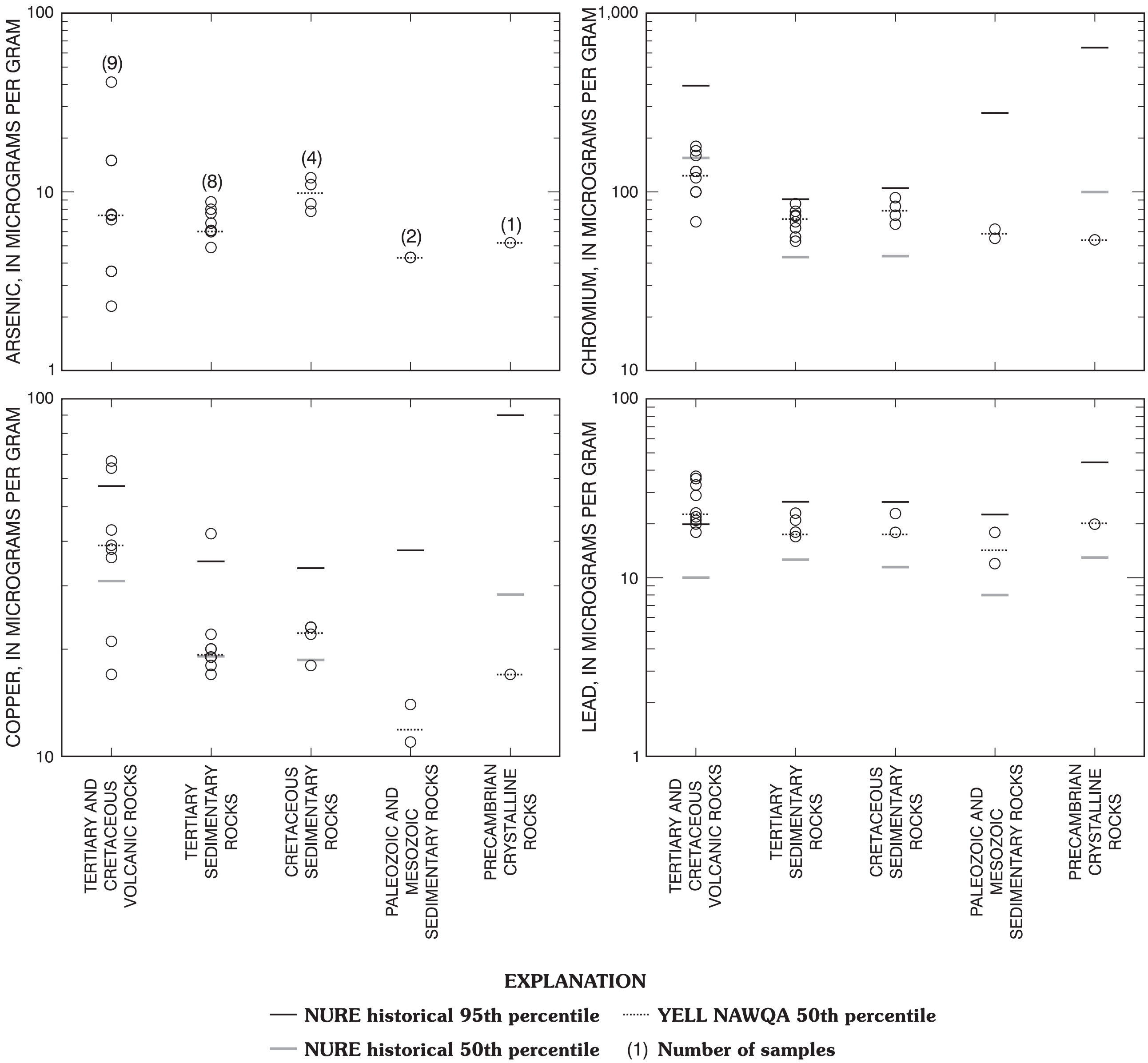


Figure 9. Relation between geologic units and concentrations of selected trace elements in bed-sediment samples, Yellowstone River Basin, 1998.

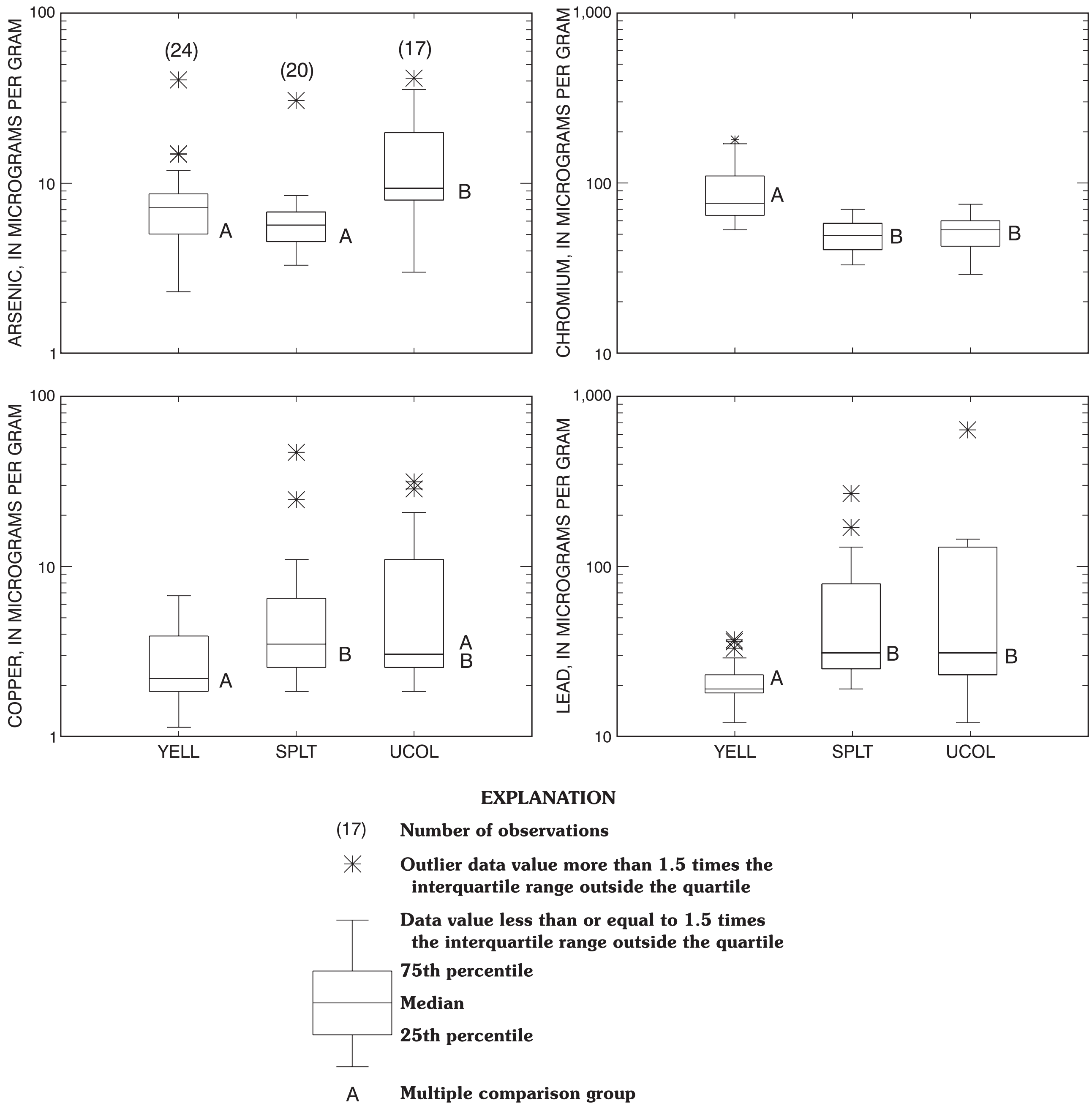


Figure 10. Concentrations of selected trace elements in bed-sediment samples from the Yellowstone River Basin (YELL), the South Platte River Basin (SPLT), and the Upper Colorado River Basin (UCOL). Boxplots that have the same letter indicate the data sets are not significantly different; those with different letters indicate significant differences from each other. See text for additional explanation.

ences ($p<0.05$) exist among the study units for all four selected trace elements. The data were then analyzed by the Wilcoxon rank sum statistical test to determine which groups were significantly different at the 0.05 level. The letters A, B, and C were assigned to each boxplot (fig. 10) to denote significant statistical differences in the data sets. Boxplots that have the same letter indicate the data sets were not significantly different from each other, and boxplots that have different letters indicate significant differences. Arsenic concentrations in the YELL were similar to those in the SPLT but significantly lower than those in the UCOL. Chromium concentrations were significantly higher in the YELL than in the other basins. Copper concentrations in the YELL were similar to those in the UCOL but significantly lower than those in the SPLT. Lead concentrations were significantly lower in the YELL than in the other study units.

Mercury Study

Samples were collected at five sites for analysis of mercury in fish muscle and bed sediment, in coordination with the USGS National Mercury Project (Krabbenhoft and others, 1999). Concentrations of mercury in muscle tissue from predatory game fish ranged from 0.743 to 3.45 µg/g dry weight (table 9). The higher mercury concentrations were in walleye from the Bighorn River (site 10), Bighorn Lake (site 11), and the Shoshone River (site 14). The walleye sample from Bighorn Lake (site 11) contained a higher concentration of mercury than the mercury concentrations in carp from Bighorn Lake reported by McDowell (1973). Higher concentrations of mercury in predatory walleye compared with the omnivorous carp are expected because of bioaccumulation and biomagnification (Eisler, 1987, Phillips and others, 1980). The mercury concentrations in walleye from sites 10, 11, and 14 are within the range of mercury concentrations in walleye from Bighorn Lake collected by the Montana Department of Fish, Wildlife and Parks (MFWP). The Montana Department of Public Health and Human Services (1995) issued a fish consumption advisory for Bighorn Lake, Tongue River Reservoir, and Cooney Reservoir in the Yellowstone River Basin on the basis of the MFWP samples. Additional information on fish consumption advisories is available from the State and a website at: ***http://www.epa.gov/OST/fish/mercury.html.***

The smallmouth bass sampled at site 19 on the Tongue River had the smallest concentration of mercury of the fish sampled. Nonpoint sources accounted for more than 80 percent of the mercury inputs to Tongue River Reservoir, which is located a few miles downstream of site 19 (Phillips and others, 1987). The mercury concentrations in the smallmouth bass from the Tongue River and sauger from the Yellowstone River near Sidney (site 24) were similar to the median and mean concentrations of mercury from a national study of chemical residues in fish (U.S. Environmental Protection Agency, 1992).

Table 9. *Mercury concentrations in fish-muscle and bed-sediment samples collected in cooperation with the National Mercury Project*

[g, grams; Hg, mercury; µg/g, micrograms per gram; ng/g, nanograms per gram; NA, not available]

Site number	Site name	Fish species	Number of fish	Average fish weight (g)	Total Hg in Fish: Dry weight (µg/g)	Total Hg in Fish: Wet weight (µg/g)	Sediment: Methyl Hg (ng/g)	Sediment: Total Hg (ng/g)
10	Bighorn River	walleye	5	452	3.29	0.635	0.60	16.3
11	Bighorn Lake	walleye	5	896	3.38	0.676	0.59	33.0
14	Shoshone River	walleye	1	1,444	3.25	0.669	0.53	11.1
14	Shoshone River	walleye	5	817	3.45	0.666	.53	11.1
19	Tongue River	smallmouth bass	1	299	0.743	0.153	3.05	27.7
24	Yellowstone River near Sidney	sauger	2	176	1.29	0.250	NA	18.7

Only a small fraction of the mercury present in the bed sediment was in the form of methyl mercury (table 9). Methyl mercury is of interest because it is the most toxic form of mercury (Eisler, 1987). The percentage of total mercury in the methyl form in the sediment samples ranged from 1.8 percent at Bighorn Lake to 11 percent in the Tongue River. The concentration of methyl mercury in the sediment from the Tongue River was 3.05 nanograms per gram (ng/g) dry weight, considerably higher than the other samples that contained 0.53 to 0.60 ng/g (table 9).

SUMMARY

An investigation of the Yellowstone River Basin was started in 1997 as part of the USGS NAWQA program. One element of the integrated approach used by NAWQA is the determination of the occurrence and distribution of organic compounds and trace elements in fish tissue and bed sediment. During 1998, bed-sediment samples were collected at 24 sites in the study area, and fish-tissue samples were collected at 21 of those sites.

Organochlorine insecticides were detected in fish tissue at relatively low concentrations. The organic compound most frequently detected in fish was p,p′-DDE, which occurred at 71 percent of the sampling sites. The presence of DDT and its metabolites in fish tissue from sites in Yellowstone Park and nearby areas likely is a result of historical DDT spraying programs for spruce budworm. Brown trout samples collected in conjunction with DDT spraying in the Park during 1957 contained about two orders of magnitude more total DDT than brown trout collected from the same site during 1998. Organochlorine insecticides were not detected in samples from six sites in other parts of the study area. Fish tissue from two sites contained PCBs. None of the concentrations of organochlorine insecticides or PCBs exceeded the guidelines for protection of wildlife that eat fish. The concentrations of insecticides and PCBs generally were low compared to concentrations from other NAWQA studies in the Rocky Mountain area and national level fish-tissue studies.

Comparison of concentrations for the 27 organochlorine insecticides and metabolites, and total PCBs analyzed in both tissue and bed sediment indicates that more compounds were detected in the fish tissue than the bed sediment. Of the 12 insecticides detected in fish tissue, only trans-chlordane and p,p′-DDT were detected in bed-sediment samples. The higher concentrations and more extensive occurrence of organochlorine insecticides and PCBs in the fish samples probably results from the lipophilic nature of the compounds, chemical partitioning, and bioaccumulation. The data suggest that fish are more sensitive indicators of insecticide and PCB contamination than bed sediment.

Bed-sediment samples also were analyzed for semivolatile organic compounds (which were not analyzed in fish tissue). About 20 polynuclear aromatic hydrocarbons (PAHs) were detected in bed-sediment samples from integrator sites in the Billings area and the Goose Creek area near Sheridan; a few PAHs were detected at other sites.

Concentrations of selenium in many of the fish-tissue samples were above background levels. Concentrations of cadmium, chromium, selenium, and several other trace elements were higher in cutthroat trout from a mining indicator site on Soda Butte Creek than two other sites where cutthroat trout were sampled.

Median concentrations of arsenic, chromium, copper, and lead were higher in bed-sediment samples from mineralized areas than non-mineralized areas. Median concentrations of chromium, copper, and lead were highest at sites located in areas of Tertiary and Cretaceous volcanic rocks. The median concentration of arsenic was highest at sites located in Cretaceous sedimentary rocks. Concentrations of arsenic, chromium, copper, and lead in some of the bed-sediment samples potentially exceed Canadian criteria for the protection of aquatic life, but generally did not exceed 95th percentile historical concentrations for the YELL.

Fish-tissue and bed-sediment samples collected in coordination with the USGS National Mercury Project indicated concentrations of mercury ranging from 0.743 to 3.45 µg/g dry weight in game fish fillets from five sites. Methyl mercury comprised 1.8 to 11 percent of the total mercury in the bed-sediment samples from the 5 sites.

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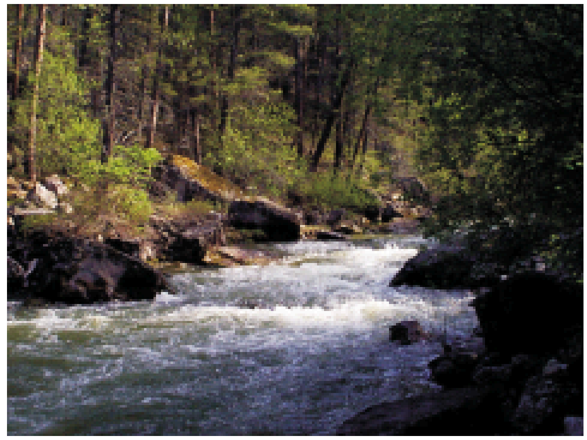
Wood River (near site 8)



Little Bighorn River (near site 15)

Yellowstone River at Forsyth (site 16)

Goose Creek near Acme (site 18)

Salt Creek near Sussex (site 20)

Powder River near Locate (site 23)

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