National Water-Quality Assessment Program
Toxic Substances Hydrology Program

Mercury in Fish, Bed Sediment, and Water from Streams Across the United States, 1998–2005

Scientific Investigations Report 2009–5109

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

Cover:
Center: Wetland-basin stream site. (Photograph by Dennis A. Wentz, U.S. Geological Survey.)
Insets left to right:
Inset 1: Urban-basin stream site. (Photograph by Barbara C. Scudder, U.S. Geological Survey.)
Inset 2: Mined-basin stream site. (Photograph by Barbara C. Scudder, U.S. Geological Survey.)
Inset 3: Forested-basin stream site. (Photograph by Faith A. Fitzpatrick, U.S. Geological Survey.)
Inset 4: Agricultural-basin stream site. (Photograph by Barbara C. Scudder, U.S. Geological Survey.)

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KEN SALAZAR, Secretary

U.S. Geological Survey
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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with reliable scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the quality of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, 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. During 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

National and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are selectively reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and groundwater. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between ***sources*** of contaminants, the ***transport*** of those contaminants through the hydrologic system, and the potential ***effects*** of contaminants on humans and aquatic ecosystems. Included are studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS 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 cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

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Conversion Factors

Multiply	By	To obtain
	Length	
nanometer (nm)	0.00000003937	inch (in.)
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (m)	0.6214	mile (mi)
	Volume	
liter (L)	0.2642	gallon (gal)
liter (L)	33.82	ounce, fluid (fl. oz)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F=(1.8×°C)+32.$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L). Concentrations of chemical constituents in fish tissue are given in micrograms per gram (µg/g); those in sediment are given in nanograms per gram (ng/g).

Mercury in Fish, Bed Sediment, and Water from Streams Across the United States, 1998–2005

By Barbara C. Scudder, Lia C. Chasar, Dennis A. Wentz, Nancy J. Bauch, Mark E. Brigham, Patrick W. Moran, and David P. Krabbenhoft

Abstract

Mercury (Hg) was examined in top-predator fish, bed sediment, and water from streams that spanned regional and national gradients of Hg source strength and other factors thought to influence methylmercury (MeHg) bioaccumulation. Sampled settings include stream basins that were agricultural, urbanized, undeveloped (forested, grassland, shrubland, and wetland land cover), and mined (for gold and Hg). Each site was sampled one time during seasonal low flow. Predator fish were targeted for collection, and composited samples of fish (primarily skin-off fillets) were analyzed for total Hg (THg), as most of the Hg found in fish tissue (95–99 percent) is MeHg. Samples of bed sediment and stream water were analyzed for THg, MeHg, and characteristics thought to affect Hg methylation, such as loss-on-ignition (LOI, a measure of organic matter content) and acid-volatile sulfide in bed sediment, and pH, dissolved organic carbon (DOC), and dissolved sulfate in water. Fish-Hg concentrations at 27 percent of sampled sites exceeded the U.S. Environmental Protection Agency human-health criterion of 0.3 micrograms per gram wet weight. Exceedances were geographically widespread, although the study design targeted specific sites and fish species and sizes, so results do not represent a true nationwide percentage of exceedances. The highest THg concentrations in fish were from blackwater coastal-plain streams draining forests or wetlands in the eastern and southeastern United States, as well as from streams draining gold- or Hg-mined basins in the western United States (1.80 and 1.95 micrograms THg per gram wet weight, respectively). For unmined basins, length-normalized Hg concentrations in largemouth bass were significantly higher in fish from predominantly undeveloped or mixed-land-use basins compared to urban basins. Hg concentrations in largemouth bass from unmined basins were correlated positively with basin percentages of evergreen forest and also woody wetland, especially with increasing proximity of these two land-cover types to the sampling site; this underscores the greater likelihood for Hg bioaccumulation to occur in these types of settings. Increasing concentrations of MeHg in unfiltered stream water, and of bed-sediment MeHg normalized by LOI, and decreasing pH and dissolved sulfate were also important in explaining increasing Hg concentrations in largemouth bass. MeHg concentrations in bed sediment correlated positively with THg, LOI, and acid-volatile sulfide. Concentrations of MeHg in water correlated positively with DOC, ultraviolet absorbance, and THg in water, the percentage of MeHg in bed sediment, and the percentage of wetland in the basin.

Introduction

Mercury (Hg) is a global pollutant that ultimately makes its way into every aquatic ecosystem through the hydrologic cycle. Anthropogenic (human-related) sources are estimated to account for 50–75 percent of the annual input of Hg to the global atmosphere and, on average, 67 percent of the total Hg in atmospheric deposition to the United States (Meili, 1991; U.S. Environmental Protection Agency, 1997; Seigneur and others, 2004). Elevated Hg concentrations that are attributed to atmospheric deposition have been documented worldwide in aquatic ecosystems that are remote from industrial sources (Fitzgerald and others, 1998).

Methylation—the microbially mediated conversion of inorganic Hg to the organic form, methylmercury (MeHg)—is the single most important step in the environmental Hg cycle because it greatly increases Hg toxicity and bioaccumulation potential. Laboratory studies estimate the bioaccumulation potential for MeHg to be a thousand-fold that of inorganic Hg (Ribeyre and Boudou, 1994). In aquatic ecosystems, MeHg is found in elevated concentrations in top predators, and physiological effects have been demonstrated at low concentrations (Briand and Cohen, 1987; Eisler, 1987; Wiener and Spry, 1996; U.S. Environmental Protection Agency, 2001; Rumbold and others, 2002; Tchounwou and others, 2003; Yokoo and others, 2003; Eisler, 2004). The process by which Hg is accumulated into the lower trophic levels of aquatic food webs is not well understood (Wiener and others, 2003). Although diet has been demonstrated to be the dominant mechanism of MeHg uptake in fish (Hall and others, 1997), factors such as size, age, community structure, feeding habits, and food-chain length are also important in the ultimate MeHg fish-tissue concentration (Wong and others, 1997; Atwell and others, 1998; Trudel and others, 2000; Wiener and others, 2003).

Accumulation of MeHg in fish tissue is considered a significant threat to the health of both wildlife and humans. Approximately 95 percent or more of the Hg found in most fish fillet/muscle tissue is MeHg (Huckabee and others, 1979; Grieb and others, 1990; Bloom 1992). Women of child-bearing age and infants are particularly vulnerable to effects from consumption of Hg-contaminated fish (U.S. Environmental Protection Agency, 2001). As of 2006, most States (48; no advisories in Alaska or Wyoming), the District of Columbia, one territory (American Samoa), and two Tribes have issued fish-consumption advisories for Hg (U.S. Environmental Protection Agency, 2007). These advisories represent 14,177,175 lake acres and 882,963 river miles, or 35 percent of the Nation's total lake acreage and about 25 percent of its river miles.

Studies of Hg in aquatic environments have focused mostly on lakes, reservoirs, and wetlands because of the predominance of lakes with Hg concerns and the importance of wetlands in Hg methylation (Bloom and others, 1991; Driscoll and others, 1994; Hurley and others, 1995; Krabbenhoft and others, 1995; St. Louis and others, 1994 and 1996; Westcott and Kalff, 1996; U.S. Environmental Protection Agency, 1997; Fitzgerald and others, 1998; Kotnik and others, 2002). Increasingly, however, studies of streams and rivers have contributed significantly to our understanding of Hg in these complex ecosystems (Hurley and others, 1995; Balogh and others, 1998; Domagalski, 1998; Wiener and Shields, 2000; Peckenham and others, 2003; Dennis and others, 2005). Sources of regional or national fish-Hg data include a U.S. Environmental Protection Agency (USEPA) assessment of fish-Hg concentrations in streams in the western United States (Peterson and others, 2007); the USEPA National Lake Fish Tissue Studies (http://www.epa.gov/waterscience/fish/study/); the National Contaminant Biomonitoring Program (NCBP) of the U.S. Fish and Wildlife Service, which later became the Biomonitoring of Environmental Status and Trends (BEST) program of the U.S. Geological Survey (USGS) (Schmitt and others, 1999, 2002 and 2004; Hinck and others, 2004a, 2004b, 2006, 2007); fish-Hg data compiled from 24 research and monitoring programs in northeastern North America (Kamman and others, 2005); and a large compilation of many State, Federal, and Tribal fish-Hg datasets (Wente, 2004; see also http://emmma.usgs.gov/datasets.aspx).

Currently, it is difficult to directly compare fish-Hg concentrations across the Nation by using any compilation of fish-Hg data. Several issues must be resolved before making effective use of other agencies' datasets, and review of other-agency data is beyond the scope of this report. These issues include (1) use of multiple analytical laboratories and analytical methods; (2) inconsistent or unknown data quality; (3) large variations in sample characteristics, including fish species, size, and tissue sampled; (4) incomplete site information (for example, locations of some sites are not adequately described, and some georeferenced sites may not be coded as to site type, such as lake, stream, or reservoir); and (5) incomplete sample information (for example, species, length, or tissue sampled are not known). Several of these issues have been described in greater detail by Wente (2004), who has developed a promising statistical modeling approach to account for variation in fish-Hg levels by species, size, and tissue sampled. It is not known, however, whether the approach performs equally well in streams as it does in lakes, or whether it performs consistently among various regions of the Nation. These issues emphasize the need for a nationwide assessment of Hg in streams for fish, bed sediment, and water based on consistent methods, as is provided by the study described herein.

Purpose and Scope

The primary objective of this report is to describe the occurrence and distribution of total mercury (THg) in fish tissue in streams in relation to regional and national gradients of Hg source strength (including atmospheric deposition, gold and Hg mining, urbanization) and other factors that are thought to affect Hg bioaccumulation, including wetland and other land-use/land-cover types (LULC). Secondary objectives are to evaluate THg and MeHg in streambed (bed) sediment and stream water in relation to these gradients and to identify ecosystem characteristics that favor the production and bioaccumulation of MeHg.

The data discussed here are presented by Bauch and others (2009). They were aggregated from 6 studies covering a total of 367 sites across the Nation (table 1). The majority of sites (266) were part of 2 studies conducted collaboratively by the USGS National Water-Quality Assessment (NAWQA) and Toxics Substances Hydrology Programs. The earliest of these, the USGS National Mercury Pilot Study (Krabbenhoft and others, 1999; Brumbaugh and others, 2001) sampled 107 streams across the Nation in 1998. During 2002 and 2004–5, an additional 159 streams were sampled by the NAWQA Program to complement those sampled during the 1998 National Mercury Pilot Study; the additional sampling sites were chosen to increase spatial coverage and to supplement source and environmental factors that previously were underrepresented. An additional 101 stream sites were sampled as part of 4 regional USGS studies in the Cheyenne-Belle Fourche River Basins, 1998–99 (S.K. Sando, USGS,

Table 1. Number of sites on United States streams sampled for mercury, 1998–2005.

[**Regional studies:** CHEY, Cheyenne-Belle Fourche River Basins, 1998–99; DELR, Delaware River Basin, 1999–2001; NECB, New England Coastal Basins, 1999–2000; and UMIS, Upper Mississippi River Basin, 2004]

Description	Number of sites
Study components	
1998 National Mercury Pilot Study	107
2002–05 Additional national studies	159
Regional studies: CHEY, DELR, NECB, UMIS	101
Total number of sites	367
Mercury data available	
Fish mercury data	291
Bed-sediment and water mercury data	352
Fish, bed-sediment, and water mercury data	274

unpublished data, 2005); Delaware River Basin, 1999–2001 (Brightbill and others, 2003); New England Coastal Basins, 1999–2000 (Chalmers and Krabbenhoft, 2001); and the Upper Mississippi River Basin, 2004 (Christensen and others, 2006). The regional studies used sample-collection, processing, and analytical techniques that were comparable to those in the two national studies, thus allowing direct comparison of the results.

Study Design

Sampled streams were predominantly within the boundaries of NAWQA study areas, which are major hydrologic basins (fig. 1). These major hydrologic basins encompass 45 percent of the land area of the conterminous United States, some portion of each of the 50 States, and 60–70 percent of water use and population served by public water supply (Leahy and others, 1990; Helsel, 1995; Gilliom and others, 2001); they represent broad ranges of hydrologic and geologic settings, LULC, and population density. Within each major basin, streams were selected to represent the specific environmental settings of interest. The resulting network of sites reflects conditions across the United States. Gilliom and others (1995), Helsel (1995), and Horowitz and Stephens (2008) discuss the advantages of the NAWQA design for sampling small streams at a national scale.

Specific site-selection criteria within each of the major hydrologic basins were based on targeted environmental settings thought to be important with regard to the source, concentration, or biogeochemical behavior of Hg in aquatic ecosystems in that basin (table 7, at back of report). Settings of particular interest included agricultural areas (enhanced runoff of dissolved and colloidal Hg associated with organic matter; particulate Hg from eroded soils); urban areas (elevated local depositional sources; enhanced Hg runoff due to impervious surfaces); undeveloped areas (atmospheric Hg deposition source only); and mined areas (cinnabar mining; historical gold mining, in which elemental Hg was used as an amalgamating agent). Site categories of agricultural, urban, undeveloped, and mixed LULC are consistent with the definitions provided by Gilliom and others (2006):

- *Agricultural basins* contained greater than 50 percent agricultural land and less than or equal to 5 percent urban land.
- *Urban basins* contained greater than 25 percent urban land and less than or equal to 25 percent agricultural land.
- *Undeveloped basins* were primarily forest, herbaceous grassland, shrubland, tundra, and wetland, and contained less than or equal to 5 percent urban land and less than or equal to 25 percent agricultural land.
- *Mixed-land-use basins* included all remaining LULC combinations.

Compared with all streams in the conterminous United States, this targeted sampling for Hg may have overrepresented urban basins and underrepresented undeveloped basins (fig. 2). Slightly more than two-thirds of the sampled Hg sites were in the eastern half of the United States compared with the western half (west of the Mississippi River).

Each site was sampled one time, typically during seasonal low flow in late summer, for Hg and related constituents in top-predator (piscivorous) fish, bed sediment, and stream water. This multimedia approach on a national scale was considered to be critical for helping to understand controls on Hg partitioning, bioaccumulation, and biomagnification (Krabbenhoft and others, 1999). Many studies have shown that mature top-predator fish generally reflect the highest potential Hg concentrations in aquatic food webs (Francesconi and Lenanton, 1992; Weiner and Spry, 1996; Boudou and Ribeyre, 1997; Morel and others, 1998; Kim and Burggraaf, 1999). Thus, largemouth bass was the piscivorous fish species targeted for collection. At sites where this species was not available in sufficient numbers, alternate top-predator fish species were collected.

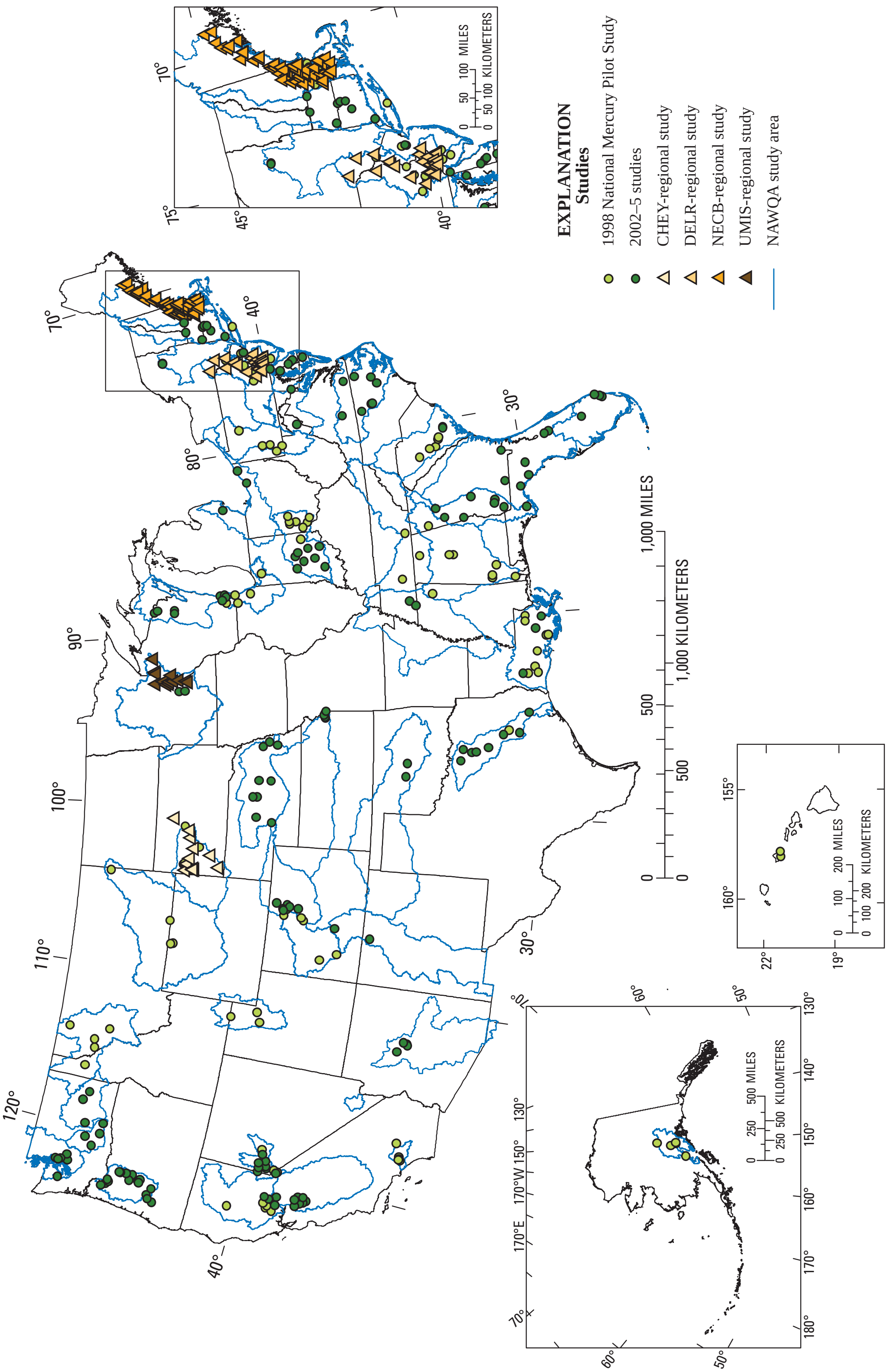

Figure 1. Streams sampled for mercury, 1998–2005. (Regional studies are: CHEY, Cheyenne-Belle Fourche River Basins, 1998–9; DELR, Delaware River Basin, 1999–2001; NECB, New England Coastal Basins, 1999–2000; and UMIS, Upper Mississippi River Basins, 2004.)

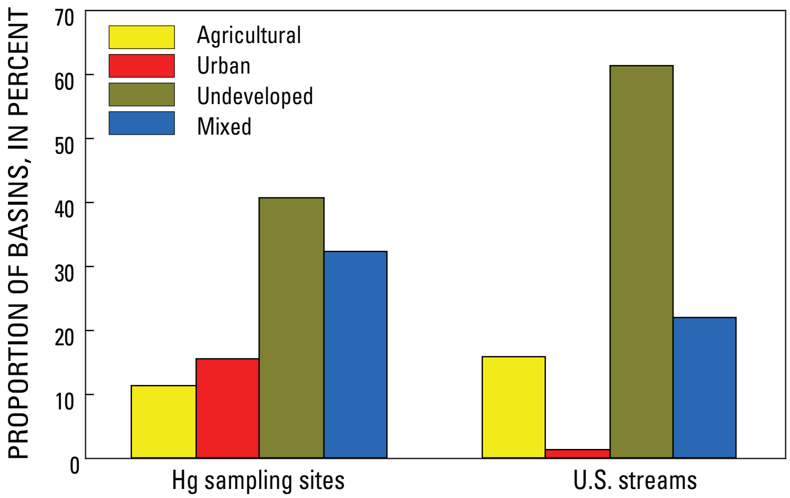

Figure 2. Land-use/land-cover categories for basins sampled for mercury, 1998–2005, and for all U.S. stream basins.

Methods

Methods for field data collection, ancillary data collection, laboratory analyses, and quality control are summarized below and described in detail elsewhere (primarily in Bauch and others, 2009; see also Lewis and Brigham, 2004; Lutz and others, 2008; Scudder and others, 2008). All data presented in this report are published in Bauch and others (2009).

Field Data Collection

Fish were collected primarily by electrofishing, but also by rod/reel and gill nets. Largemouth bass (3-year age class) were targeted for collection; alternate top predators were selected if largemouth bass were not available. Fish were measured for total length and weight. Fish axial muscle, primarily skinless fillet (skin-on fillet at four sites in the Upper Mississippi River Basin regional study), was dissected from most fish in the field or laboratory by use of trace-metal clean procedures (Scudder and others, 2008). Fish weighing less than about 60 g were processed as whole-body or headless fish (15 sites). For all samples except those collected during 2004–5, 1 to 10 fish (median of 5 fish) of the same species and similar size for a site were composited to form a single composite sample for analysis of THg. Fish collected during 2004–5 were processed individually for laboratory analyses. After processing, fish samples were frozen until analysis. Fish were not collected in the Cheyenne-Belle Fourche River Basins.

Bed-sediment samples were collected by use of trace-metal clean sampling techniques (Shelton and Capel, 1994; Lutz and others, 2008). A Teflon® or plastic scoop was used to remove the upper 2 to 4 cm of bed sediment from 5 to 10 depositional areas; samples were composited in Teflon® or plastic containers into a single sample for each site. Each sample was homogenized and subsampled for THg and MeHg, loss-on-ignition (LOI, a measure of organic matter content), acid-volatile sulfide (AVS), and sand/silt particle size (percent less than 63 µm) analyses. Samples were unsieved, so as to minimize disturbance of the natural partitioning of MeHg and THg in the bed sediment and volatilization of sulfides. Subsamples for Hg analysis were placed in Teflon® vials and frozen.

Stream-water samples were collected by dipping Teflon® or PETG (Nalgene) bottles in the centroid of streamflow by use of trace-metal clean techniques (Olson and DeWild, 1999; Lewis and Brigham, 2004). Unfiltered THg samples were acidified to 1 percent HCl by volume; unfiltered MeHg samples were stored in a dark cooler until frozen (Krabbenhoft and others, 1999). Samples for filtered THg and MeHg analyses were passed through quartz fiber filters (47-mm diameter, 0.7-µm pore size) in the field, placed into Teflon® bottles, acidified to 1 percent HCl by volume, and stored in the dark. Filters were placed on dry ice and stored frozen until analysis of particulate THg and MeHg. Samples were collected for additional water-quality characteristics, such as pH, specific conductance, ultraviolet (UV) absorbance, specific UV absorbance (SUVA) at 254 nanometers (nm), and concentrations of dissolved organic carbon (DOC), sulfate, and suspended sediment (total suspended sediment concentration and fraction less than 63 µm). Streamflow was measured one time during Hg sampling at sites without stream gages.

Ancillary Data Collection

A detailed description of selected ancillary spatial data for each stream basin is given in Bauch and others (2009). Stream-basin boundaries were delineated by using 1:24,000- to 1:250,000-scale digital topographic and hydrologic maps (Nakagaki and Wolock, 2005) or 30-m resolution Elevation Derivatives for National Applications (EDNA) reach catchments (U.S. Geological Survey, 2002). To verify accuracy, additional independent checks were made of selected basin boundaries. Natural features and potential human influences within the study basins were characterized by using Geographic Information System (GIS) coverages. LULC information was obtained from 30-m resolution National Land Cover Data (NLCD) that were based on satellite imagery from the early to mid-1990s (Vogelmann and others, 2001) and modified and enhanced (NLCDe 92) with Geographic Information Retrieval and Analysis System (GIRAS) data to give 25 LULC categories, as described in Nakagaki and Wolock (2005). These were the most up-to-date, nationally consistent LULC data at the time of our analysis. All LULC values used in our report are percentages of total basin area. Four initial groupings of sites were based on criteria in Gilliom and others (2006): agricultural, urban, undeveloped, and mixed. To address the possibility that conditions observed at the sampling site were influenced more by LULC closer to the site than by LULC farther from the site, LULC percentages were weighted by the inverse Euclidean distance from the site and reported as distance-weighted LULC. This resulted in a basin-scale percentage for each LULC category that was adjusted for spatial proximity to the sampling site; an area of a particular LULC category that was closer to the site received a higher weight and value than an area farther away (Wente, 2000; Falcone and others, 2007).

Gold and Hg mining can result in significant contributions of Hg to aquatic systems, so it was important to characterize sites with regard to this particular land use. Potential sources of Hg from past or current mining operations were determined for each stream basin by using the Mineral Availability System/Mineral Industry Location System (MAS/MILS) database from the Bureau of Mines (V.C. Stephens, U.S. Geological Survey, written commun., 2004), which is now part of the Mineral Resources Data System (MRDS) of the USGS (U.S. Geological Survey, 2004). The sites were identified as (1) Hg mining operations, in general, (2) Hg "producers," (3) gold mining operations, in general, and (4) gold "producers." Producers included current or past production mining operations. The highest densities of gold or Hg production mining sites are in Arkansas, California, Colorado, Idaho, Montana, and Nevada. A total of 89 basins were designated as "mined" and treated separately for the purposes of our data analyses; however, this distinction was made only for data analyses in our report and does not necessarily imply impacts of mining in these basins (fig. 3). In addition, our study was not designed specifically to address impacts of mining, so there may be areas of intense gold and Hg mining that were not represented. Mined basins in the eastern United States represented only gold mining.

Key soil characteristics were compiled from the U.S. Department of Agriculture State Soil Geographic (STATSGO) database (U.S. Department of Agriculture, 1994). Percent organic matter, soil erodibility factor, and land-surface slope were from Wolock (1997) and were linked by mapping-unit identification code to a 100-m resolution national grid of STATSGO geographic mapping units.

Basin hydrologic data were derived from various sources. Mean annual precipitation is the average value predicted from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly, Neilson, and Phillips, 1994; Daly, Taylor, and Gibson, 1997) based on annual precipitation (1961–90) at 2-km resolution obtained from the Spatial Climate Analysis Service at Oregon State University, Corvallis, Oreg. Mean base-flow index, potential and actual evapotranspiration, and topographic-wetness index values were as calculated for each basin on national grids of 1 km (Wolock and McCabe, 2000; Wolock, 2003a, 2003b; D.M Wolock, U.S. Geological Survey, written commun., 2007).

Data from the National Atmospheric Deposition Program (NADP) included information about measured wet Hg deposition. Annual precipitation-weighted Hg deposition concentrations for sites in the Mercury Deposition Network (MDN; Roger Claybrooke, Illinois State Water Survey, written commun., 2005) were averaged for 2000–2003. There were few MDN sites in the western United States, so the mean value for the seven most western MDN sites of the country (4.56 $\mu g/m^2$) was assigned to Western States (Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming). Mean basin wet-deposition concentrations of Hg were computed by overlaying the basins with the average Hg deposition maps for 2000 through 2003. Finally, Hg loading rates were computed by multiplying the MDN basin-averaged concentrations by the mean annual modeled PRISM precipitation (Daly, Neilson, and Phillips, 1994; Daly, Taylor, and Gibson, 1997). In addition, wet, dry, and THg deposition rates were estimated by using modeled results from Seigneur and others (2004).

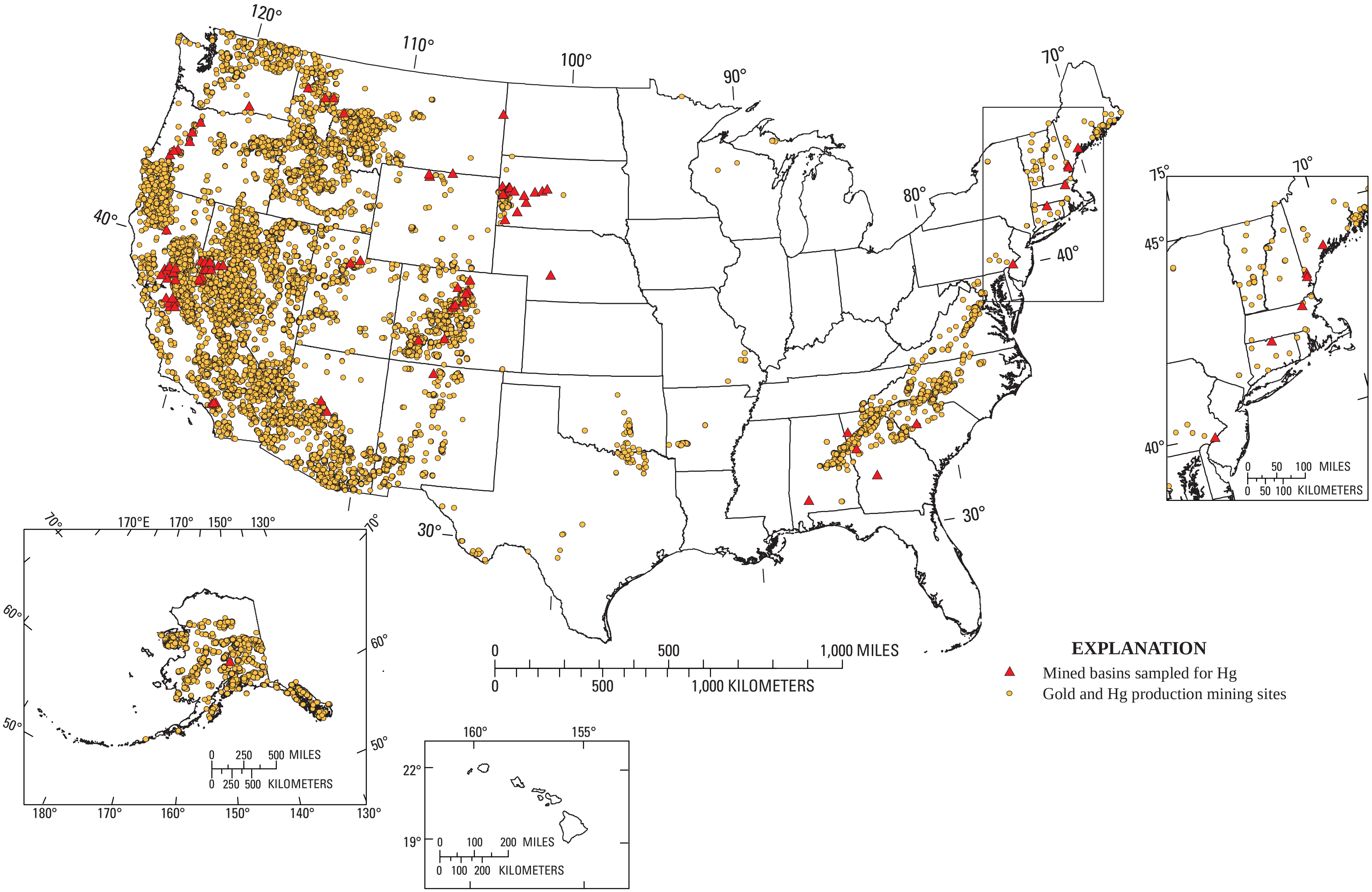

Figure 3. Sites in mined basins sampled for mercury, 1998–2005, and all known gold and mercury production mining sites (present and historical). [Locations for production mining sites from Mineral Availability System-Mineral Industry Location System of the U.S. Bureau of Mines and Mineral Resources Data System of the U.S. Geological Survey) (U.S. Geological Survey, 2004.]

Laboratory Analyses

Fish samples were analyzed only for THg because 95 percent or more of the Hg found in most fish fillet/muscle tissue is MeHg (Huckabee and others, 1979; Grieb and others, 1990; Bloom 1992). Five laboratories were used for these analyses over the course of the study:

- USGS Columbia Environmental Research Center (CERC; 1998 National Mercury Pilot Study),
- USGS National Water Quality Laboratory (NWQL; 2002 samples; Delaware River Basin regional study, 2001 samples),
- Texas A&M University Trace Element Research Laboratory (TERL; 2004–5 samples),
- USGS Wisconsin Mercury Research Laboratory (WMRL; Delaware River Basin regional study, 1999 samples; New England Coastal Basins regional study), and
- River Studies Center, University of Wisconsin, La Crosse, Wis. (Upper Mississippi River Basin regional study, 2004 samples).

Analytical Hg procedures for all laboratories except TERL included digestion and quantification with cold vapor atomic fluorescence spectroscopy (CVAFS) according to USEPA Methods 3052 and 7474, or modifications of USEPA Method 1631 Revision E (U.S. Environmental Protection Agency, 1996a and b, 2002; Olson and DeWild, 1999; Brumbaugh and others, 2001). The TERL analyzed fish samples for Hg by thermal decomposition, amalgamation, and atomic absorption spectrophotometry according to USEPA Method 7473 (U.S. Environmental Protection Agency, 1998). Fish ages were estimated from sagittal otoliths, scales, or spines by the CERC (1998 samples) or the USGS South Carolina Cooperative Fish and Wildlife Research Unit (Columbia, S.C.; 2002 and 2004–05 samples) (Jearld, 1983; Porak and others, 1986; Brumbaugh and others, 2001).

Bed sediment, stream water, and suspended particulate material were analyzed for THg and MeHg by the WMRL in Middleton, Wis. THg in stream water and particulate material was analyzed by use of CVAFS according to USEPA Method 1631 Revision E (U.S. Environmental Protection Agency, 1996a and b, 2002), with modifications by the WMRL (Olson and others, 1997; Olson and DeWild, 1999; Olund and others, 2004). MeHg in stream water and particulate samples was determined by distillation, aqueous-phase ethylation, gas-phase separation, and CVAFS (Bloom, 1989, as modified by Horvat and others 1993; Olson and DeWild, 1999; DeWild and others, 2002). Bed-sediment samples were analyzed for THg and MeHg by use of similar analytical procedures as those described above for stream water and particulate samples, with some modifications (DeWild and others, 2004; Olund and others, 2004).

Bed-sediment LOI was determined by the WMRL by using methods described in Heiri and others (2001). AVS was analyzed by the WMRL (1998 samples and New England Coastal Basin regional study) or by the USGS Sulfur Geochemistry Laboratory (SGL) in Reston, Va. (2002 and 2004–5 samples; Upper Mississippi River Basin regional study). At the WMRL, AVS samples were acidified with hydrochloric acid, anti-oxidant buffer was added, and sulfide was determined with an ion-specific electrode (Allen and others, 1991). At the SGL, AVS was extracted with hydrochloric acid, re-precipitated as silver sulfide, and percent by weight of AVS determined gravimetrically (Allen and others, 1991; Bates and others, 1993).

DOC concentrations in water were determined by the USGS National Research Program Organic Carbon Transformations Laboratory (NRP OCTL) in Boulder, Colo., (1998 and 2004–5 samples; Upper Mississippi River Basin regional study) or by the WMRL (Cheyenne-Belle Fourche River Basins regional study) using a persulfate wet oxidation method described in Aiken (1992). For 2002 samples and the Delaware River Basin, DOC concentrations were analyzed at the NWQL with UV-promoted persulfate oxidation and infrared spectroscopy (Brenton and Arnett, 1993). SUVA was measured by the NRP OCTL as the UV absorbance of a water sample at 254 nm, divided by the DOC concentration (Weishaar and others, 2003); SUVA units are liters per milligram carbon per meter. Stream-water samples were analyzed for sulfate by ion chromatography (Fishman and Friedman, 1989).

Data Analyses

Biota Accumulation Factors (BAFs) for fish with respect to water and bed sediment were computed as follows:

$$\mathrm{BAF} = \mathrm{Log}_{10}(C_b / C_w), \tag{1}$$

where

C_b is the wet-weight Hg concentration in the fish, in milligrams per kilogram and,

C_w is the MeHg concentration in filtered water, in milligrams per liter, or the MeHg concentration in bed sediment, in milligrams per kilogram.

Although fish-Hg concentrations on a wet-weight (ww) basis were used for computing water BAFs (Watras and Bloom, 1992), fish-Hg concentrations on a dry-weight (dw) basis were used for sediment BAFs because only dry-weight-based bed sediment values were available. Higher BAFs indicate greater differences between Hg concentrations in fish with respect to Hg concentrations in water or bed sediment.

Concentrations of Hg in each composite sample of fish were normalized by the mean fish length for that sample (units are micrograms per gram per meter), and these length-normalized Hg concentrations for fish were used in comparisons to environmental characteristics. This was done to minimize the effect of age and growth rate on evaluations of any relations to environmental characteristics. Previous studies have shown that Hg concentrations in fish tend to increase with fish age, and length is commonly used as a surrogate for age in normalizing Hg concentrations.

Concentrations of THg and MeHg in unfiltered water were used for analysis of Hg in streams. For those sites with filtered and particulate THg and MeHg data but no unfiltered data, unfiltered THg and MeHg concentrations were computed by summing filtered and particulate fractions. Suspended particulate concentrations were expressed on a mass basis (nanograms of Hg per gram of particulate material) by dividing particulate Hg concentrations by suspended-sediment concentrations (DeWild and others, 2004).

Parametric statistical tests were used, where possible, after transforming data to meet assumptions of normal distributions; nonparametric tests were used when normalization was not possible. Mann-Whitney U tests were used to assess differences in Hg concentrations between sites grouped as mined basins compared to unmined basins. Because of concerns with unequal sample sizes among groups and non-normality of residuals, one-way ANOVA tests on ranked data were used to compare Hg concentrations among LULC groups for selected media. Principal Components Analysis (PCA) and Spearman rank correlation (r_s, Spearman correlation coefficient) were used to select the subset of variables for stepwise multiple-linear regression and Redundancy Analysis (RDA); less responsive metrics were eliminated. PCA and RDA were done in CANOCO Version 4.5 with centering and standardization of previously transformed variables (ter Braak, 2002). RDA is a constrained form of multiple regression and was used with forward selection as an alternative exploratory tool to evaluate which suite of environmental characteristics best explained the variation of Hg concentrations in fish, bed sediment, and water. The reduced-model RDA was used with Monte Carlo testing. Data Desk version 6.1 (Data Description, Inc., 1996) and S-Plus version 7.0 (Insightful Corporation, 1998–2005) were used for Spearman correlations, Mann-Whitney U tests, ANOVA tests, and stepwise multiple-linear regression. All statistical tests were considered significant at a probability level of 0.05 unless otherwise stated.

Quality Control

The quality (bias and variability) of Hg data for fish was evaluated by using laboratory blank and replicate samples, spike recoveries, and reference materials; quality-assurance results are presented in Bauch and others (2009). Each type of quality-control sample was not available for all laboratories. Results indicated low bias and good reproducibility in Hg data for fish samples analyzed at the CERC, TERL, and University of Wisconsin-La Crosse. Results for fish samples analyzed at the NWQL in 2002 indicated possible low bias and moderate variability in fish-Hg concentrations, and this may have reduced the strength of some relations between fish Hg and environmental characteristics. The quality of bed-sediment and water THg and MeHg data was investigated through blank and replicate samples collected in the field (Bauch and others, 2009). Unfiltered, filtered, and particulate THg and MeHg generally were either not detected in most blank samples or were detected at concentrations that would not affect data analysis. However, overlap of some high particulate THg concentrations in blanks with low concentrations in environmental samples may indicate a small positive bias of particulate THg for some environmental data. Variability in THg and MeHg determined from field-replicate samples depended on the type of sample—unfiltered or filtered water, particulate, or bed sediment—and concentrations being analyzed; however, there was no effect on data analysis.

Spatial Distribution of Mercury in Fish, Bed Sediment, and Stream Water

The spatial distributions of Hg in fish, bed sediment, and water were assessed by use of maps and exceedance frequency distributions. The majority of sites were in the eastern half of the United States, and most but not all sites in mined basins were in the western half of the United States (west of the Mississippi River; fig. 3).

Fish

No one fish species could be used across the United States for comparative assessment of fish Hg accumulation. Fish were collected at 291 sites, and 34 fish species made up the total set of samples (table 2). The most commonly collected fish were largemouth bass (*Micropterus salmoides*; 62 sites), smallmouth bass (*Micropterus dolomieu*; 60 sites), brown trout (*Salmo trutta*; 22 sites), pumpkinseed (*Lepomis gibbosus*; 18 sites), rock bass (*Ambloplites rupestris*; 17 sites), spotted bass (*Micropterus punctulatus*; 14 sites), rainbow trout (*Oncorhynchus mykiss; 14 sites)*, cutthroat trout (*Oncorhynchus clarkii*; 12 sites), and channel catfish (*Ictalurus punctatus*; 12 sites) (fig. 4). Hg comparisons across species should be viewed with caution as different species accumulate Hg at different rates, and concentrations generally increase with increasing age or length of the fish.

Hg was detected (> 0.01 µg/g THg ww) in all fish collected and ranged from 0.014 to 1.95 µg/g ww; the median value was 0.169 µg/g ww (table 3A). The highest fish-Hg concentrations among all sampled sites generally were for fish collected from forest- or wetland-dominated coastal-plain streams in the eastern and southeastern United States and from streams that drain gold- or Hg-mined basins in the western United States (fig. 5). The highest value (1.95 µg/g ww) was from a composite sample of smallmouth bass from the Carson River at Dayton, Nev., a site in a basin with known Hg contamination from historical gold mining. The next highest value (1.80 µg/g ww) was from a composite of largemouth bass from an unmined basin—the North Fork Edisto River near Fairview Crossroads, S.C. Largemouth, smallmouth, and spotted bass had the highest mean and median concentrations, whereas brown trout, rainbow-cutthroat trout, and channel catfish had the lowest. Concentrations of Hg in trout were generally low compared to those in all other sampled fish, and the median value was less than 0.1 µg/g ww (table 3A). Fish-Hg concentrations were less than about 0.33 µg/g ww at 75 percent of sites and less than about 0.60 µg/g ww at 90 percent of sites (fig. 6).

Table 2. Summary of fish species sampled for mercury in U.S. streams, 1998–2005.

[**Abbreviations:** n, number of sites where fish species was collected; game-fish species shown in **bold**]

Family	Common name	Latin name	n
Bowfins	Bowfin	*Amia calva*	1
Catfishes	**White catfish**	*Ameiurus catus*	1
	Yellow bullhead	*Ameiurus natalis*	1
	Brown bullhead	*Ameiurus nebulosus*	2
	Blue catfish	*Ictalurus furcatus*	1
	Channel catfish	*Ictalurus punctatus*	12
	Flathead catfish	*Pylodictis olivaris*	2
Cichlids	**Blackchin tilapia**	*Sarotherodon melanotheron*	1
Minnows	**Common Carp**	*Cyprinus carpio*	1
	Creek chub	*Semotilus atromaculatus*	1
Perches	**Sauger**	*Sander canadensis*	1
	Walleye	*Sander vitreus*	2
Pikes	**Chain pickerel**	*Esox niger*	6
Sculpins	Slimy sculpin	*Cottus cognatus*	2
Suckers	White sucker	*Catostomus commersonii*	1
Sunfishes	**Roanoke bass**	*Ambloplites cavifrons*	1
	Rock bass	*Ambloplites rupestris*	17
	Redbreast sunfish	*Lepomis auritus*	8
	Green sunfish	*Lepomis cyanellus*	8
	Green × Longear Sunfish (hybrid)	*Lepomis cyanellus x L. megalotis*	1
	Pumpkinseed	*Lepomis gibbosus*	18
	Bluegill	*Lepomis macrochirus*	8
	Longear sunfish	*Lepomis megalotis*	1
	Shoal bass	*Micropterus cataractae*	2
	Red-eyed bass	*Micropterus coosae*	1
	Smallmouth bass	*Micropterus dolomieu*	60
	Spotted bass	*Micropterus punctulatus*	14
	Largemouth bass	*Micropterus salmoides*	62
	Black crappie	*Pomoxis nigromaculatus*	2
Trout	**Cutthroat trout**	*Oncorhynchus clarkii*	12
	Rainbow trout	*Oncorhynchus mykiss*	14
	Mountain whitefish	*Prosopium williamsoni*	3
	Brown trout	*Salmo trutta*	22
	Dolly Varden	*Salvelinus malma*	2
Total number of fish sampling sites			**291**

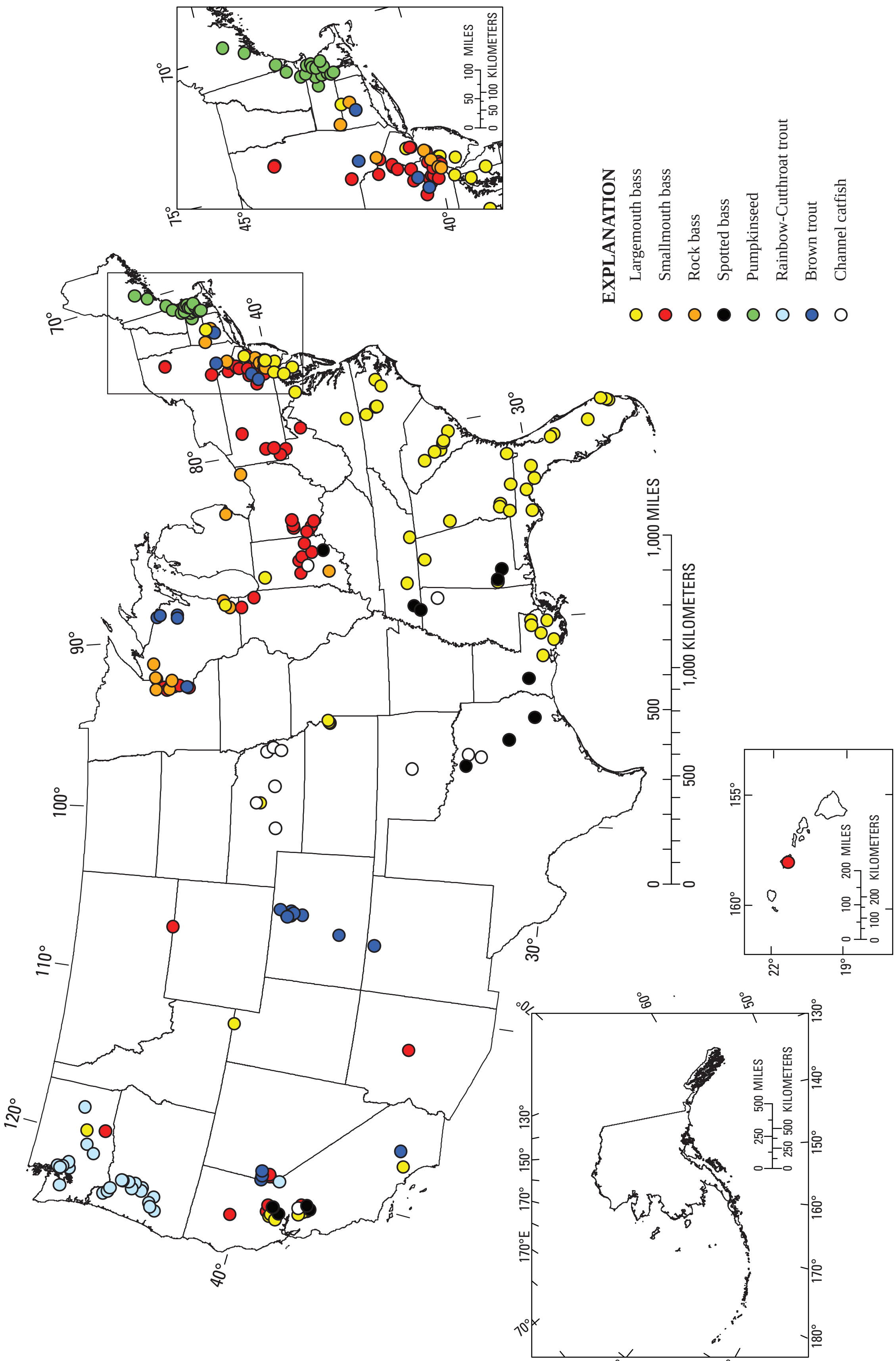

Figure 4. Spatial distribution of the fish species most commonly sampled for mercury, 1998–2005.

Table 3A. Summary statistics for mercury in U.S. streams, 1998–2005: Total mercury in fish.

[THg concentrations are in micrograms per gram on a wet-weight basis; fish length in centimeters. **Abbreviations:** n, number of samples (with number of samples from mined basins in parentheses for family and species level); Std Dev, standard deviation; –, not computed]

Parameter	Site grouping	Mercury concentration					Fish length		n
		Mean	Median	Std Dev	Minimum	Maximum	Mean	Range	
All fish	All sites	0.261	0.169	0.278	0.014	1.95	–	–	291
	Sites in unmined basins	0.238	0.165	0.241	0.014	1.80	–	–	232
	Sites in mined basins	0.351	0.235	0.379	0.020	1.95	–	–	59
All fish, by family									
Sunfish family	All sites	0.304	0.213	0.289	0.020	1.95	–	–	203 (33)
Trout family	All sites	0.109	0.089	0.115	0.014	0.588	–	–	53 (20)
Catfish family	All sites	0.200	0.097	0.351	0.036	1.58	–	–	19 (3)
Pike family	All sites	0.344	0.288	0.251	0.060	0.769	–	–	6 (0)
Perch family	All sites	0.517	0.635	0.232	0.250	0.666	–	–	3 (3)
Other	All sites	0.078	0.060	0.051	0.030	0.175	–	–	7 (0)
Species most commonly sampled									
Largemouth bass	All sites	0.460	0.333	0.346	0.081	1.80	29.7	15.8 - 47.0	62 (10)
Smallmouth bass	All sites	0.245	0.204	0.257	0.020	1.95	26.2	12.6 - 41.5	60 (9)
Rock bass	All sites	0.175	0.139	0.118	0.039	0.506	16.0	8.96 - 20.8	17 (0)
Spotted bass	All sites	0.485	0.420	0.228	0.148	0.943	28.8	17.2 - 37.0	14 (5)
Pumpkinseed	All sites	0.139	0.111	0.095	0.042	0.379	10.6	6.66 - 13.7	18 (2)
Rainbow-cutthroat trout	All sites	0.110	0.070	0.137	0.014	0.588	20.7	13.2 - 28.1	26 (7)
Brown trout	All sites	0.113	0.091	0.098	0.014	0.457	28.0	19.4 - 51.3	22 (9)
Channel catfish	All sites	0.084	0.080	0.029	0.036	0.131	33.3	16.0 - 47.7	12 (2)

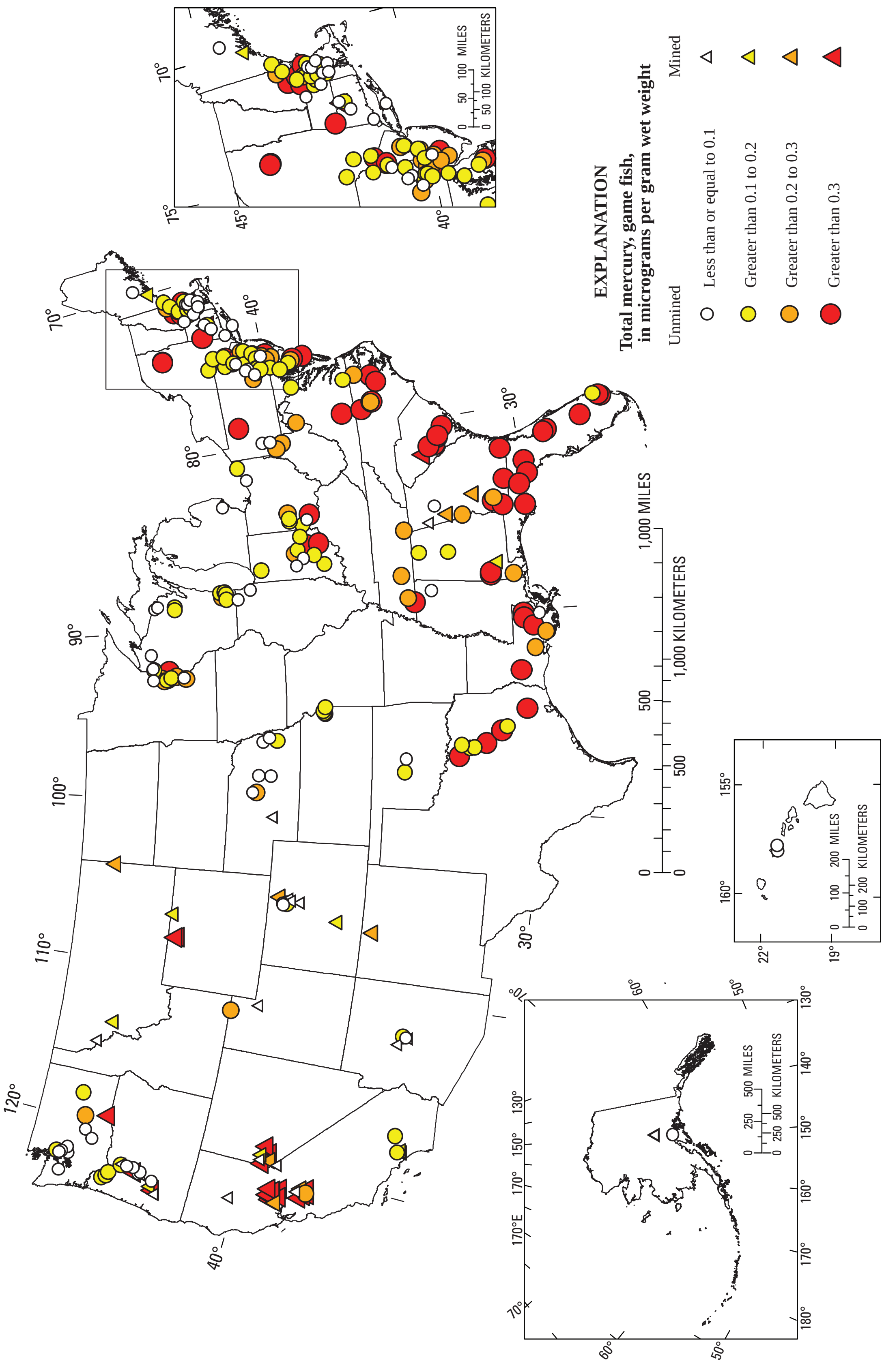

Figure 5. Spatial distribution of total mercury concentrations in game fish, 1998–2005.

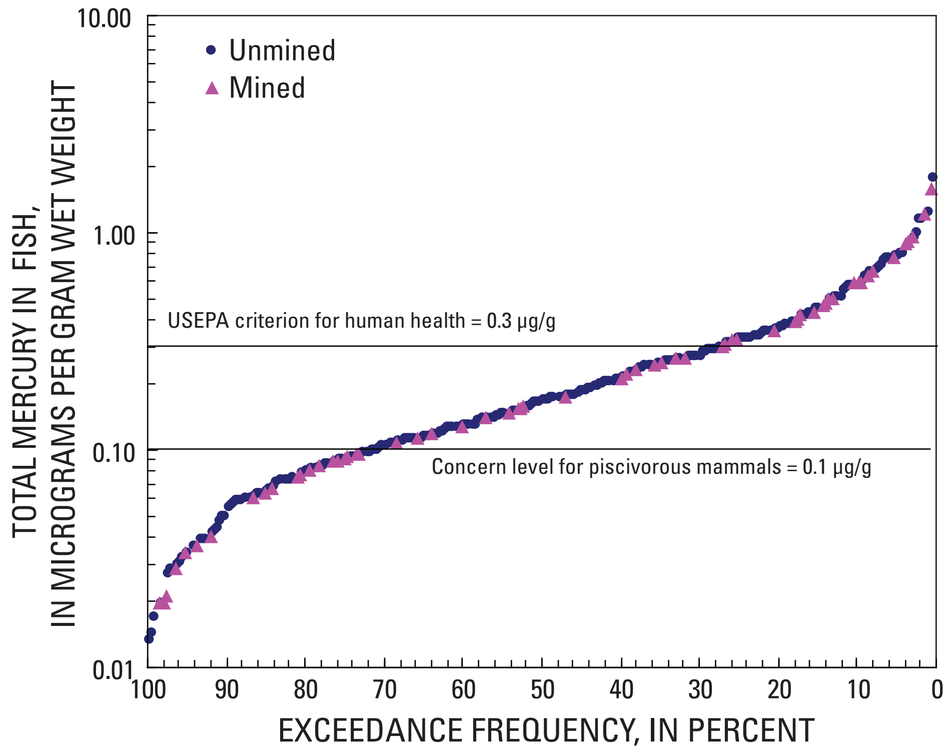

Figure 6. Frequency distribution of total mercury concentrations in fish, 1998–2005, showing the percentage of samples that equalled or exceeded benchmark or guideline concentrations. [USEPA methylmercury criterion for human health (U.S. Environmental Protection Agency, 2001) = 0.3 µg/g wet weight; concern level for piscivorous mammals (Yeardley and others, 1998) = 0.1 µg/g wet weight.]

Distributions of length-normalized THg concentrations for the top four fish species collected (largemouth bass, smallmouth bass, rainbow-cutthroat trout, and brown trout) are each shown separately on U.S. maps in figures 7 through 10. Largemouth bass were collected across the broadest area of all fish species but were mostly in eastern and southern U.S. streams (fig. 7). The highest length-normalized THg concentrations in largemouth bass were found in coastal streams in unmined basins of Louisiana, Georgia, Florida, and North and South Carolina; one stream in a mined basin from California was in this group of highest fish THg, but concentrations at this site were lower than at most of the coastal unmined sites in the group. In contrast, smallmouth bass were not collected in the southern part of the United States but instead were commonly collected in the upper Midwest and northeastern United States (fig. 8); the highest length-normalized THg concentrations were at western sites in mined basins, but also from the Hudson River in New York. Rainbow and cutthroat trout were collected only in western States and were the primary target top-predator fish for sites in Oregon and Washington (fig. 9). Because of their similar habitats, feeding habits, and ability to hybridize where their ranges overlap, these two species were combined for purposes of data analysis. The highest length-normalized THg values in rainbow-cutthroat trout were found at stream sites in mined, urban, and geothermally affected basins in tributaries to the Willamette Basin in western Oregon, and in North Creek near Bothell, Wash., an urban site on a tributary to Puget Sound. Brown trout were collected in isolated areas across the United States, and the highest length-normalized THg concentrations for this fish species were at several sites in mined basins of Colorado and Nevada and in three unmined, undeveloped basins of southern California, Colorado, and New York (fig. 10).

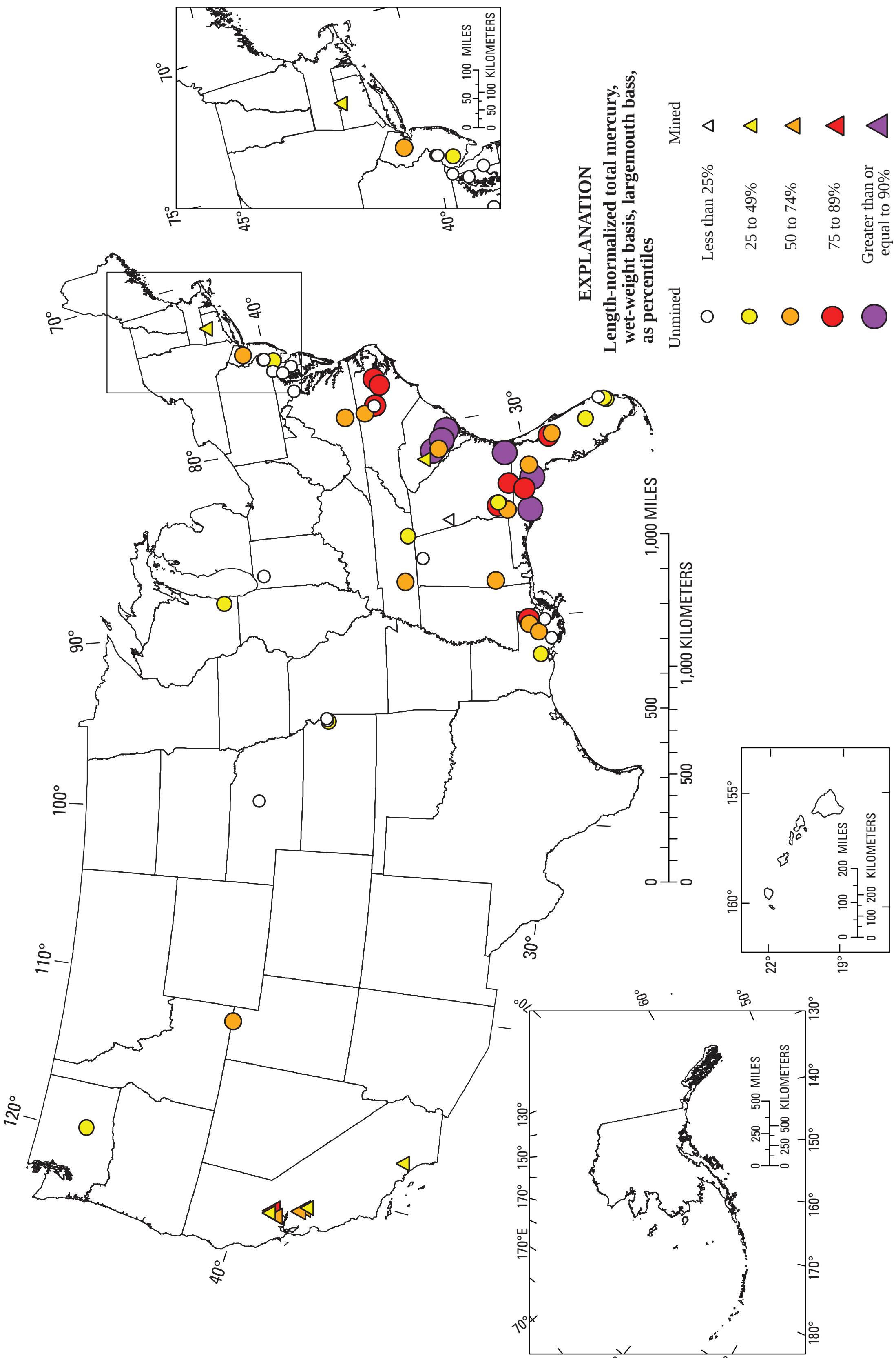

Figure 7. Spatial distribution of length-normalized total mercury concentrations in largemouth bass, 1998–2005.

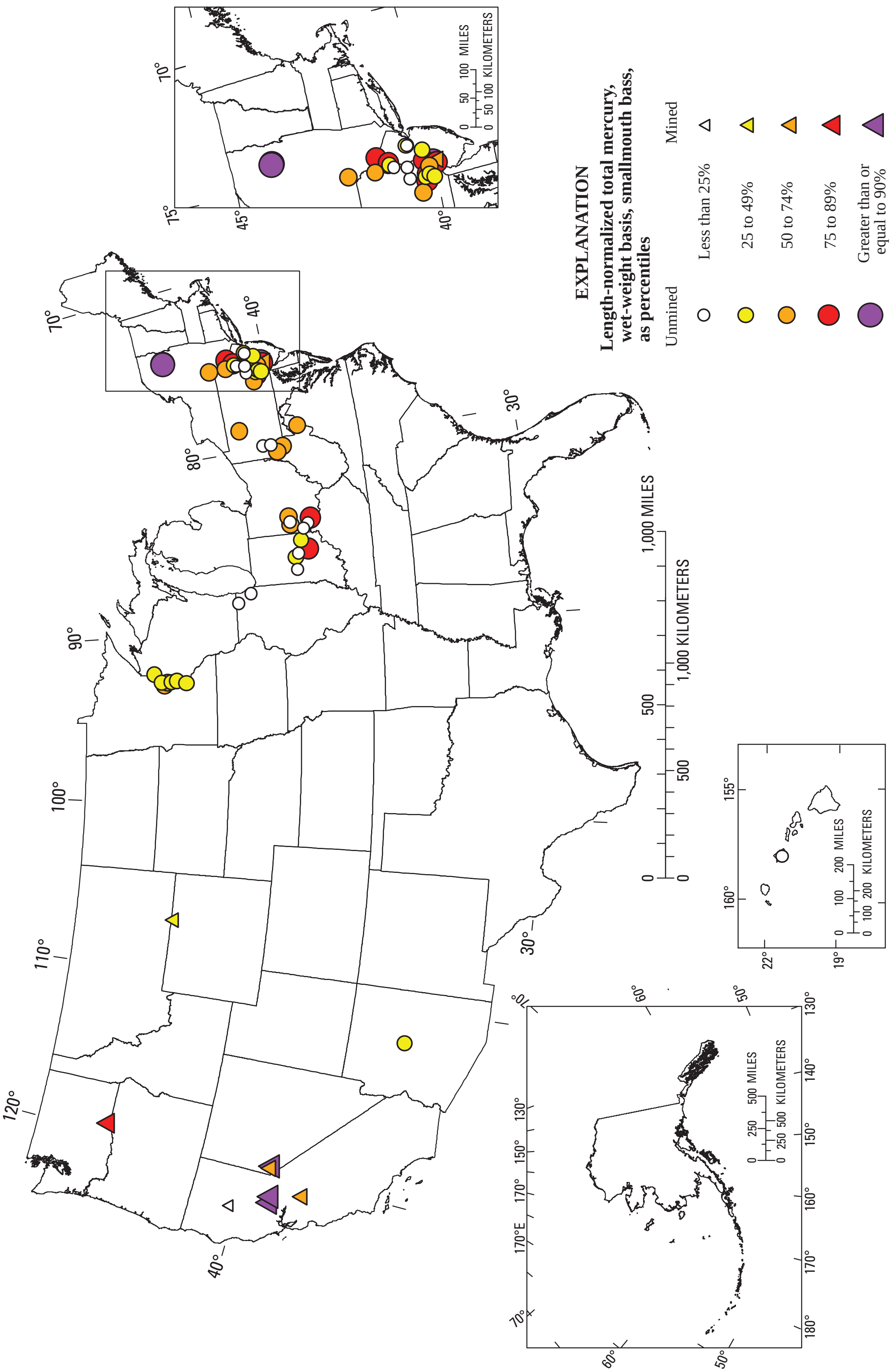

Figure 8. Spatial distribution of length-normalized total mercury concentrations in smallmouth bass, 1998–2005.

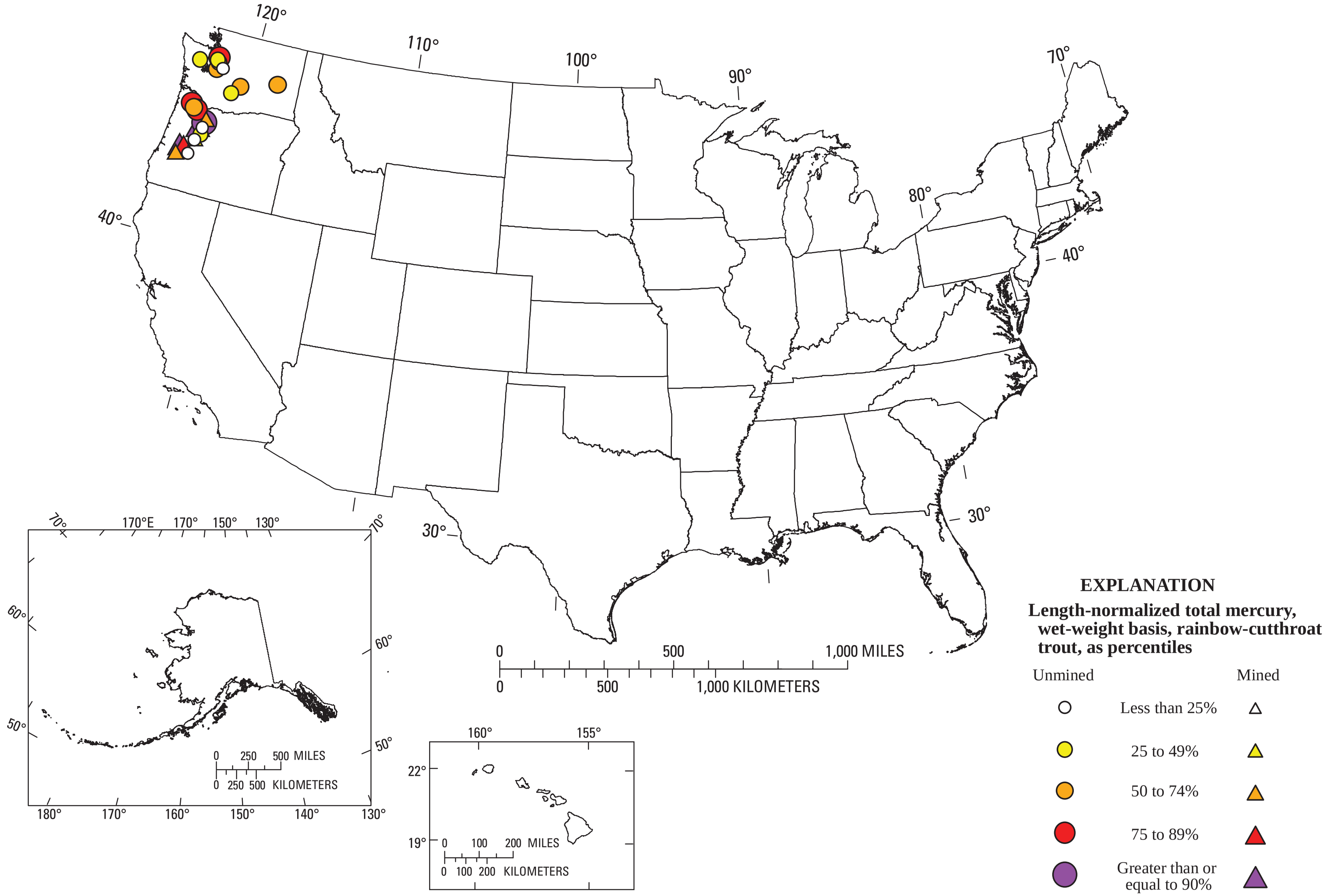

Figure 9. Spatial distribution of length-normalized total mercury concentrations in rainbow-cutthroat trout, 1998–2005.

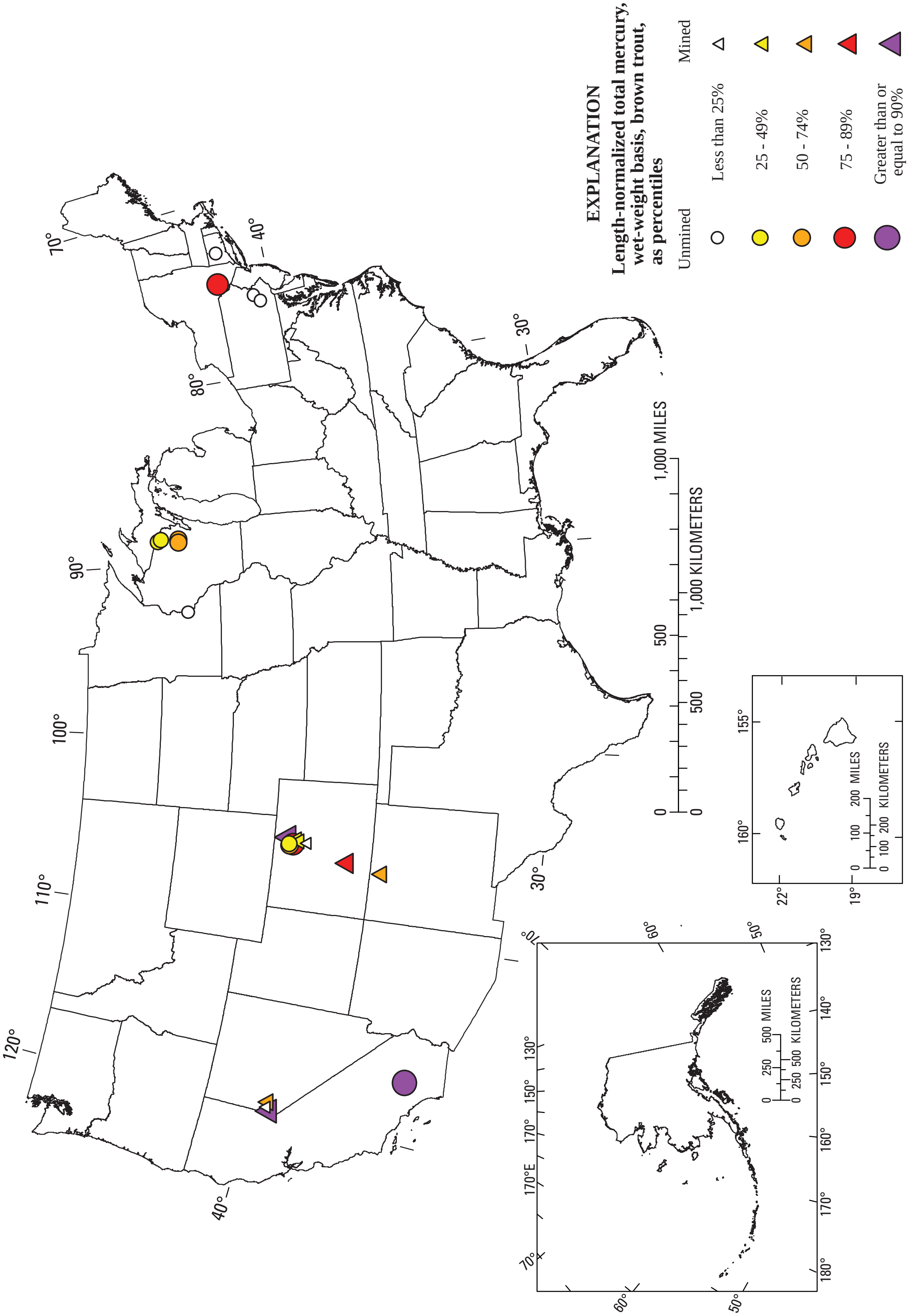

Figure 10. Spatial distribution for percentiles of length-normalized total mercury concentrations in brown trout, 1998–2005.

Bed Sediment

With the exception of sites in mined basins, many high THg concentrations in bed sediment were in the northeast; however, values in the top quartile of THg concentrations were scattered across the United States (fig. 11). Concentrations of THg in bed sediment (dry-weight basis) ranged from 0.84 to 4,520 ng/g (table 3B). Concentrations were less than about 80 ng/g THg at 75 percent of sites and less than about 250 ng/g at 90 percent of sites (fig. 12A).

Concentrations of MeHg in bed sediment ranged from 0.01 to 15.6 ng/g (table 3B). The highest MeHg values were from a group of New England coastal streams, including sites in mined as well as unmined basins (fig. 13). Some of these New England streams, such as the Sudbury River in Massachusetts, are unmined but known to have historical industrial contamination of Hg in the basin (Massachusetts Department of Environmental Protection, 1995; Flannagan and others, 1999; Waldron and others, 2000; Wiener and Shields, 2000; Chalmers, 2002). About 75 percent of all MeHg values were less than 2 ng/g, and 90 percent of concentrations were less than about 5 ng/g (fig.12B).

Table 3B. Summary statistics for mercury in U.S. streams, 1998–2005: Total and methylmercury and ancillary chemical characteristics of bed sediment.

[Mercury concentrations are on a dry-weight basis. **Abbreviations:** ng/g, nanograms per gram; µg/g, micrograms per gram; n, number of samples]

Parameter	Site grouping	Mean	Median	Std Dev	Minimum	Maximum	n	Units	Comparison
Methylmercury	All sites	1.65	0.510	2.54	0.01	15.6	344	ng/g	No significant difference
	Sites in unmined basins	1.73	0.510	2.62	0.01	15.6	257		
	Sites in mined basins	1.41	0.516	2.28	0.04	14.6	87		
Total mercury	All sites	110	31.8	343	0.84	4,520	345	ng/g	Mined > Unmined ($p<0.01$)
	Sites in unmined basins	88.7	30.3	243	0.90	2,480	259		
	Sites in mined basins	175	48.5	539	0.84	4,520	86		
Methyl/Total mercury	All sites	3.24	1.60	4.68	0.020	41.0	337	Percent	Unmined > Mined ($p<0.05$)
	Sites in unmined basins	3.26	1.72	4.58	0.020	41.0	253		
	Sites in mined basins	3.18	1.27	5.01	0.024	24.8	84		
Loss-on-ignition (LOI)	All sites	7.38	4.26	8.14	0.11	43.5	327	Percent	No significant difference
	Sites in unmined basins	8.12	4.50	8.78	0.11	43.5	254		
	Sites in mined basins	4.78	3.51	4.52	0.50	27.7	73		
Methylmercury/LOI	All sites	0.227	0.137	0.300	0.0040	2.56	325	(ng/g)/ percent	Mined > Unmined ($p<0.001$)
	Sites in unmined basins	0.195	0.125	0.255	0.0040	2.56	252		
	Sites in mined basins	0.338	0.201	0.402	0.0116	1.83	73		
Total mercury/LOI	All sites	25.3	6.61	129	0.15	1,940	325	(ng/g)/ percent	Mined > Unmined ($p<0.0001$)
	Sites in unmined basins	10.1	5.91	14.5	0.15	122	253		
	Sites in mined basins	78.6	10.5	267	<0.58	1,940	72		
Acid-volatile sulfide	All sites	84.9	5.34	235	<0.01	2,630	252	µg/g	No significant difference
	Sites in unmined basins	89.9	5.03	258	<0.01	2,630	187		
	Sites in mined basins	70.4	6.58	149	0.01	690	65		

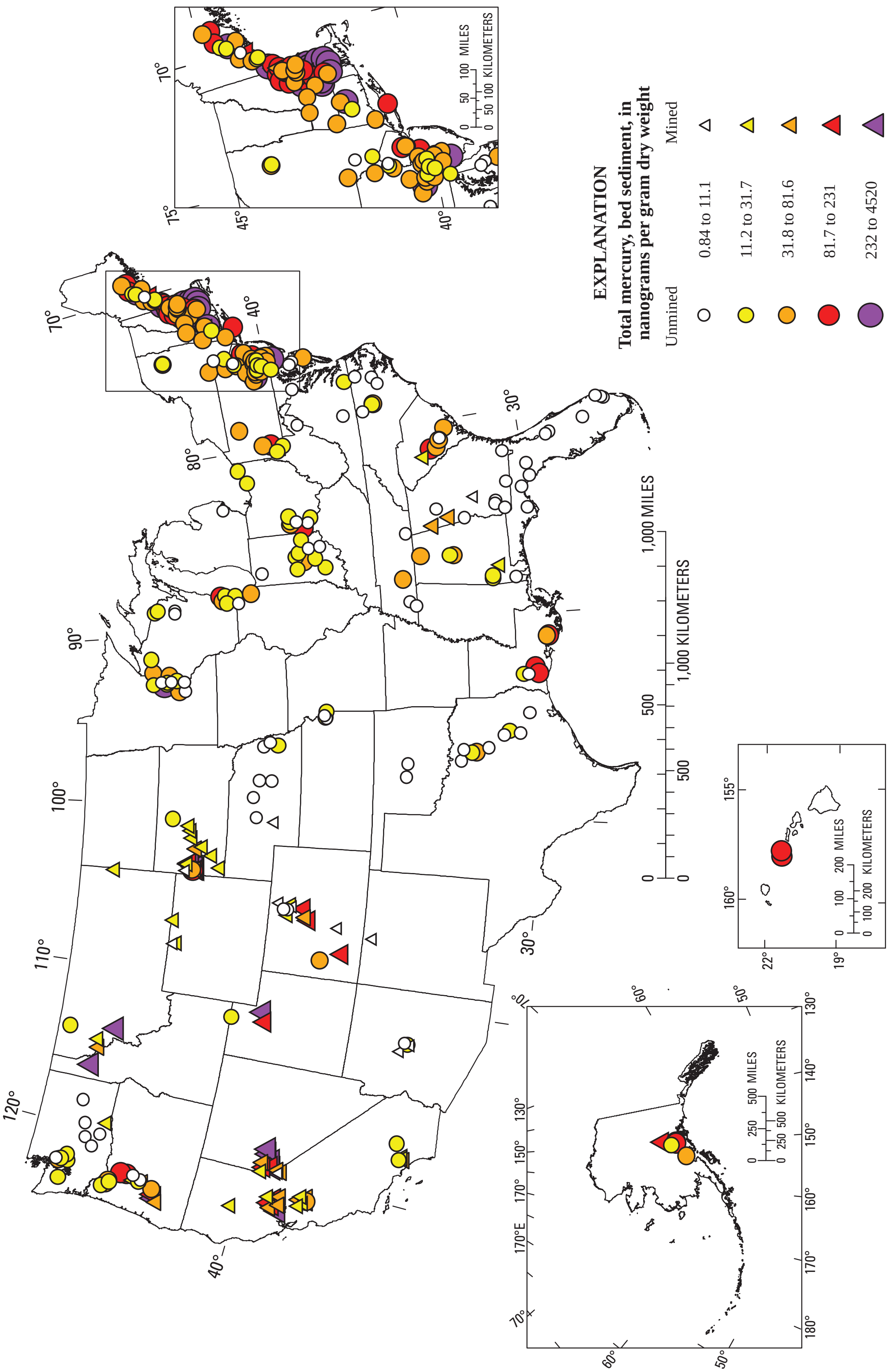

Figure 11. Spatial distribution of total mercury concentrations in bed sediment, 1998–2005. [Percentiles shown: 0 to 24 (white), 25 to 49 (yellow), 50 to 74 (orange), 75 to 89 (red), and greater than or equal to 90 (purple).]

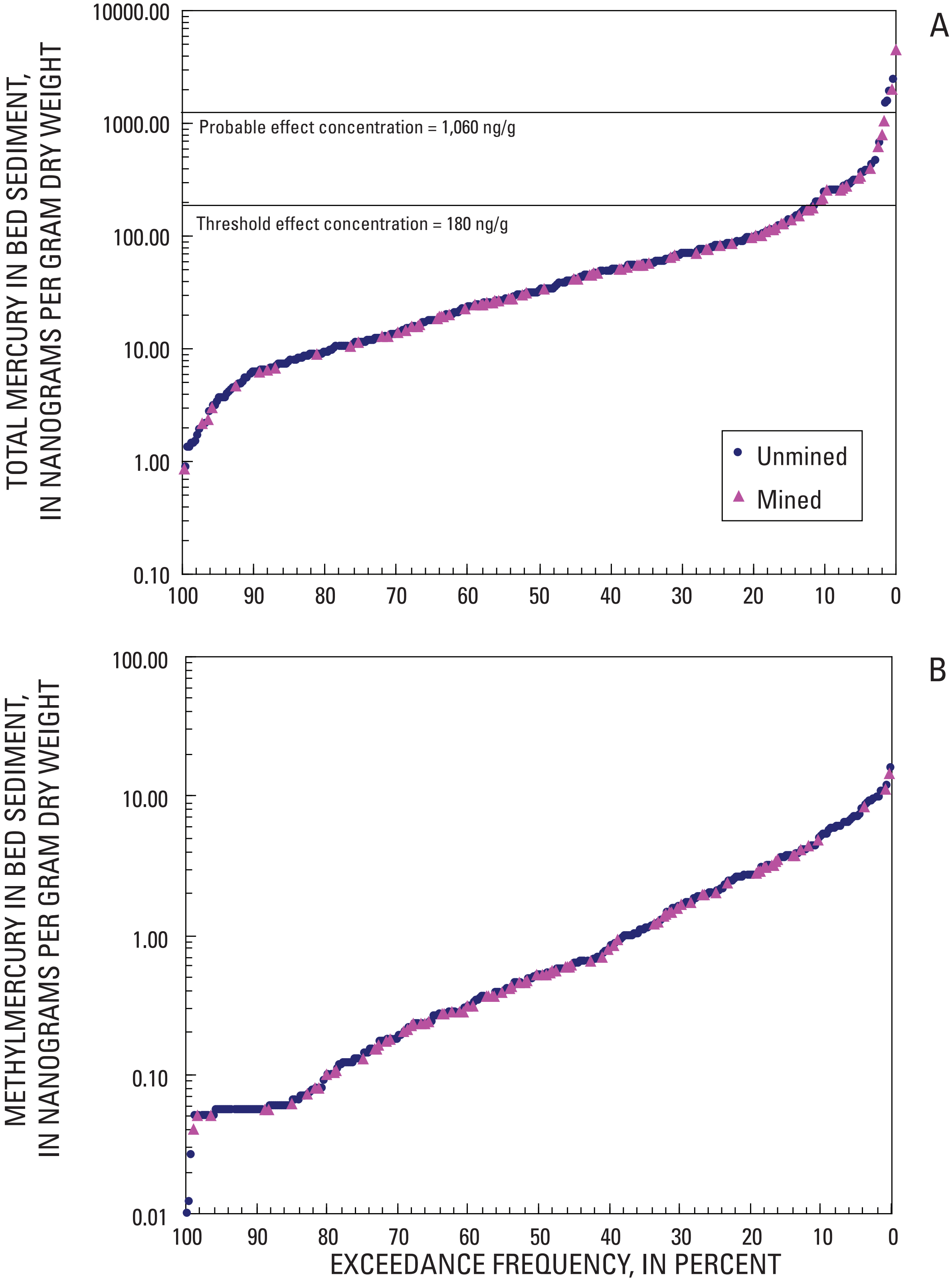

Figure 12. Frequency distribution of mercury concentrations in bed sediment, 1998–2005, showing the percentage of samples that equalled or exceeded benchmark or guideline concentrations; A, Total mercury; B, Methylmercury. [Probable Effect Concentration, consensus-based (MacDonald and others, 2000) = 1,060 ng/g, dry weight; Threshold Effect Concentration, consensus-based (MacDonald and others, 2000) = 180 ng/g dry weight.]

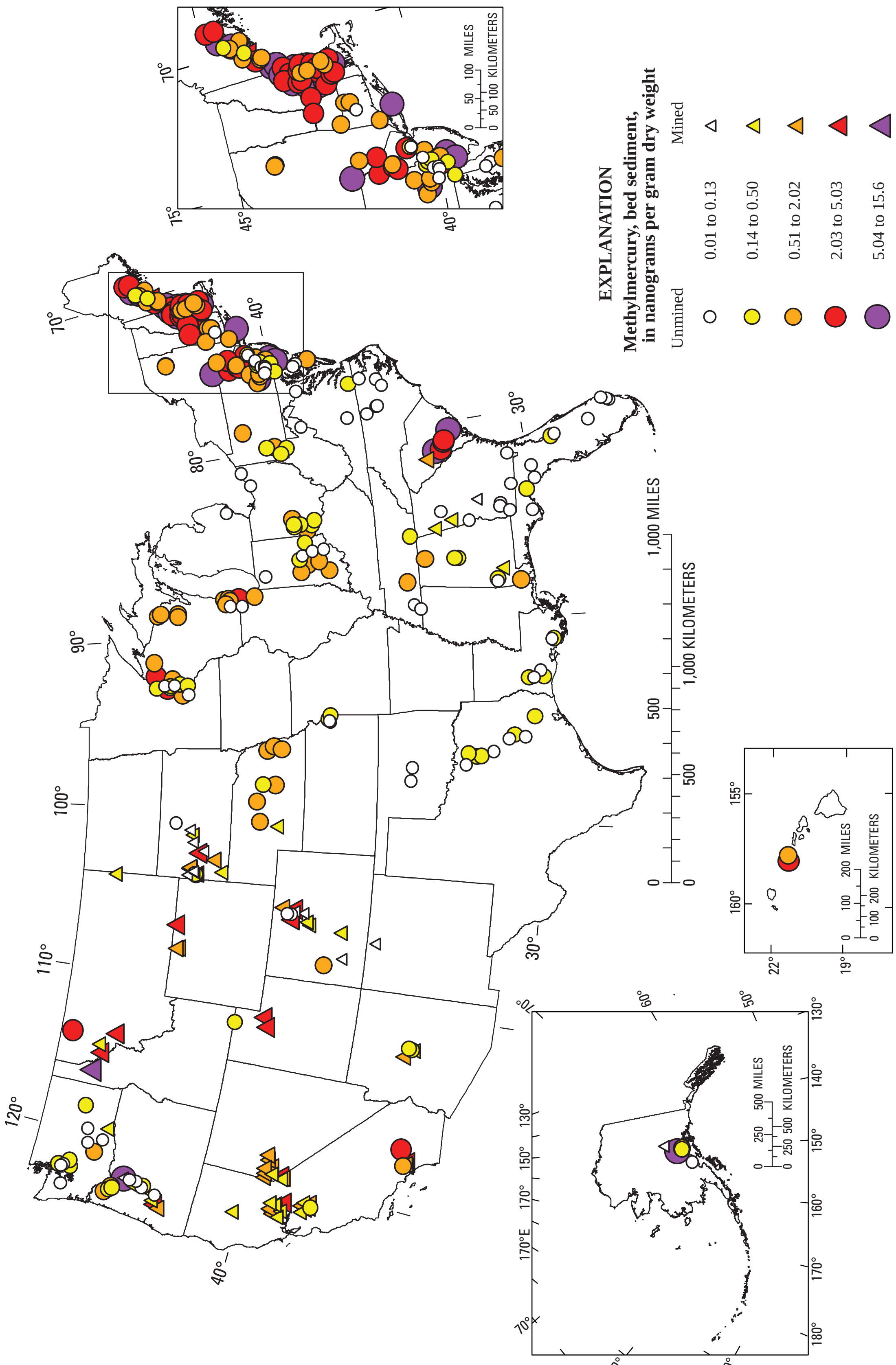

Figure 13. Spatial distribution of methylmercury concentrations in bed sediment, 1998–2005. [Percentiles shown: 0 to 24 (white), 25 to 49 (yellow), 50 to 74 (orange), 75 to 89 (red), and greater than or equal to 90 (purple).]

Stream Water

There was wide variation in concentrations of THg in unfiltered water across the United States, as one might expect for a dataset that included sites that were relatively pristine to sites in gold- or Hg-mined basins (table 3C; fig. 14). Concentrations of unfiltered THg ranged from 0.27 to 446 ng/L, and the median value was 2.09 ng/L. THg concentrations were less than about 4 ng/L at 75 percent of sites and less than about 9 ng/L at 90 percent of sites (fig. 15A).

Concentrations of MeHg in unfiltered water were somewhat less variable than for THg across sites (fig. 16). Values ranged from less than 0.01 to 4.11 ng/L, and the median MeHg concentration was 0.11 (table 3C). MeHg concentrations were less than about 0.2 ng/L at 75 percent of the sites and less than about 0.4 ng/L at 90 percent of sites (fig. 15B). Moreover, MeHg concentrations at 97 percent of the sites were less than 0.8 ng/L, which is consistent with findings of Krabbenhoft and others (2007), who reviewed the literature and found that most surface waters had MeHg concentrations in the range of approximately 0.04 to 0.8 ng/L (St. Louis and others, 1994; Hurley and others, 1995; Babiarz and others, 1998; Bodaly and others, 1998; Gilmour and others, 1998; Krabbenhoft and others, 1999).

Table 3C. Summary statistics for mercury in U.S. streams, 1998–2005: Total and methylmercury and ancillary water quality characteristics of unfiltered stream water.

[Values equal to 1/2 minimum reporting limits were substituted for censored values in computations. **Abbreviations:** DOC, dissolved organic carbon; UV, ultraviolet absorbance at 254 nm; SUVA, specific UV absorbance at 254 nm; nm, nanometers; (L/mg C)/m, liters per milligram carbon per meter; ng/L, nanograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; n, number of samples]

Parameter	Site grouping	Mean	Median	Std Dev	Min	Max	n	Units	Comparison
Methylmercury	All sites	0.19	0.11	0.35	<0.010	4.11	337	ng/L	No significant difference
	Sites in unmined basins	0.20	0.11	0.37	<0.010	4.11	257		
	Sites in mined basins	0.18	0.10	0.31	<0.010	2.02	80		
Total mercury	All sites	8.22	2.09	32.8	0.27	446	336	ng/L	Mined > Unmined (p<0.0001)
	Sites in unmined basins	2.96	1.90	5.29	0.27	75.1	250		
	Sites in mined basins	23.5	3.79	62.1	0.48	446	86		
Methyl/Total mercury	All sites	7.08	4.60	8.18	0.02	81.5	328	Percent	Unmined > Mined (p<0.0001)
	Sites in unmined basins	7.46	5.35	6.72	0.19	46.8	249		
	Sites in mined basins	5.87	2.37	11.6	0.02	81.5	79		
Specific conductance	All sites	389	247	493	15.6	6,080	349	µS/cm	Mined > Unmined (p<0.001)
	Sites in unmined basins	349	246	467	15.6	6,080	263		
	Sites in mined basins	513	252	551	34.1	2,350	86		
pH	All sites	7.48	7.50	0.73	3.30	10.1	352	Standard units	Mined > Unmined (p<0.01)
	Sites in unmined basins	7.38	7.42	0.72	5.50	10.1	264		
	Sites in mined basins	7.78	7.90	0.70	3.30	9.00	88		
Suspended sediment	All sites	75.4	7.00	501	0	6,170	177	mg/L	No significant difference
	Sites in unmined basins	26.3	7.00	53.1	0	391	130		
	Sites in mined basins	212	8.00	966	1	6,170	47		
DOC	All sites	5.09	3.80	6.49	0.34	76.9	349	mg/L	Unmined > Mined (p<0.0001)
	Sites in unmined basins	5.82	4.38	7.29	0.34	76.9	261		
	Sites in mined basins	2.90	2.61	1.77	0.40	11.6	88		
UV	All sites	0.15	0.11	0.17	0.003	1.2	138	Dimensionless	Unmined > Mined (p<0.001)
	Sites in unmined basins	0.18	0.13	0.18	0.005	1.2	107		
	Sites in mined basins	0.08	0.07	0.05	0.003	0.3	31		
SUVA	All sites	2.92	2.80	1.43	0.30	15.5	138	(L/mg C)/m	No significant difference
	Sites in unmined basins	2.92	2.90	0.91	0.60	5.7	107		
	Sites in mined basins	2.92	2.60	2.52	0.30	15.5	31		
Sulfate	All sites	45.9	10.9	123	0.09	954	343	mg/L	Mined > Unmined (p<0.01)
	Sites in unmined basins	28.3	9.95	73.7	0.09	954	263		
	Sites in mined basins	104	16.1	208	0.47	860	80		

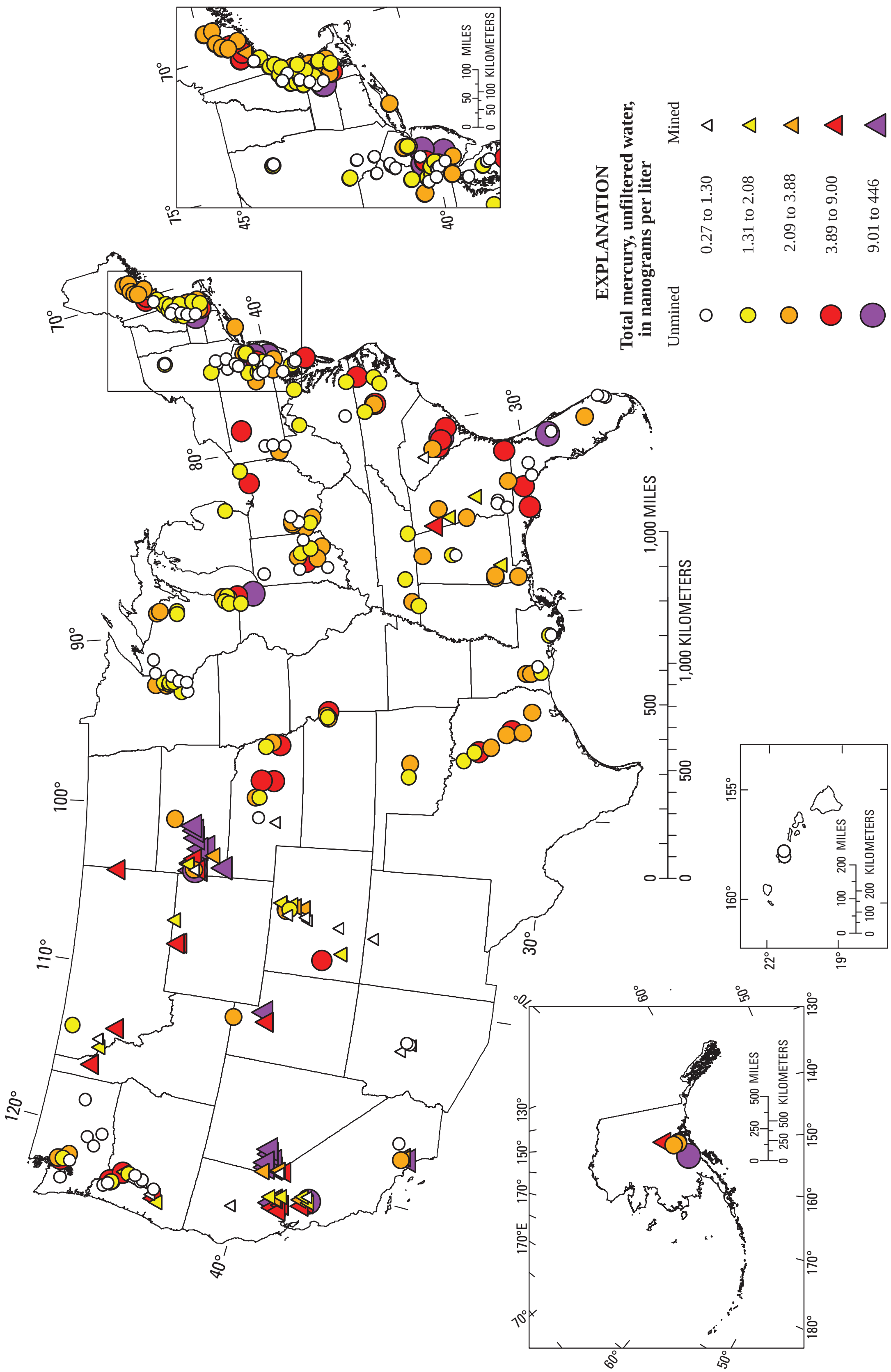

Figure 14. Spatial distribution of total mercury concentrations in unfiltered stream water, 1998–2005. [Percentiles shown: 0 to 24 (white), 25 to 49 (yellow), 50 to 74 (orange), 75 to 89 (red), and greater than or equal to 90 (purple).]

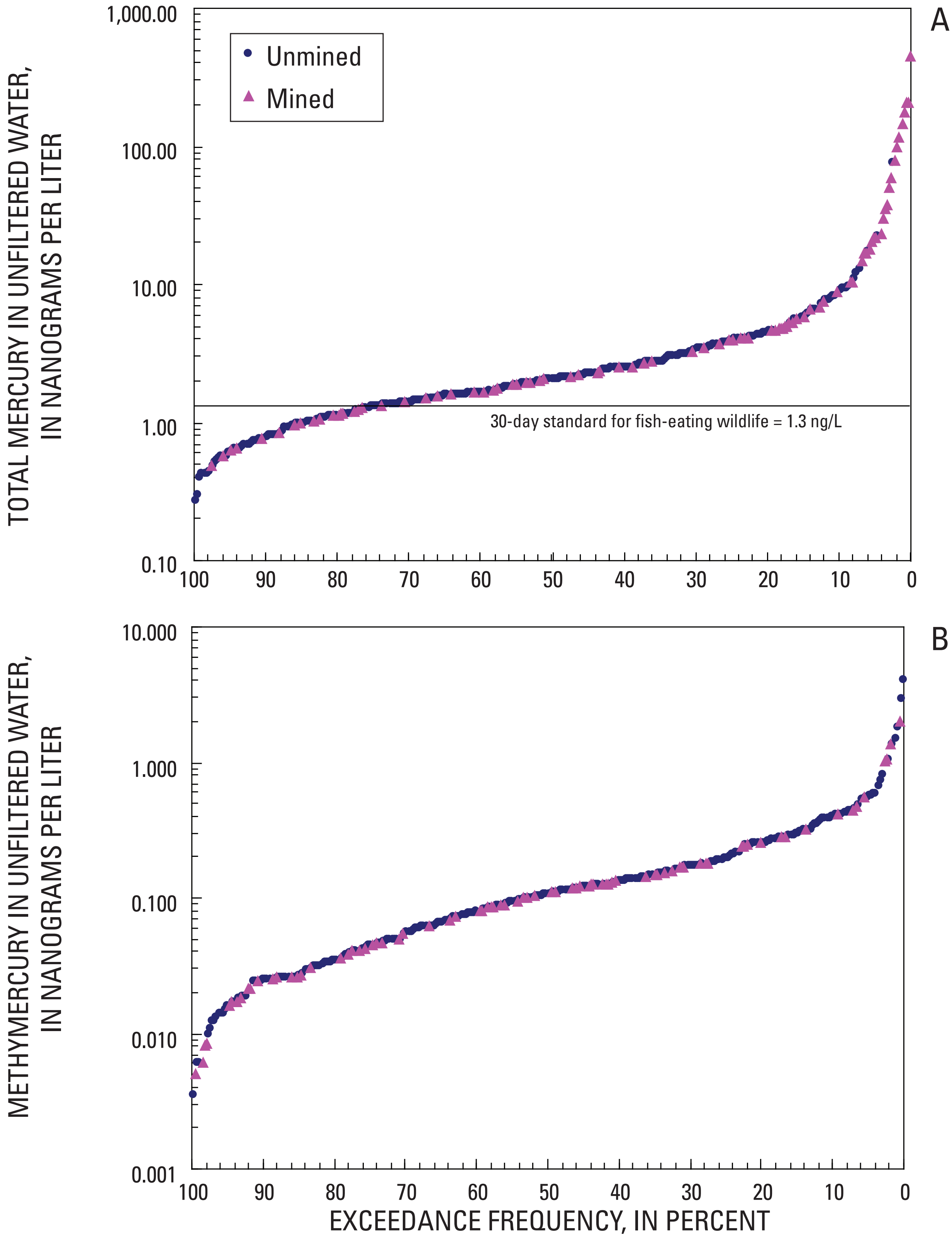

Figure 15. Frequency distribution of mercury concentrations in unfiltered water, 1998–2005, showing the percentage of samples that equalled or exceeded benchmark or guideline concentrations; A, Total mercury; B, Methylmercury. [Great Lakes States 30-day standard for fish-eating wildlife (U.S. Environmental Protection Agency,1997) = 1.3 ng/L.]

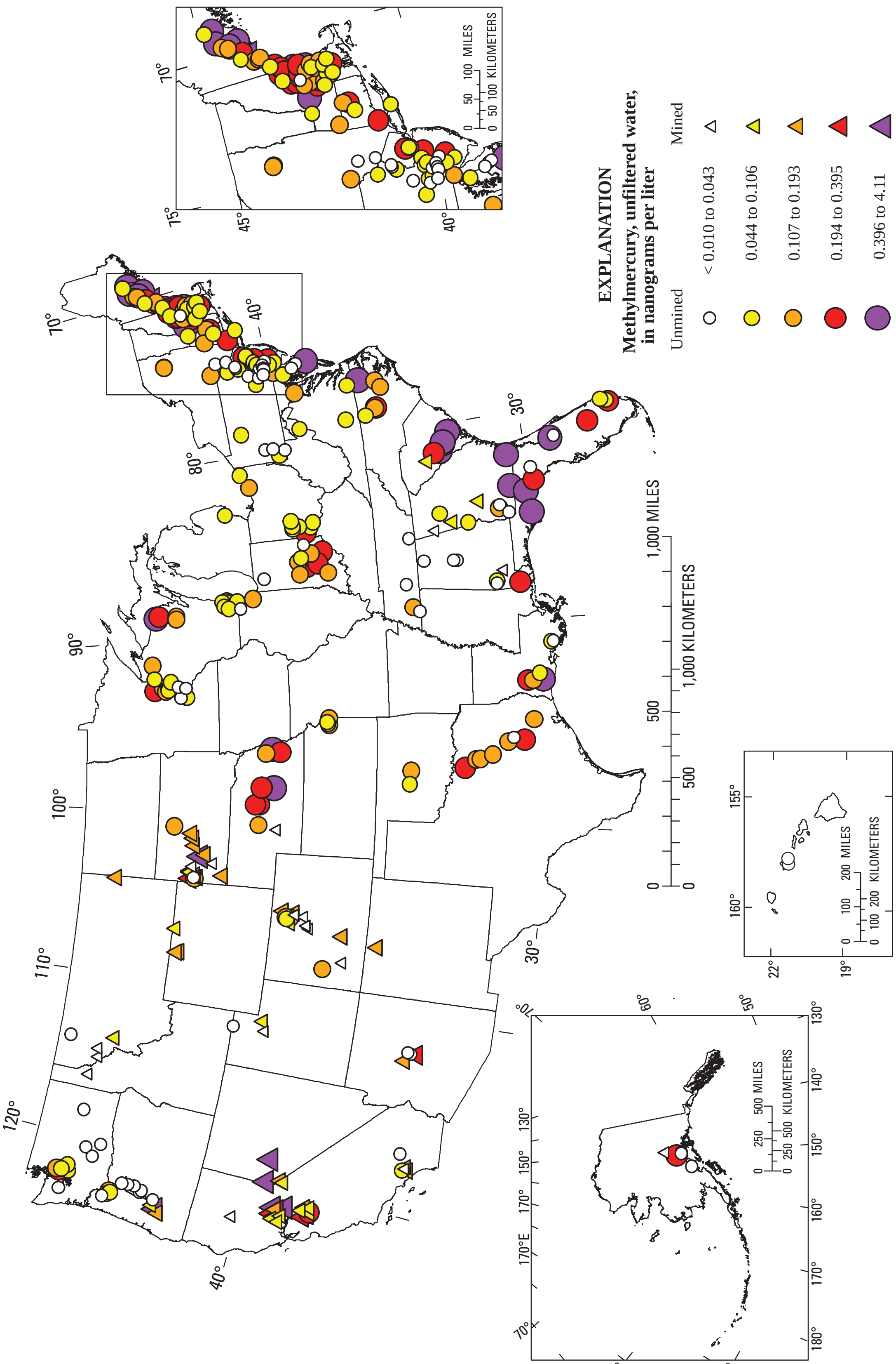

Figure 16. Spatial distribution of methylmercury concentrations in unfiltered stream water, 1998–2005. [Percentiles shown: 0 to 24 (white), 25 to 49 (yellow), 50 to 74 (orange), 75 to 89 (red), and greater than or equal to 90 (purple).]

Comparisons to Benchmarks and Guidelines

Hg concentrations in fish at most sites (71 percent, 208 of 291 sites) exceeded the value of 0.1 µg/g THg (ww) that is of concern for the protection of fish-eating mammals, including mink and otters (fig. 6; Yeardley and others, 1998; Peterson and others, 2007). Concentrations at 27 percent of the sites (79 of 291) exceeded 0.3 µg/g THg ww in fish. As mentioned earlier, most of the Hg found in fish tissue is MeHg (Huckabee and others, 1979; Grieb and others, 1990; Bloom 1992), and a concentration of 0.3 µg/g MeHg ww in fish is the USEPA MeHg criterion for the protection of human health (U.S. Environmental Protection Agency, 2001, 2009).

Two sediment-quality guidelines were used to evaluate THg concentrations in bed sediment in our study. These consensus-based concentrations of MacDonald and others (2000) are currently considered to be the best predictive guidelines. However, MacDonald and others (2000) noted that the consensus-based Threshold Effect Concentration (TEC) for THg correctly predicted toxicity only 34 percent of the time, whereas the consensus-based Probable Effect Concentration (PEC) correctly predicted toxicity 100 percent of the time although based on only 4 values. Because the primary toxic form of Hg is MeHg, THg-based toxicity estimates are not expected to be highly accurate; however, MeHg-based guidelines are unavailable at this time. In our study, concentrations of THg at 12 percent of sites (40 of 345 sites) exceeded the TEC of 180 ng/g. Total Hg in bed sediment from six of the sites exceeded the PEC of 1,060 ng/g; these sites included two western sites in mined basins (South Fork Coeur d'Alene River and Carson River below Carson Diversion Dam) and four sites from the northeast (Mousam River in Maine; Aberjona, Assabet, and Neponset Rivers near Boston, Massachussetts). These results indicate the potential for toxic effects on benthic communities at some sites sampled as part of this study.

Because of the complicated nature of Hg methylation and bioaccumulation, there are currently no national guidelines for protection of wildlife from exposure to Hg in water. However, of 336 sites with data for THg in unfiltered water, THg at three-quarters of the sites exceeded 1.3 ng/L, the 30-day standard derived by the USEPA for Great Lakes States fish-eating wildlife and slightly less than the value of 1.8 ng/L derived for protection of eagles (U.S. Environmental Protection Agency, 1995a, 1995b, 1997; Wolfe and others, 2007). Concentrations of unfiltered THg at 14 sites exceeded 26 ng/L, the Interim Canadian Water Quality Guideline for the protection of freshwater life (Environment Canada, 2005). All but one site with unfiltered THg concentrations greater than 26 ng/L were in the western United States, in basins where gold and (or) Hg mining took place in the past. The exception, Whitewood Creek above Lead, S.D., was within the highly mineralized area of the Black Hills of South Dakota (Norton, 1975; Goddard, 1988). There are gold mines in the area that could have contributed to high Hg concentrations, but some sites in this geochemically rich region are likely to be naturally enriched in Hg. The unfiltered THg concentration above Lead was similar to that found downstream at Deadwood (75.1 and 77.8 ng/L, respectively). In contrast to the sampling timing for the majority of our synoptic sites, the South Dakota sampling was intentionally timed to catch runoff with high-suspended sediment loads, when most of the Hg was in the particulate phase (Steve Sando, U.S. Geological Survey, oral commun., October 2007).

Comparisons Among Fish, Bed Sediment, and Stream Water

Because of bioaccumulation and biomagnification, Hg concentrations in fish were several orders of magnitude higher than in stream water. Overall, results of our study agreed with results in the literature for lakes and other waterbody types that have described relatively large differences in mean concentrations among fish, bed sediment, and water (Wiener and Stokes, 1990; Wiener, 1995; U.S. Environmental Protection Agency, 1997; Mason and others, 2000). We found a high accumulation of Hg in top-predator fish compared to stream water and bed sediment. This accumulation resulted in Hg concentrations in top-predator fish that were more than six orders of magnitude higher than concentrations of Hg in the water that the fish inhabit (fig. 17).

For all fish species and sites combined, the mean Biota Accumulation Factor (BAF, in $\log_{10}$; see equation 1, p. 8) for THg in fish relative to MeHg in water was 6.33 L/kg (range = 4.36 to 7.59) and for THg in fish relative to MeHg in bed sediment was 3.42 (range = 1.52 to 5.09) (table 4A). The BAF values determined in our studies were not significantly different at sites in mined basins when compared to sites in unmined basins. However, mean and median BAF values were lower for bed sediment than for water (tables 4B and 4C). Our mean water BAF value of 6.33 L/kg was slightly lower than the national mean BAF value of 6.40 L/kg reported by the USEPA for Hg in riverine fish relative to water (U.S. Environmental Protection Agency, 2000).

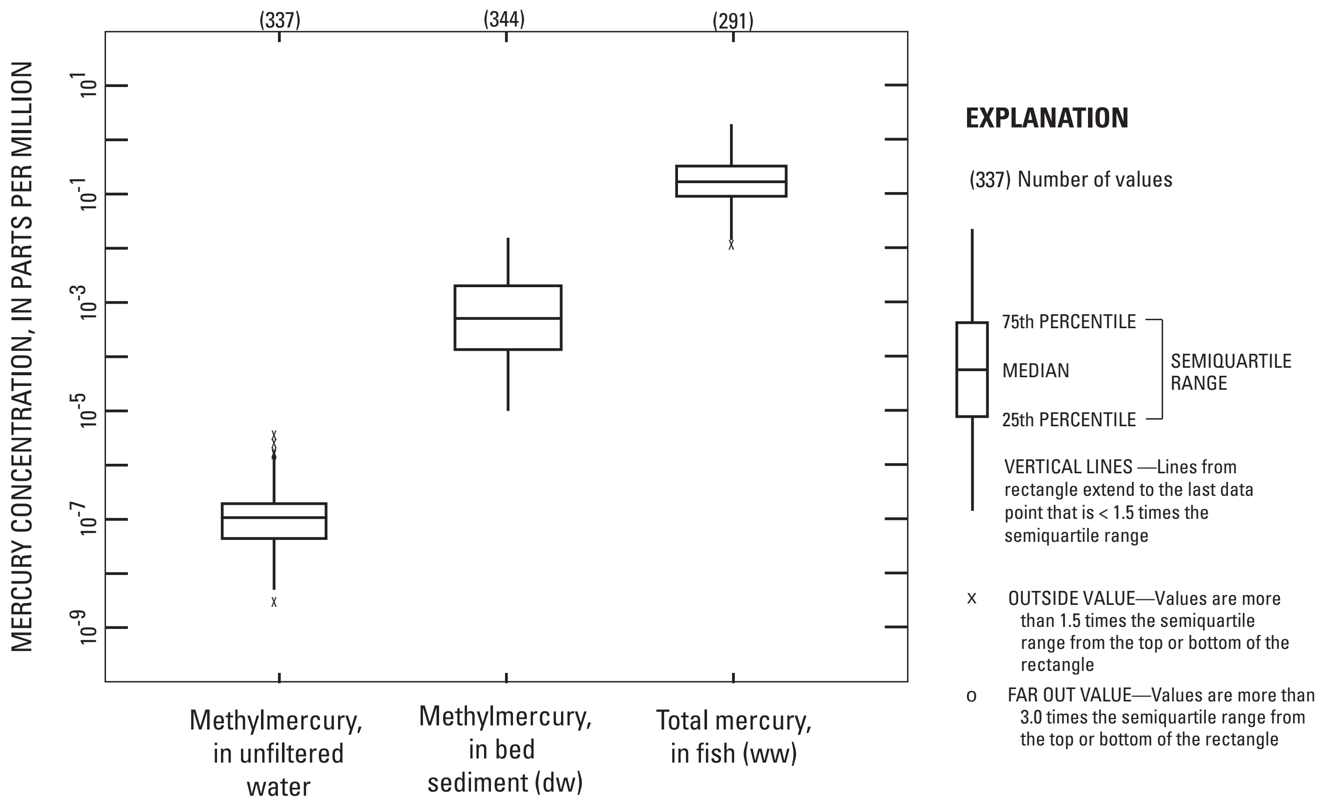

Figure 17. Statistical distributions of mercury concentrations in fish, bed sediment, and water, 1998–2005. (dw, dry weight; ww, wet weight)

Table 4A. Summary statistics for mercury Biota Accumulation Factors (BAFs) for fish from U.S. streams, 1998–2005: BAFs for fish with respect to water and bed sediment, all species.

[**Abbreviations:** BAF, Biota Accumulation Factor; water BAF values are for THg in fish with respect to MeHg in filtered water, in $\log_{10}$ (liters per kilogram); sediment BAF values are for THg in fish with respect to MeHg in bed sediment, in $\log_{10}$ (grams per gram); Std Dev, standard deviation; n, number of samples]

Parameter	Site grouping	Mean	Median	Std Dev	Minimum	Maximum	n
BAF (water)	All sites	6.33	6.33	0.50	4.36	7.59	166
	Sites in unmined basins	6.32	6.30	0.50	4.36	7.59	128
	Sites in mined basins	6.36	6.35	0.48	5.46	7.47	38
BAF (sediment)	All sites	3.42	3.43	0.76	1.52	5.09	229
	Sites in unmined basins	3.45	3.43	0.80	1.52	5.09	175
	Sites in mined basins	3.32	3.49	0.61	1.92	4.42	54

Table 4B. Summary statistics for mercury Biota Accumulation Factors (BAFs) for fish from U.S. streams, 1998–2005: BAFs for fish with respect to water, individual species.

[**Abbreviations:** BAF, Biota Accumulation Factor; water BAF values are for THg in fish with respect to MeHg in filtered water, in $\log_{10}$ (liters per kilogram); Std Dev, standard deviation; ND, no data; *, insufficient data to compute summary metric; n, number of samples]

Parameter	Site grouping	Mean	Median	Std Dev	Minimum	Maximum	n
Largemouth bass	All sites	6.61	6.61	0.46	5.22	7.59	38
	Sites in unmined basins	6.58	6.60	0.47	5.22	7.59	33
	Sites in mined basins	6.82	6.81	0.38	6.34	7.39	5
Smallmouth bass	All sites	6.32	6.37	0.48	5.25	7.08	20
	Sites in unmined basins	6.41	6.38	0.43	5.25	7.08	15
	Sites in mined basins	6.02	5.93	0.53	5.46	6.70	5
Rock bass	All sites	6.18	6.24	0.42	5.38	7.00	11
	Sites in unmined basins	6.18	6.24	0.42	5.38	7.00	11
	Sites in mined basins	ND	ND	ND	ND	ND	ND
Spotted bass	All sites	6.59	6.52	0.35	6.09	7.32	12
	Sites in unmined basins	6.52	6.40	0.38	6.09	7.32	8
	Sites in mined basins	6.73	6.72	0.27	6.42	7.07	4
Pumpkinseed	All sites	ND	ND	ND	ND	ND	ND
	Sites in unmined basins	ND	ND	ND	ND	ND	ND
	Sites in mined basins	ND	ND	ND	ND	ND	ND
Rainbow-cutthroat trout	All sites	6.31	6.27	0.40	5.54	7.47	26
	Sites in unmined basins	6.26	6.29	0.36	5.54	6.92	19
	Sites in mined basins	6.43	6.26	0.51	5.92	7.47	7
Brown trout	All sites	6.04	6.04	0.42	5.25	6.96	18
	Sites in unmined basins	5.87	6.03	0.34	5.25	6.25	9
	Sites in mined basins	6.21	6.34	0.44	5.63	6.96	9
Channel catfish	All sites	6.12	6.02	0.36	5.56	6.76	11
	Sites in unmined basins	6.08	6.00	0.36	5.56	6.76	9
	Sites in mined basins	*	*	*	5.84	6.02	2

Table 4C. Summary statistics for mercury Biota Accumulation Factors (BAFs) for fish from U.S. streams, 1998–2005: BAFs for fish with respect to bed sediment, individual species.

[**Abbreviations:** BAF, Biota Accumulation Factor; sediment BAF values are for THg in fish with respect to MeHg in bed sediment, in $\log_{10}$ (grams per gram); Std Dev, standard deviation; ND, no data, *, insufficient data to compute summary metric; n, number of samples]

Parameter	Site grouping	Mean	Median	Std Dev	Minimum	Maximum	n
Largemouth bass	All sites	3.99	4.08	0.67	2.37	5.09	51
	Sites in unmined basins	4.08	4.26	0.71	2.37	5.09	42
	Sites in mined basins	3.59	3.57	0.23	3.12	3.91	9
Smallmouth bass	All sites	3.43	3.55	0.63	1.73	4.96	44
	Sites in unmined basins	3.41	3.40	0.65	1.73	4.96	36
	Sites in mined basins	3.50	3.72	0.52	2.39	3.87	8
Rock bass	All sites	3.24	3.20	0.71	2.09	4.61	14
	Sites in unmined basins	3.24	3.20	0.71	2.09	4.61	14
	Sites in mined basins	ND	ND	ND	ND	ND	ND
Spotted bass	All sites	4.07	4.07	0.35	3.53	4.51	14
	Sites in unmined basins	4.23	4.37	0.32	3.53	4.51	9
	Sites in mined basins	3.76	3.78	0.14	3.54	3.90	5
Pumpkinseed	All sites	1.91	2.04	0.26	1.52	2.16	5
	Sites in unmined basins	1.91	2.04	0.26	1.52	2.16	5
	Sites in mined basins	ND	ND	ND	ND	ND	ND
Rainbow-cutthroat trout	All sites	3.16	3.13	0.51	2.20	4.10	26
	Sites in unmined basins	3.18	3.15	0.47	2.20	3.98	19
	Sites in mined basins	3.12	2.93	0.66	2.35	4.10	7
Brown trout	All sites	3.03	2.97	0.63	1.92	4.25	17
	Sites in unmined basins	3.01	2.75	0.52	2.51	3.82	8
	Sites in mined basins	3.04	3.04	0.75	1.92	4.25	9
Channel catfish	All sites	2.89	2.75	0.46	2.38	3.67	11
	Sites in unmined basins	2.90	2.75	0.46	2.38	3.67	9
	Sites in mined basins	*	*	*	2.38	3.32	2

Comparisons Between Mined and Unmined Basins

All sites in Hg-mined basins and most sites in gold-mined basins were in the western half of the United States (fig. 3). Across all sites, fish Hg, as wet weight (raw or length-normalized), was not significantly different between sites in unmined basins and mined basins, except for smallmouth bass. That exception was solely due to a single high outlier for the composite sample of smallmouth bass from the Carson River at Dayton, Nev., a mined basin. Concentrations of MeHg in bed sediment and unfiltered stream water from sites in unmined basins were not significantly different from those in mined basins; however, THg concentrations were significantly higher in bed sediment and stream water from sites in mined basins (tables 3B,C; fig.18).

It also should be noted that the percentages of MeHg (percent MeHg/THg) in bed sediment and unfiltered water were significantly higher in unmined basins (tables 3B, 3C). The percentage of MeHg is considered to be a useful estimate of methylation efficiency (Gilmour and others, 1998). Although THg concentrations in unfiltered water were higher as a group from streams in mined basins, MeHg concentrations from many of these same streams were not high relative to those at other sampled sites. More importantly, water from many sites in unmined basins with relatively low THg was relatively high in MeHg. This finding emphasizes the importance of Hg methylation in these ecosystems.

Examination of Hg relations to environmental characteristics for fish species from sites in mined basins was limited to largemouth bass and brown trout because of small sample sizes for other species. Concentrations of Hg in largemouth bass at these sites increased with increasing suspended sediment ($r_s = 0.98$, $p < 0.05$, $n = 5$) and THg in unfiltered water ($r_s = 0.67$, $p < 0.05$, $n = 9$). In contrast, Hg in brown trout at sites in mined basins increased significantly with increasing MeHg concentration in unfiltered water ($r_s = 0.93$, $p < 0.01$, $n = 7$).

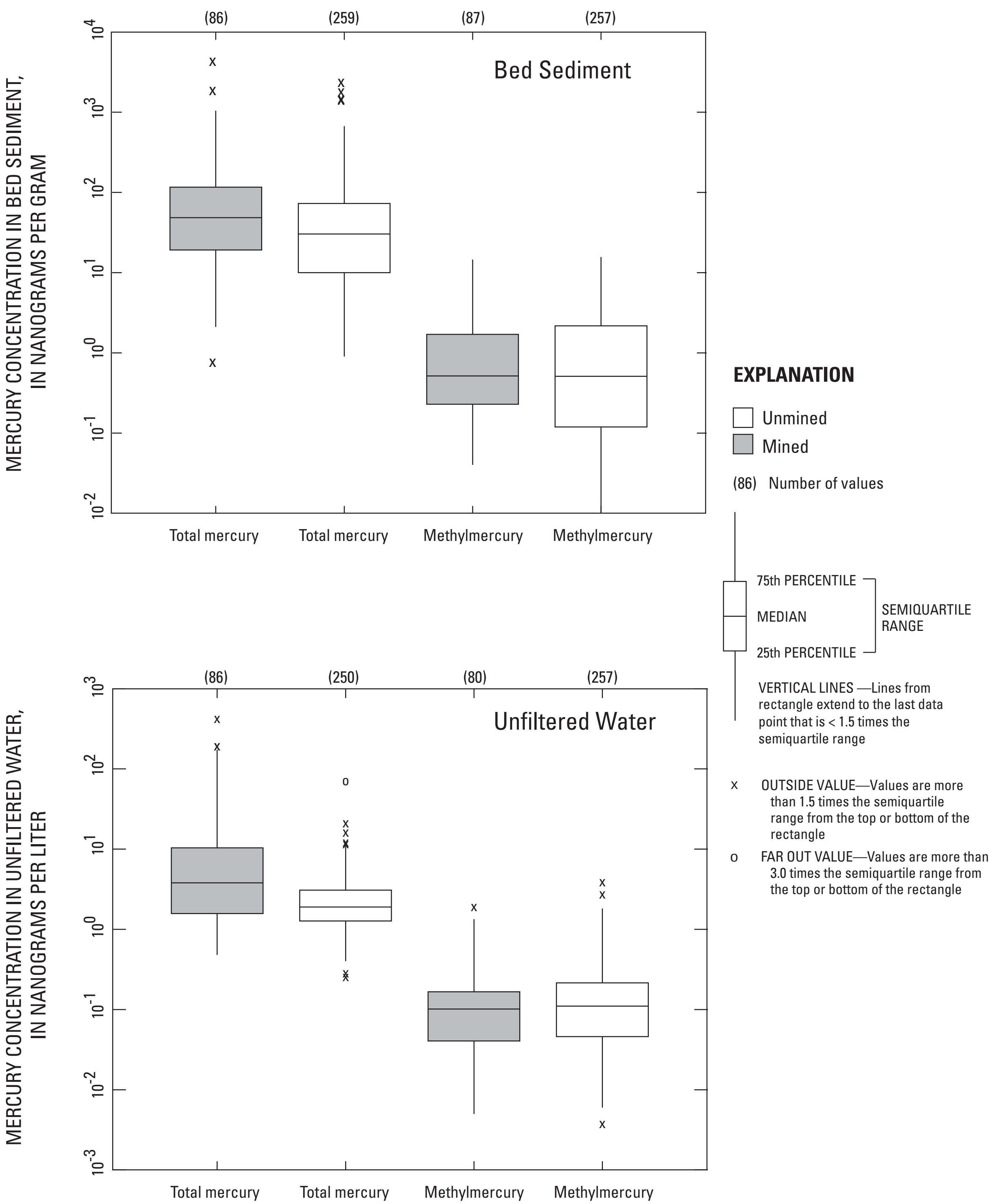

Figure 18. Statistical distributions of mercury concentrations in bed sediment and unfiltered water at stream sites in mined and unmined basins, 1998–2005.

Factors Related to Mercury Bioaccumulation in Fish

The remainder of this report describes relations between environmental characteristics and length-normalized Hg concentrations (micrograms per gram per meter) in unmined basins for the fish species that were most commonly collected: largemouth bass, smallmouth bass, rainbow-cutthroat trout, brown trout, pumpkinseed, rock bass, spotted bass, and channel catfish. Data for sites in mined basins were removed from these analyses to allow for evaluation of factors other than mining that could be important in fish Hg bioaccumulation. Most of the 89 sites in mined basins were in just two LULC categories: undeveloped (61 sites) or mixed (21 sites), and for several fish species—especially brown trout—the land-use relation often became weak or nonexistent when sites in mined basins were included.

Comparisons Among Land-Use/Land-Cover Categories

Significant differences among LULC categories were found for unmined basins (but not for mined basins) with respect to Hg. For unmined sites, largemouth bass from predominantly undeveloped or mixed-land-use basins were significantly higher in Hg than those from urban basins and were somewhat higher ($p = 0.059$) than those from agricultural basins (fig. 19); a similar difference was seen between undeveloped and urban basins for brown trout. Spotted bass from undeveloped basins were somewhat higher in Hg than those from agricultural basins ($p = 0.051$). In contrast to fish THg, bed sediment THg (whether normalized by LOI or not) and AVS were higher at urban sites compared to agricultural, undeveloped, or mixed-land-use sites. Although there were no significant differences among LULC categories for MeHg in bed sediment, the percentage of MeHg in bed sediment was higher at undeveloped sites than at urban sites. Undeveloped sites tended to have more wetland and forest cover in the basin. Differences among LULC categories were not found for THg or MeHg in unfiltered water.

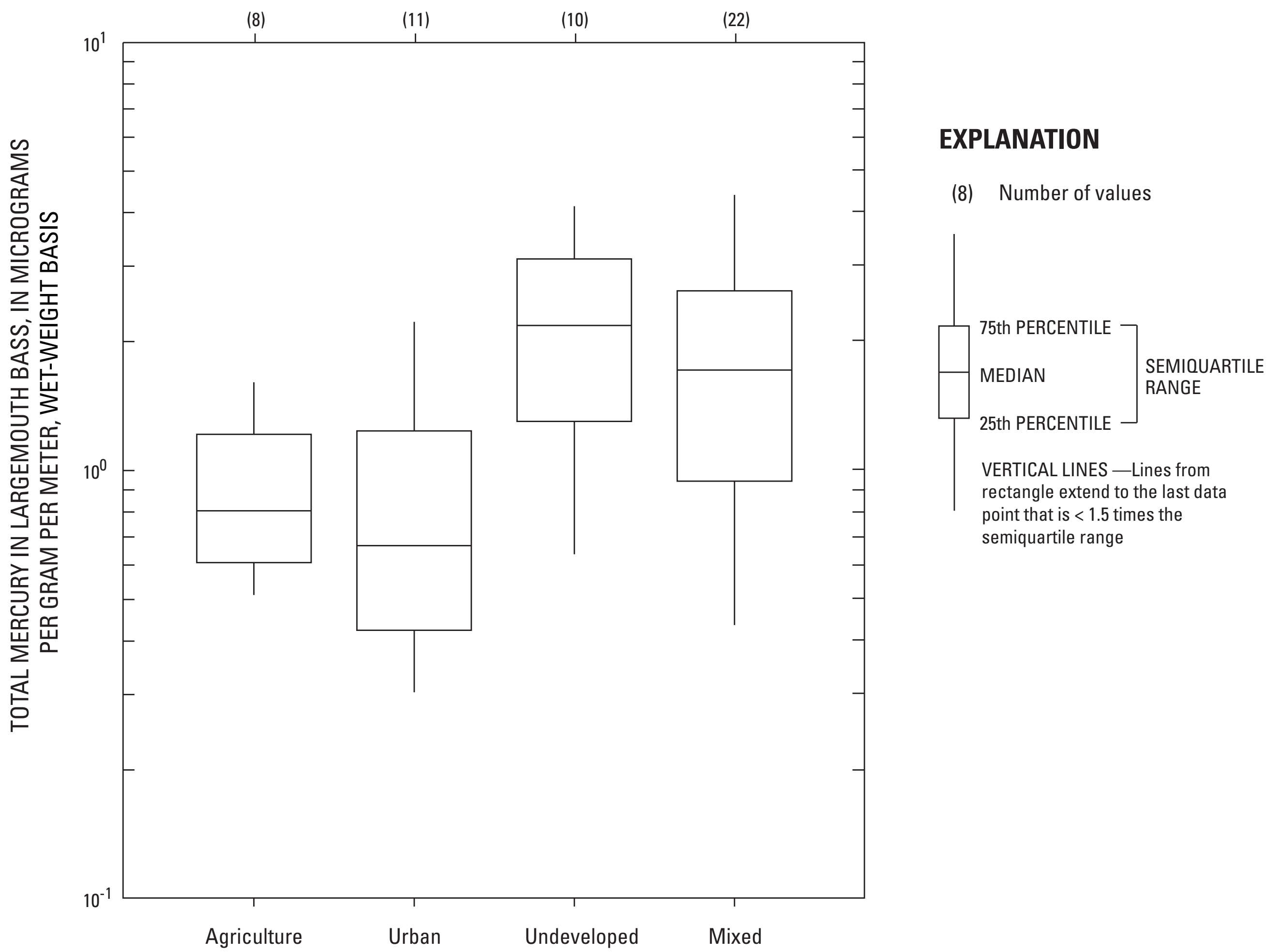

Figure 19. Statistical distributions of length-normalized mercury concentrations in largemouth bass for U.S. streams draining various land-use/land-cover categories, 1998–2005.

For those fish species with enough data available to test subcategories within the undeveloped LULC category for unmined sites (largemouth bass, smallmouth bass, rock bass, and brown trout), only largemouth bass showed significant differences between two subcategories: Hg concentrations in largemouth bass from sites in forested areas with high percentages of wetland (>15 percent) were significantly higher than in largemouth bass from sites in forested areas with low percentages of wetland (<10 percent) (means ± standard deviations were 2.92 ± 0.79 (µg/g)/m and 1.28 ± 0.05 (µg/g)/m, n = 6 and 3, respectively). The comparison should be viewed with caution due to the small sample sizes.

Fish Species-Specific Relations with Environmental Characteristics

Relations between fish Hg and environmental characteristics varied in their significance with the group of fish examined (table 5). Fish length correlated positively with Hg concentration for largemouth bass, rock bass, and rainbow-cutthroat trout, so length-normalized Hg concentrations for all fish were used in comparisons to environmental characteristics (Boudou and Ribeyre, 1983; Ribeyre and Boudou, 1984; Goldstein and others, 1996, Brumbaugh and others, 2001). Perhaps because of differences in species spatial distribution, as well as feeding habits, many statistically significant relations to environmental characteristics were found for Hg in largemouth bass (n = 52, unmined), whereas none were found for smallmouth bass (n = 51, unmined). Sample numbers of other fish species were more limited (n < 20, unmined), and significant relations also were less common than for largemouth bass. The apparent absence of relations for these other fish species may have been due in part to small sample sizes. Most bass samples in our study were from the eastern and southern United States. Largemouth bass appeared to be a good indicator for Hg in top-predator fish on the basis of (1) its ability to accumulate Hg from a predominantly piscivorous diet; (2) relations between Hg in largemouth bass and LULC, and MeHg in water or bed sediment; and (3) its generally ubiquitous distribution and status as a game fish. Factors related to Hg bioaccumulation in largemouth bass from unmined basins were subsequently examined in greater detail.

Stepwise multiple-linear regression revealed that increasing length-normalized Hg concentrations in largemouth bass from unmined basins were primarily related to increasing basin percentages of evergreen forest and woody wetland, especially with increasing proximity of evergreen forest and woody wetland to the sampling site (adjusted $r^2 = 0.66$):

$$\ln[Hg_{LMB}] = -0.592 + 0.0319 \arcsin[L_{ef}] + 0.0194 \arcsin[L_{ww}] , \quad (2)$$

where

Hg_{LMB} is the length-normalized THg concentration in largemouth bass, in micrograms per gram per meter,

L_{ef} is the distance-weighted percentage of basin LULC that is evergreen forest, and

L_{ww} is the distance-weighted percentage of basin LULC that is woody wetland.

This equation underscores the sensitivity of these two LULC types in comparison to other types with regard to Hg bioaccumulation in largemouth bass. Evergreen forest and woody wetland were positively correlated with each other ($r_s = 0.60$) in the largemouth bass dataset even though these characteristics were uncorrelated in the larger dataset. Redundancy Analysis (RDA) confirmed the significance of these two characteristics and additionally indicated that increasing amounts of MeHg in unfiltered stream water and LOI normalized MeHg concentrations in bed sediment, and decreasing pH and dissolved sulfate, were important for explaining variability in fish-Hg concentrations (fig. 20). Normalizing MeHg in bed sediment by organic content (as measured by LOI) provided a way to account for differences in the Hg concentrations of bed sediment collected from zones of inorganic sediment as compared to zones of organic muck. The similar results from multiple regression and RDA confirm the importance of evergreen forest, woody wetland, and MeHg in bed sediment and stream water for predicting THg in largemouth bass. Details of these relations are provided below.

The strength and direction of relations to LULC varied with fish species examined. As mentioned above, as the percentage of evergreen forest and woody wetland in the basin increased, Hg concentrations in largemouth bass also increased (figs. 21A, B). When the percentages of woody wetland were distance-weighted, r_s values for largemouth bass increased from 0.62 to 0.72 (table 5). This indicates that the closer woody wetland was to the sampling site, the higher the concentration of fish Hg. Spotted bass and brown trout Hg were also positively correlated with evergreen forest, including distance-weighted evergreen forest (fig. 21C, 21D). Hg in smallmouth bass did not correlate significantly with either forest or wetland. In general, positive relations were also seen between fish Hg and either total forest or total wetland in the basin; however, the relations were weaker than with evergreen forest or woody wetland.

Table 5. Spearman rank correlation coefficients (r_s) for relations between length-normalized total mercury in composite samples of fish and selected environmental characteristics for U.S. streams, 1998–2005.

[Definitions of variable abbreviations are listed in Appendix 1. Values are for sites in unmined basins only. Color coding of r_s based on p values, $p < 0.001$ (pink), $p < 0.01$ (orange), and $p < 0.05$ (yellow). **Abbreviations:** n, number of samples available for correlation;*, insufficient n or too many values less than the detection limit]

	Largemouth bass	Smallmouth bass	Rock bass	Spotted bass	Pumpkinseed	Rainbow - cutthroat trout	Brown trout	Channel catfish
Maximum n	52	51	17	9	16	19	13	10
Streamwater								
pH	-0.43	-0.03	-0.14	0.24	0.30	0.18	-0.25	-0.49
DOC	0.13	0.01	-0.61	-0.45	0.04	0.28	-0.60	0.15
Sulfate	-0.54	-0.23	-0.04	-0.52	-0.41	0.65	-0.65	0.18
UMeHg	0.50	0.19	-0.04	-0.07	0.79	0.24	-0.26	-0.12
UTHg	0.37	0.09	-0.24	-0.17	-0.52	0.54	-0.35	0.21
UMeHg/UTHg	0.36	0.21	-0.42	0.45	0.86	-0.38	-0.52	-0.19
Bed sediment								
SMeHg	0.07	-0.01	0.13	0.47	0.67	0.41	0.31	-0.20
STHg	-0.09	-0.08	0.35	-0.10	-0.17	0.32	-0.26	-0.08
SMeHg/STHg	0.32	0.04	-0.04	0.73	0.74	0.16	0.85	0.12
SMeHg/LOI	0.35	0.01	-0.03	0.60	0.29	0.56	0.42	-0.27
STHg/LOI	-0.03	-0.05	0.07	-0.23	-0.59	0.40	-0.77	0.03
Land use/land cover, percentage of basin area								
SUM_FOREST	0.56	0.25	0.05	0.68	0.19	*	0.62	0.47
EVR_FOREST	0.77	0.18	-0.25	0.72	0.44	*	0.82	0.39
EVR_FOREST_DW	0.77	0.16	-0.37	0.72	0.54	*	0.86	0.31
SUM_WETLAND	0.46	-0.19	-0.52	-0.12	0.25	0.15	-0.18	-0.21
WOODWETLAND	0.62	-0.28	-0.50	0.28	0.32	0.33	-0.19	-0.04
WOODWETLAND_DW	0.72	-0.25	-0.42	0.17	0.35	0.33	-0.25	-0.15
HERBWETLAND	-0.01	-0.06	-0.51	-0.15	-0.14	-0.07	-0.38	-0.19
HERBWETLAND_DW	0.06	-0.03	-0.40	-0.15	-0.04	-0.06	-0.37	-0.13
SUM_UNDEVELOPED	0.58	0.22	-0.11	0.70	0.20	-0.60	0.67	0.31
SUM_URBAN	-0.48	-0.20	0.13	-0.20	-0.16	*	-0.58	0.25
POPDEN00	-0.50	-0.22	0.37	-0.60	-0.39	*	-0.75	0.27
SUM_AGRICULTURE	-0.14	-0.24	0.14	-0.72	0.24	*	-0.78	-0.31
ROW_CROP	0.10	-0.31	0.05	-0.70	0.30	0.08	-0.65	-0.39
ROW_CROP_DW	0.11	-0.31	0.05	-0.70	0.22	*	-0.66	-0.30
Other								
AWET.PRE	0.28	-0.26	-0.01	0.53	-0.46	*	-0.31	0.10
ATOT.SEI	-0.16	0.02	0.76	*	0.09	-0.20	-0.32	0.12

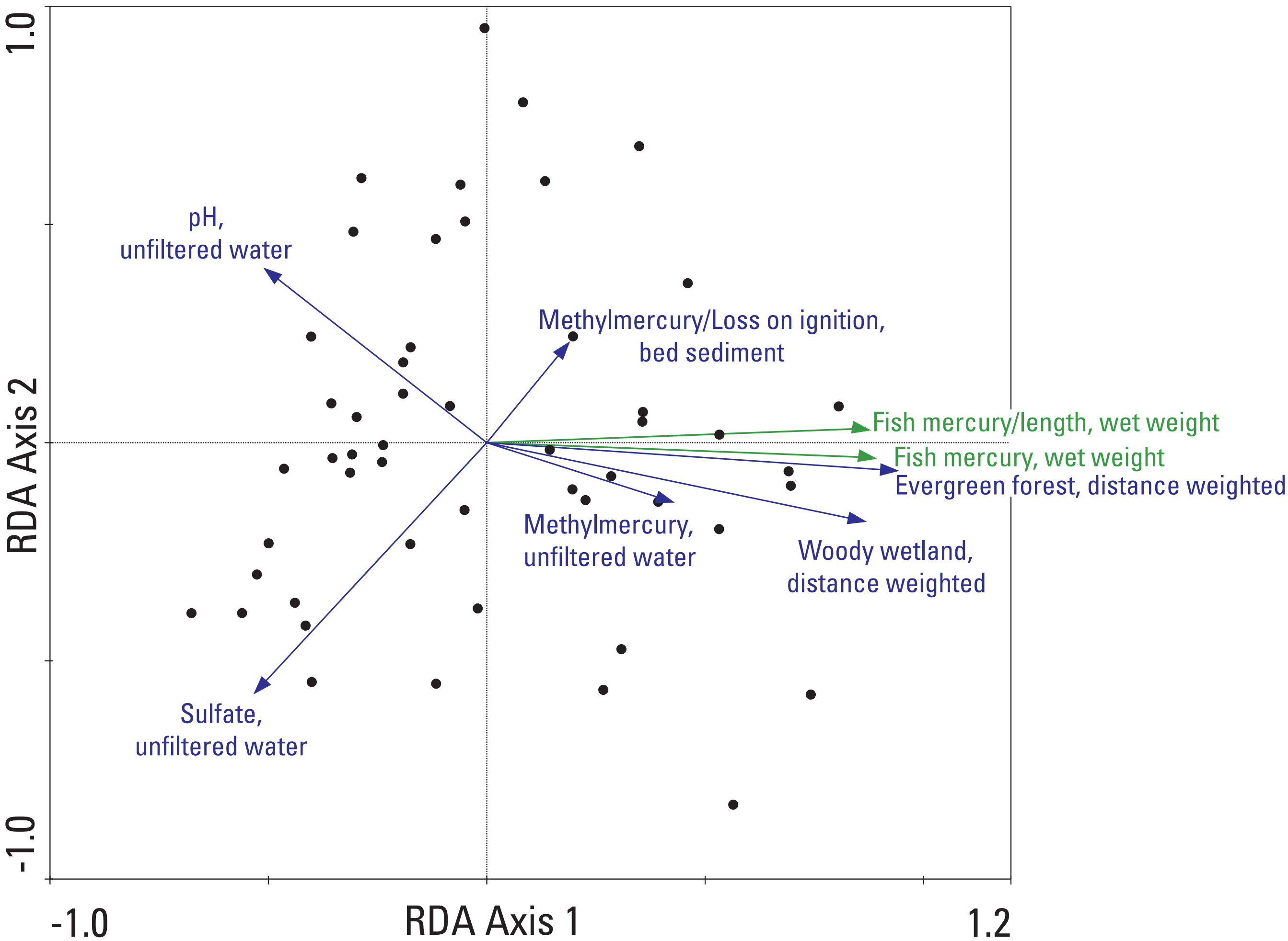

Figure 20. Redundancy Analysis (RDA) showing relative importance of selected environmental characteristics (blue arrows and labels) to concentrations of mercury in largemouth bass (green arrows and labels), 1998–2005. (Arrows extending in the same direction indicate a positive correlation, arrows in opposite directions indicate a negative correlation, and arrows at right angles indicate no correlation; arrow length indicates the relative importance of the variable in the relation.)

LULC data that correlated negatively with fish Hg included the percentage of urban developed land and Census 2000 population density (fig. 21E, largemouth bass; fig 21F, brown trout), and percentage of row crops (brown trout only; table 5). Chalmers (2002) in the New England Coastal Basins regional study data included here, also found a negative correlation (r_s = -0.72) between fish Hg and population density. Brumbaugh and others (2001) found a negative correlation with urban land and fish Hg, although most of the fish sampled from urban streams were largemouth or smallmouth bass. The above results underscore the importance of considering LULC and especially its proximity to the sampling site when interpreting fish-Hg concentrations.

Although fish Hg in largemouth bass, spotted bass, pumpkinseed, brown trout, and rainbow-cutthroat trout correlated with various measures of bed sediment Hg, fish Hg in smallmouth bass, rock bass, and channel catfish did not (table 5). Fish Hg correlated with LOI only for pumpkinseed (r_s = 0.58, $p < 0.05$), whereas Hg in largemouth bass, spotted bass, and rainbow-cutthroat trout correlated positively with bed sediment MeHg as normalized by LOI (fig. 21G–21I), and, in general, these correlations were higher than with bed-sediment MeHg concentrations that were not normalized by LOI (table 5). An exception was found for pumpkinseed; fish Hg in pumpkinseed was more highly correlated with bed-sediment MeHg concentrations not normalized by LOI (fig. 21J). An estimate of Hg methylation potential, the percentage of MeHg in bed sediment also correlated positively with Hg in brown trout (fig. 21K), pumpkinseed (fig. 21L), and spotted bass, but only weakly for largemouth bass. Sediment-fish BAF values for several species decreased with increasing LOI percentages and with AVS for largemouth bass (fig. 22A–22F).

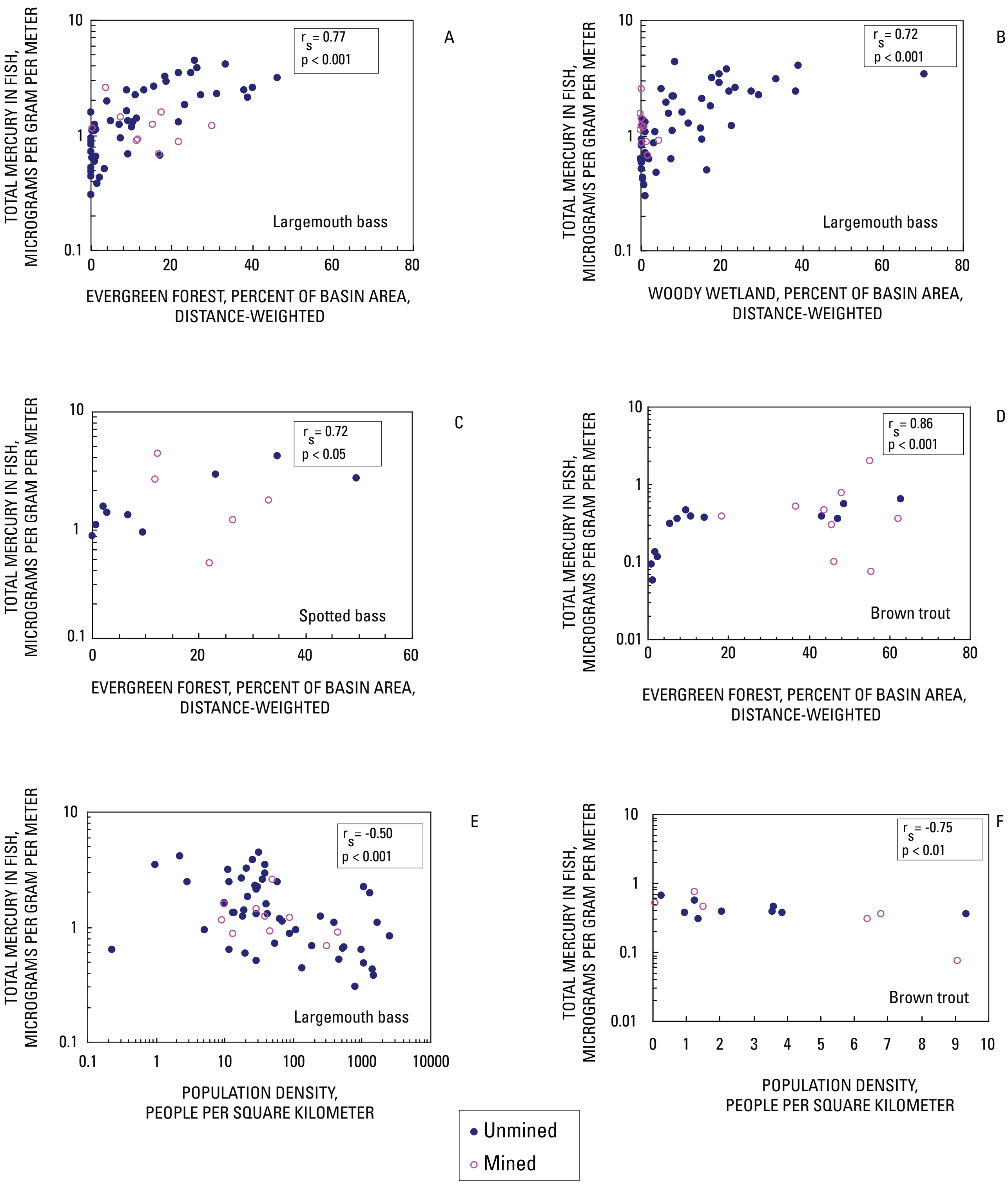

Figure 21. Correlations between length-normalized mercury concentrations in fish and selected environmental characteristics, 1998–2005. [Data for all sites shown, unmined and mined; however, Spearman rank correlation coefficients (r_s) are for unmined sites only.]

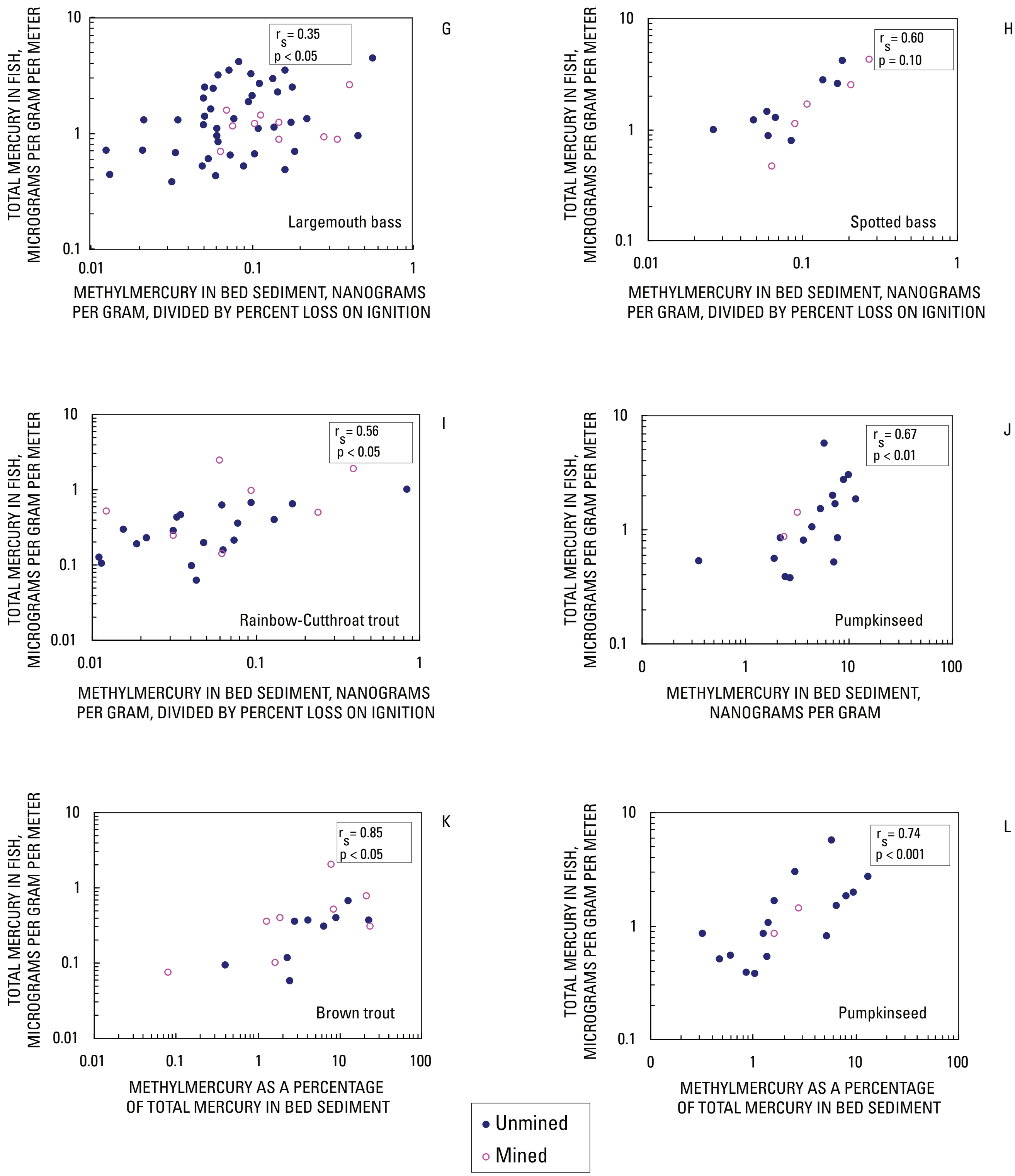

Figure 21.—Continued.

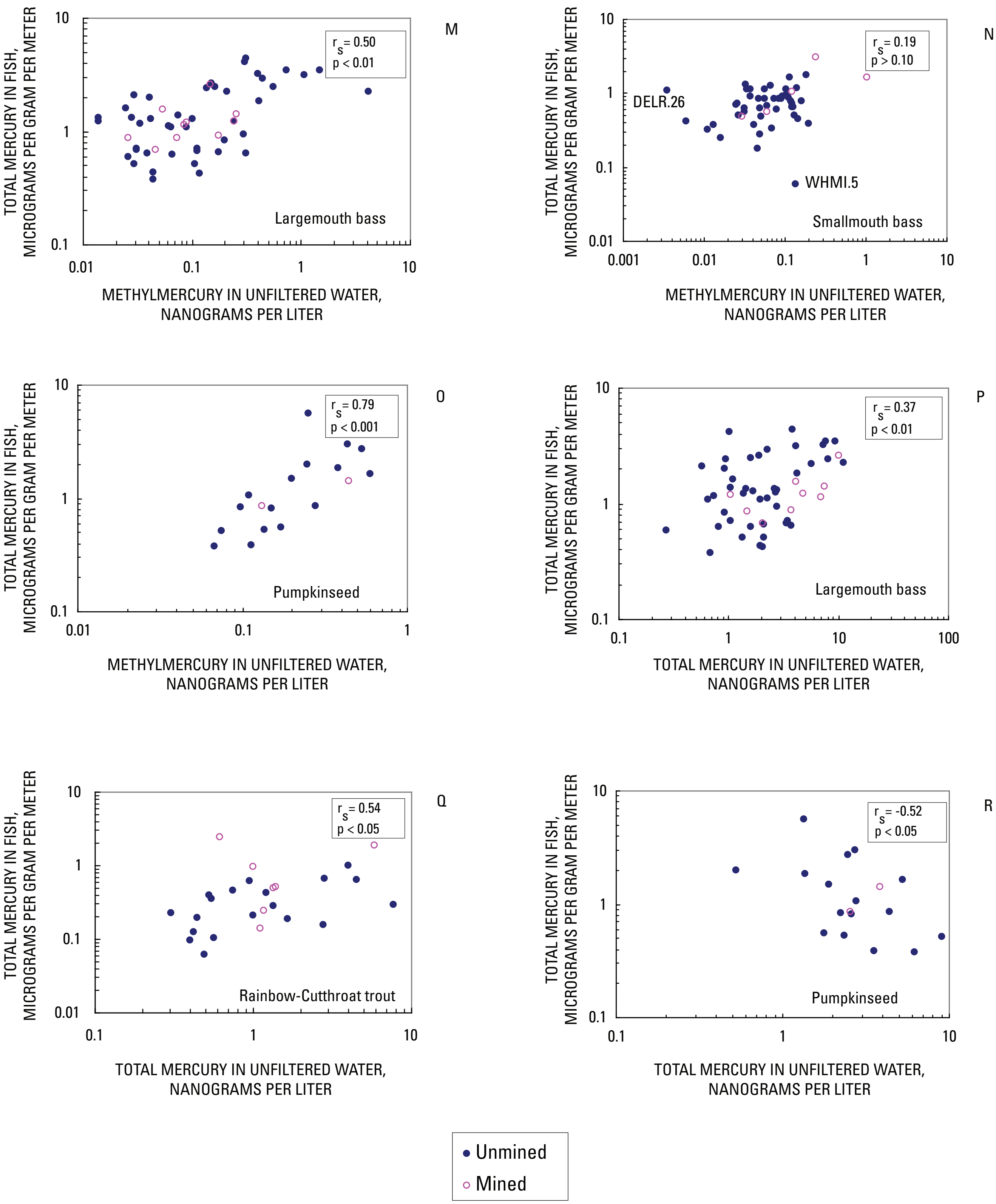

Figure 21.—Continued.

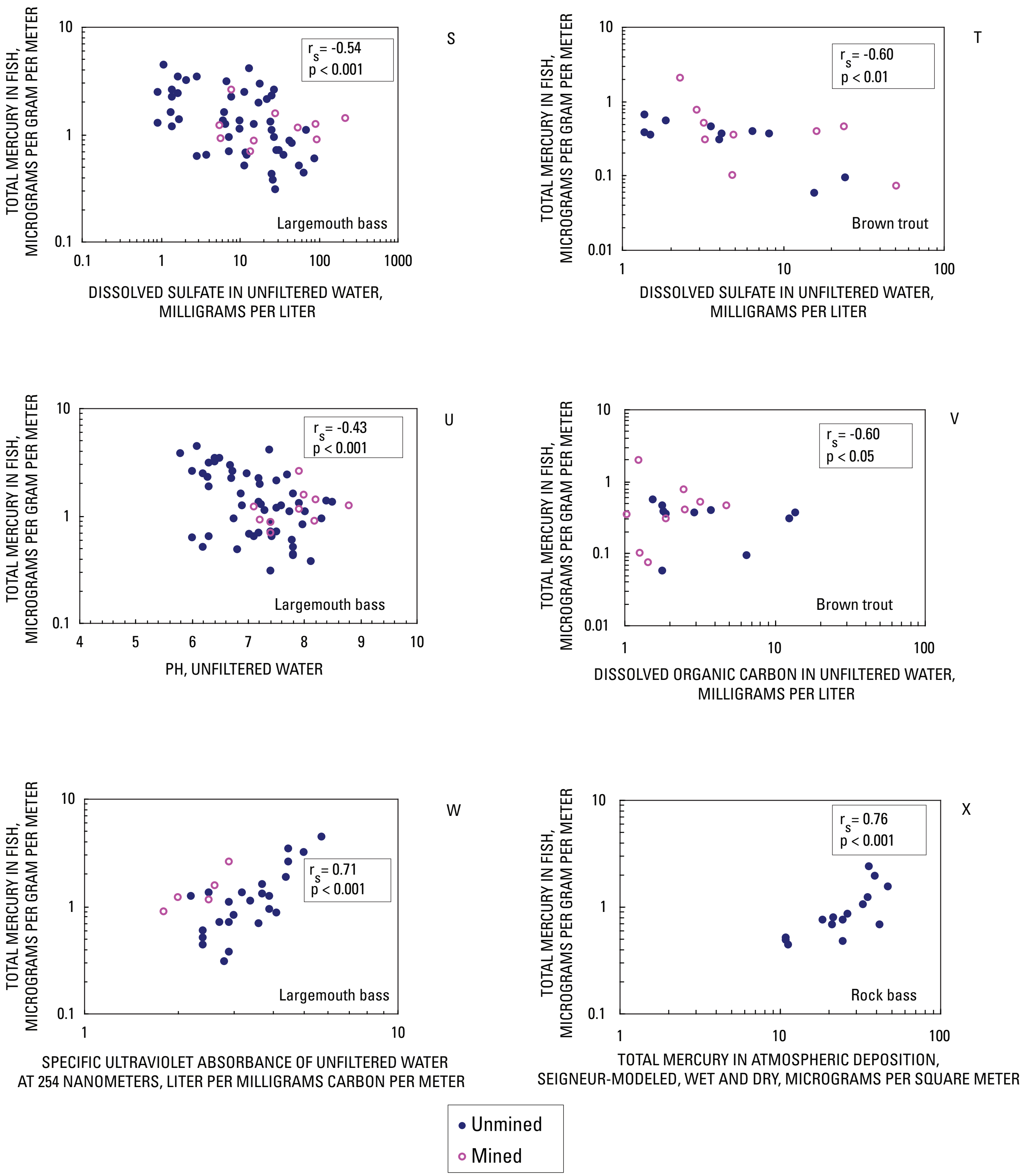

Figure 21.—Continued.

For the 1998 National Mercury Pilot, Brumbaugh and others (2001) showed a highly significant correlation between length-normalized Hg in largemouth bass and MeHg in unfiltered water ($r_s = 0.71$, $p < 0.001$). In our study, fish-Hg concentrations also correlated positively with unfiltered MeHg for largemouth bass ($r_s = 0.50$; fig. 21M) and pumpkinseed ($r_s = 0.79$; fig. 21O), but the relation was not significant for smallmouth bass (fig. 21N) or other fish species evaluated (table 5). Fish Hg appeared to be similarly correlated with filtered MeHg concentrations; however, some correlations with this parameter must be viewed with caution because filtered Hg data were available at far fewer sites than unfiltered Hg data, and concentrations at many of these sites were below detection limits. Fish Hg also correlated with THg in unfiltered water, but generally more weakly than to MeHg; this relation was positive for largemouth bass and rainbow-cutthroat trout, and was negative for pumpkinseed (figs. 21P–21R). Total Hg in filtered samples appeared to be a better predictor of spotted bass Hg concentrations than MeHg in unfiltered water, although it is MeHg in water that is accumulated in the aquatic food web eventually to fish. Noise in the correlations with MeHg in unfiltered water might be reduced with increased water sampling, such as was done by Chasar and others (2009). Multiple samples over a range of hydrologic conditions, and possibly lower detection limits, would be needed to improve correlations.

In general, length-normalized Hg concentrations in fish correlated weakly to selected ancillary water chemistry characteristics. Fish Hg in largemouth bass and brown trout were negatively correlated with concentrations of dissolved sulfate in water (figs. 21S, 21T). Sulfate may exert concentration-dependent positive or negative effects on Hg methylation and, therefore, bioaccumulation by fish (Compeau and Bartha, 1983, 1987; Gilmour and others, 1992, 1998; Benoit and others, 2003). A negative correlation with pH was found for Hg in largemouth bass only ($r_s = -0.43$; fig. 21U). Lower pH waters (more acidic) tend to be associated with a greater partitioning of Hg to the dissolved phase, enhancing Hg methylation, and resulting in higher rates of Hg bioaccumulation (Watras and Bloom, 1992). Although DOC and fish Hg directly correlated only in rock bass (table 5) and brown trout (fig. 21V), water BAF values for largemouth bass and brown trout decreased with increasing concentrations of DOC in unfiltered water (figs. 22G, H). In contrast, Hg in largemouth bass positively correlated with SUVA of DOC (fig. 21W). This supports the importance of the indirect and positive effect of DOC and DOC complexity in fish Hg bioaccumulation, as also found by Chasar and others (2009) for DOC and SUVA for top-predator fish.

With the exception of rock bass, no relation was found between atmospheric THg deposition and fish-Hg concentrations when examined at sites across the United States (fig. 21X); however, variation in local environmental characteristics in stream basins may confound evidence of the potential effects of atmospheric deposition. The three bass species that are widespread in the eastern half of the United States (largemouth, smallmouth, and rock bass) were examined further for relations to atmospheric THg deposition by confining analyses to sites from mixed and undeveloped LULC; sites from mined, urban, and agricultural LULC were excluded to minimize confounding effects of nonatmospheric Hg sources and land-use disturbances. Length-normalized Hg in fish was compared to three estimates of Hg deposition: total combined [sum of precipitation-weighted wet THg deposition measured at MDN sites and modeled dry THg deposition (Seigneur and others, 2004)]; total modeled [sum of modeled wet and dry THg deposition from Seigneur and others (2004)]; and wet only [precipitation-weighted wet THg deposition measured at MDN sites]. In addition to the positive correlation mentioned earlier for total modeled Hg deposition with rock bass (fig. 21X), total combined deposition positively correlated with rock bass Hg (not shown). The positive relation for rock bass Hg with Hg deposition also remained significant in the multiple regression model that included evergreen forest and woody wetland abundance. Relations between largemouth bass Hg levels and either total combined or wet only Hg deposition were deemed not reliable because four influential samples were in Kansas and Nebraska, where the western U.S. average was used as an estimate of Hg deposition. Given the lack of wet deposition measurements in that part of the country we do not have confidence in the accuracy of this estimate for Kansas and Nebraska. When the four low-Hg deposition samples were excluded, there was no significant relation. Relations for smallmouth bass with atmospheric Hg were not significant.

Hammerschmidt and Fitzgerald (2006) examined a large, historical data set for 25 States and found positive relations between statewide average Hg in largemouth bass and wet Hg deposition. Our site-based (rather than statewide) analysis provides limited support for positive relation between fish-Hg concentration and Hg deposition. One explanation for the limited connection between Hg in fish and deposition in our study is that variation in Hg methylation among ecosystems is greater than the variation in Hg deposition, particularly in the eastern United States, where most of our bass were sampled.

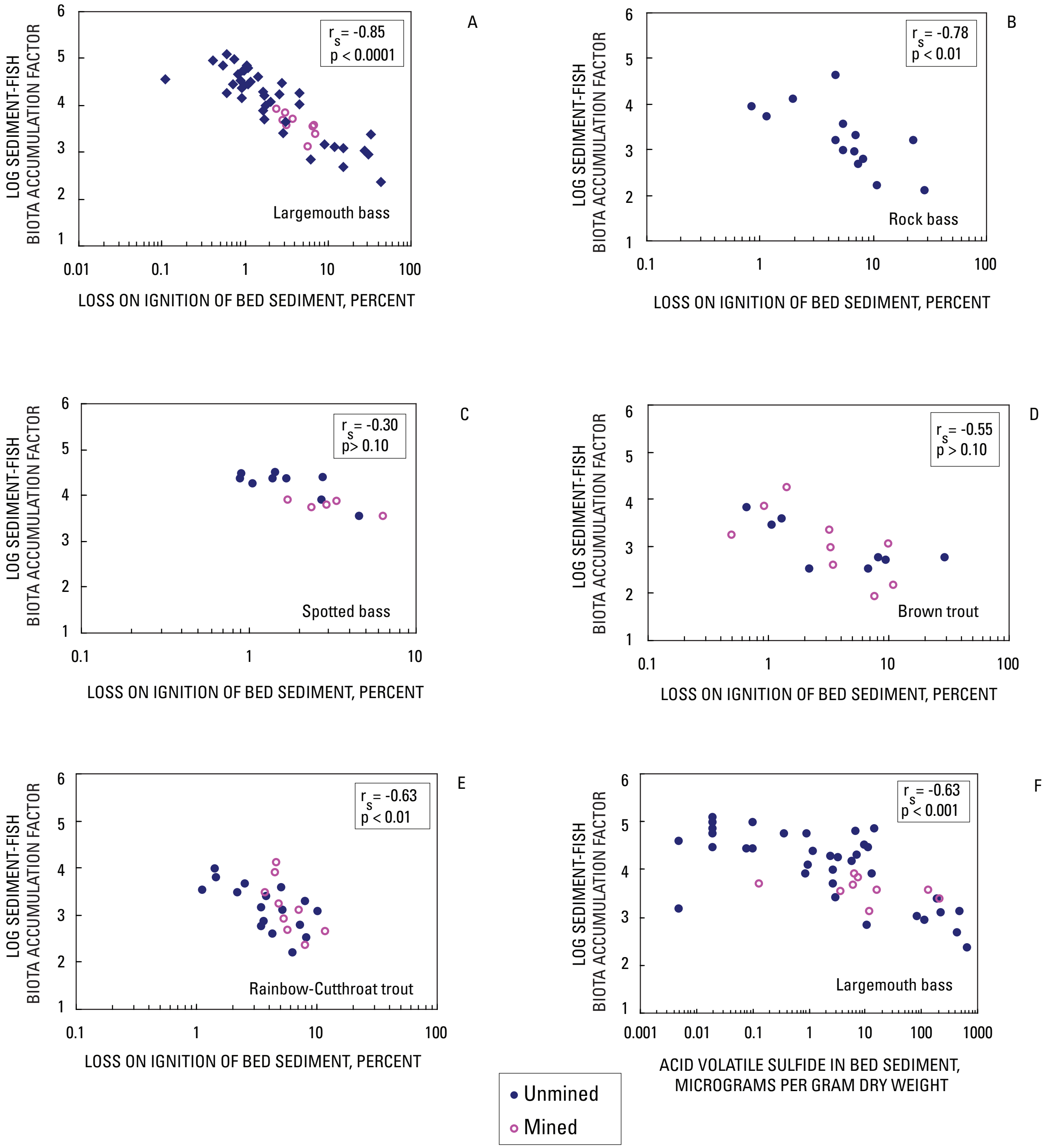

Figure 22. Biota Accumulation Factors (BAF) for fish in relation to selected environmental characteristics, 1998–2005. [Data for all sites are shown, unmined and mined; however, Spearman rank correlation coefficients (r_s) are for unmined only. BAF values are in Log_{10}.]

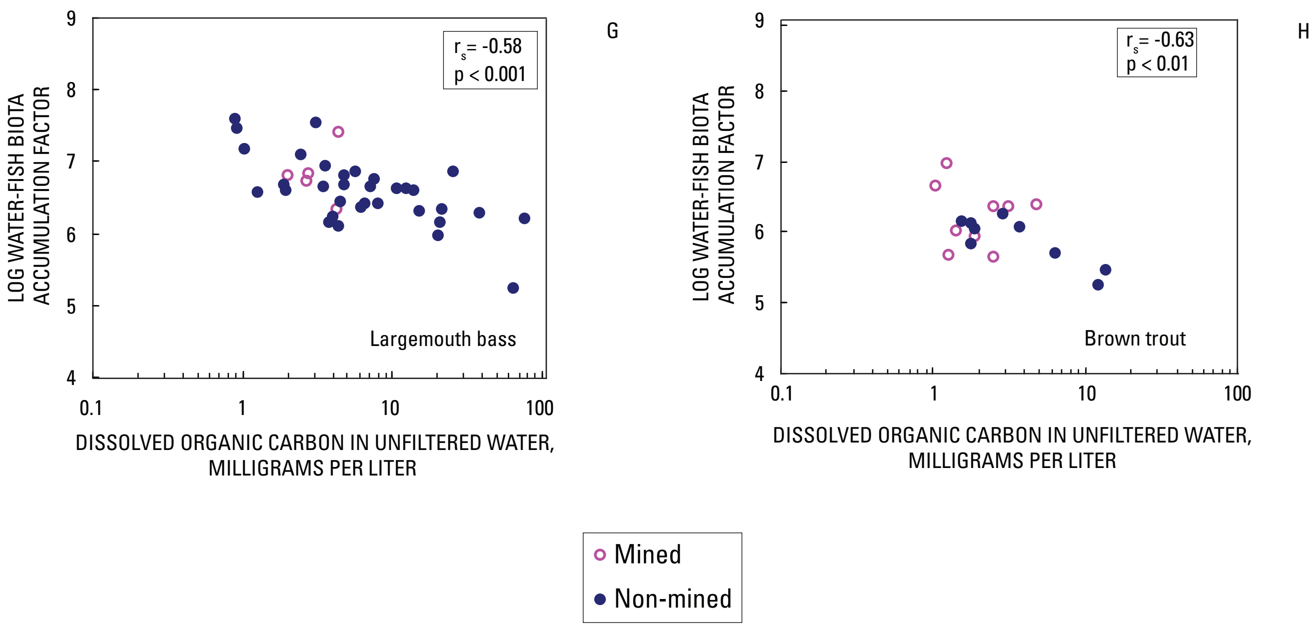

Figure 22.—Continued

Bed-Sediment Relations with Environmental Characteristics

Higher concentrations of MeHg in bed sediment at sites in unmined basins (n = 183) were significantly related to higher LOI, THg, and AVS of the sediment, as shown in equation 3 (adjusted $r^2 = 0.73$):

$$\ln[\mathrm{MeHg}_{BS}] = -2.857 + 0.925\ \ln[\mathrm{LOI}] + 0.247\ \ln[\mathrm{THg}_{BS}] + 0.048\ \ln[\mathrm{AVS}]\ , \quad (3)$$

where

MeHg_{BS} is the bed sediment MeHg concentration, in nanograms per gram,

LOI is the loss-on-ignition of the bed sediment in percent,

THg_{BS} is the bed sediment THg concentration, in nanograms per gram, and

AVS is the acid-volatile sulfide concentration, in micrograms per gram.

LOI was a strong predictor of MeHg in bed sediment ($r_s = 0.81$, fig. 23A) and THg in bed sediment (r_s=0.78; table 6). Although bed sediment MeHg was near or below detection at many sites, MeHg and THg were more highly related in bed sediment ($r_s = 0.72$) (fig. 23B, table 6) than in unfiltered water ($r_s = 0.40$). Krabbenhoft and others (1999) also found a high positive correlation between bed sediment MeHg and LOI, as well as with sediment organic carbon. Recent work by Marvin-DiPasquale and others (2009) found that MeHg in bed sediment from streams with predominantly atmospheric Hg inputs was a function of sediment organic content and the activity of Hg-methylating microbes. AVS correlated positively with bed sediment MeHg and THg in our study (fig. 23C) but contributed least to the predictive power of equation 3. Key LULC categories, such as forest cover, wetland, urban, and agriculture, were at most only weakly correlated with Hg concentrations in bed sediment (table 6).

As atmospheric Hg concentrations increased, concentrations of THg in bed sediment increased, and the highest correlation ($r_s = 0.53$) was found for Seigneur-modeled dry atmospheric deposition with bed sediment THg (fig. 23D; table 6); the correlation between THg and Seigneur-modeled total (wet + dry) atmospheric deposition was lower, but still significant ($r_s = 0.39$).

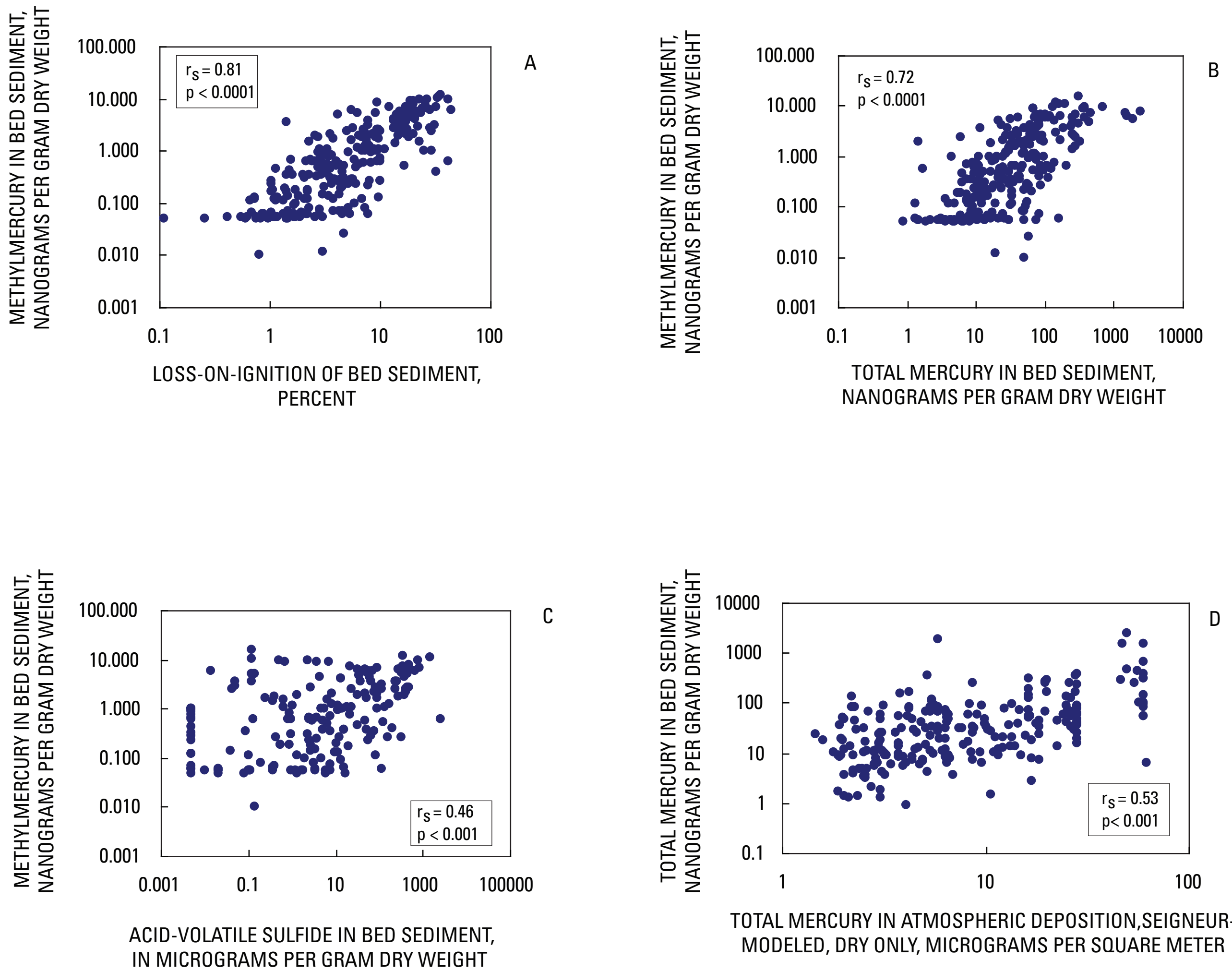

Figure 23. Correlations between mercury in bed sediment and selected environmental characteristics in unmined basins, 1998–2005. (r_s, Spearman rank correlation coefficient; modeled mercury is based on Seigneur and others, 2004.)

Table 6. Spearman rank correlation coefficients (r_s) for relations between selected environmental characteristics from U.S. streams, 1998–2005.

[Definitions of variable abbreviations are listed in Appendix 1. Values are for sites in unmined basins only. Color coding of r_s based on p values, $p < 0.001$ (pink), $p < 0.01$ (orange), and $p < 0.05$ (yellow)]

Parameter	pH	DOC	UV	SUVA	Sulfate	SS_ conc	UMeHg	UTHg	UMeHg/ UTHg	FMeHg	FTHg	PMeHg	PTHg	SMeHg/ LOI	SMeHg	STHg / LOI	STHg	SMeHg/ STHg	LOI	AVS
Stream water																				
pH	1.00																			
DOC	-0.23	1.00																		
UV	-0.24	0.92	1.00																	
SUVA	-0.55	0.31	0.60	1.00																
Sulfate	0.40	0.12	-0.16	-0.45	1.00															
SS_conc	0.09	0.36	-0.22	0.05	0.27	1.00														
UMeHg	-0.39	0.59	0.67	0.47	-0.09	0.55	1.00													
UTHg	-0.23	0.43	0.31	0.28	0.14	0.62	0.54	1.00												
UMeHg/UTHg	-0.29	0.37	0.48	0.30	-0.26	0.13	0.72	-0.12	1.00											
FMeHg	-0.31	0.56	0.51	0.42	0.07	0.26	0.83	0.50	0.58	1.00										
FTHg	-0.31	0.49	0.31	0.31	0.03	0.27	0.61	0.79	0.04	0.67	1.00									
PMeHg	-0.07	0.31	0.03	-0.06	0.40	0.69	0.77	0.72	0.22	0.46	0.45	1.00								
PTHg	-0.08	0.15	0.04	-0.16	0.42	0.61	0.45	0.79	-0.29	0.19	0.36	0.72	1.00							
Bed sediment																				
SMeHg/LOI	-0.20	0.03	-0.15	0.16	0.01	0.07	0.28	0.23	0.14	0.27	0.21	0.36	0.21	1.00						
SMeHg	-0.28	0.08	-0.06	0.28	-0.13	0.15	0.28	0.16	0.19	0.09	0.11	0.31	0.17	0.77	1.00					
STHg/LOI	-0.05	0.10	-0.21	-0.19	0.33	-0.01	-0.08	0.29	-0.33	0.13	0.26	0.14	0.34	0.26	0.08	1.00				
STHg	-0.25	0.16	-0.03	0.14	0.02	0.05	0.10	0.22	-0.08	0.02	0.17	0.17	0.27	0.39	0.72	0.51	1.00			
SMeHg/STHg	-0.08	-0.07	-0.04	0.19	-0.23	0.07	0.31	-0.03	0.39	0.09	-0.04	0.16	-0.12	0.63	0.59	-0.50	-0.06	1.00		
LOI	-0.28	0.13	0.12	0.31	-0.22	0.05	0.21	0.07	0.18	-0.02	0.00	0.12	0.03	0.29	0.81	-0.08	0.78	0.30	1.00	
AVS	-0.27	0.14	0.42	0.32	0.03	0.07	0.08	0.14	-0.03	0.09	0.16	0.14	0.04	0.31	0.46	0.17	0.40	0.13	0.42	1.00
Atmospheric deposition																				
SULF.DEP	-0.08	-0.03	-0.21	-0.03	0.32	-0.16	-0.08	-0.03	-0.12	0.35	0.19	0.18	0.20	0.24	0.17	0.44	0.28	-0.11	0.05	0.17
ADRY.SEI	-0.20	0.10	-0.21	-0.09	0.29	-0.20	0.01	-0.01	-0.04	0.25	0.09	0.10	0.15	0.36	0.42	0.44	0.53	-0.03	0.35	0.26
ATOT.SEI	-0.16	-0.06	-0.28	-0.15	0.22	-0.39	-0.12	-0.09	-0.12	0.06	-0.03	-0.11	-0.03	0.25	0.25	0.45	0.39	-0.12	0.19	0.12
AWET.MDN	-0.04	0.07	0.13	0.23	0.17	-0.08	-0.10	0.00	-0.12	0.36	0.11	0.03	-0.00	-0.16	-0.37	0.21	-0.27	-0.24	-0.44	-0.13
AWET.PRE	-0.07	0.13	0.18	0.27	0.20	0.03	-0.05	0.01	-0.06	0.37	0.12	0.12	0.03	-0.11	-0.26	0.18	-0.18	-0.18	-0.31	-0.09
PREC.PR	-0.45	-0.04	0.12	0.33	-0.35	-0.49	-0.03	-0.05	0.03	0.13	0.09	-0.31	-0.22	0.05	0.02	0.22	0.15	-0.10	0.06	0.06
WET_DEP_AVE	0.24	-0.51	-0.50	-0.19	-0.18	-0.07	-0.27	-0.16	-0.20	-0.44	-0.26	-0.13	-0.09	-0.08	-0.02	-0.23	-0.10	0.10	0.02	-0.09
Other																				
POPDEN00	-0.11	0.28	0.23	0.04	0.42	-0.04	0.01	0.14	-0.14	0.13	0.08	0.10	0.34	0.11	0.15	0.47	0.40	-0.25	0.17	0.18
ELEV.AVG	0.54	-0.41	-0.52	-0.53	0.01	0.01	-0.31	-0.17	-0.24	-0.37	-0.15	-0.08	-0.08	-0.02	-0.05	-0.26	-0.21	0.15	-0.12	-0.14
HYDRIC SOILS	-0.22	0.48	0.56	0.35	0.06	0.11	0.31	0.09	0.28	0.36	0.19	0.09	-0.06	0.04	0.01	0.13	0.05	-0.04	-0.01	0.04
PET	-0.14	0.18	0.32	0.25	0.28	0.17	0.12	0.18	0.00	0.31	0.11	0.21	0.22	-0.26	-0.42	0.10	-0.30	-0.27	-0.40	-0.11
AET	-0.25	0.18	0.28	0.34	0.18	0.04	0.10	0.12	0.04	0.37	0.16	0.12	0.10	-0.18	-0.32	0.17	-0.17	-0.25	-0.30	-0.10

Table 6. Spearman rank correlation coefficients (r_s) for relations between selected environmental characteristics from U.S. streams, 1998–2005.—Continued

[Definitions of variable abbreviations are listed in Appendix 1. Values are for sites in unmined basins only. Color coding of r_s based on p values, $p < 0.001$ (pink), $p < 0.01$ (orange), and $p < 0.05$ (yellow)]

Parameter	pH	DOC	UV	SUVA	Sulfate	SS_ conc	UMeHg	UTHg	UMeHg/ UTHg	FMeHg	FTHg	PMeHg	PTHg	SMeHg/ LOI	SMeHg	STHg / LOI	STHg	SMeHg/ STHg	LOI	AVS
Land use / land cover																				
SUM_FOREST	-0.26	-0.19	-0.30	0.11	-0.56	-0.41	-0.04	-0.15	0.10	0.03	0.15	-0.30	-0.41	0.18	0.30	-0.15	0.18	0.27	0.31	0.02
EVR_FOREST	-0.32	-0.16	-0.10	0.23	-0.68	-0.30	0.03	-0.08	0.14	-0.04	0.09	-0.38	-0.47	0.04	0.05	-0.25	-0.07	0.23	0.08	-0.10
EVR_FOREST_DW	-0.32	-0.16	-0.14	0.21	-0.68	-0.30	0.05	-0.08	0.17	-0.01	0.10	-0.35	-0.45	0.05	0.07	-0.29	-0.08	0.26	0.09	-0.12
SUM_WETLAND	-0.45	0.49	0.66	0.55	-0.22	0.19	0.47	0.18	0.41	0.38	0.24	0.15	-0.05	0.09	0.17	-0.02	0.13	0.09	0.21	0.20
WOODWETLAND	-0.50	0.47	0.58	0.58	-0.25	0.09	0.42	0.15	0.37	0.43	0.29	0.06	-0.12	0.10	0.17	0.05	0.17	0.07	0.21	0.20
WOODWETLAND_DW	-0.51	0.45	0.55	0.57	-0.26	0.15	0.44	0.19	0.37	0.44	0.29	0.10	-0.09	0.08	0.14	0.02	0.14	0.07	0.20	0.19
HERBWETLAND	-0.22	0.51	0.67	0.35	-0.06	0.19	0.39	0.14	0.37	0.21	0.10	0.17	0.02	0.12	0.25	-0.02	0.25	0.07	0.32	0.21
HERBWETLAND_DW	-0.23	0.52	0.70	0.38	-0.06	0.21	0.39	0.15	0.36	0.22	0.11	0.18	0.01	0.11	0.23	0.00	0.24	0.05	0.29	0.24
SUM_UNDEVELOPED	-0.16	-0.17	-0.13	0.13	-0.62	-0.19	0.07	-0.10	0.19	-0.05	0.09	-0.13	-0.38	0.12	0.17	-0.34	-0.03	0.32	0.19	-0.00
SUM_URBAN	-0.14	0.28	0.21	0.05	0.39	0.00	0.07	0.16	-0.11	0.18	0.11	0.16	0.36	0.15	0.16	0.45	0.38	-0.21	0.15	0.18
RES_L_URBAN	-0.17	0.29	0.20	0.05	0.40	-0.02	0.08	0.18	-0.09	0.18	0.08	0.16	0.35	0.17	0.18	0.49	0.41	-0.22	0.17	0.19
RES_L_URBAN_DW	-0.15	0.29	0.17	-0.02	0.40	-0.01	0.08	0.18	-0.09	0.19	0.10	0.17	0.36	0.19	0.20	0.52	0.42	-0.21	0.16	0.18
RES_H_URBAN	-0.07	0.26	0.23	0.06	0.46	0.02	-0.05	0.18	-0.23	0.14	0.06	0.05	0.24	0.03	-0.02	0.45	0.21	-0.32	-0.02	0.10
RES_H_URBAN_DW	-0.05	0.26	0.22	0.00	0.46	0.02	-0.05	0.18	-0.23	0.15	0.06	0.06	0.24	0.04	-0.00	0.46	0.22	-0.31	-0.02	0.09
COM_INDUSTR	-0.12	0.33	0.27	0.09	0.40	0.12	0.11	0.20	-0.08	0.17	0.16	0.20	0.40	0.09	0.13	0.41	0.35	-0.22	0.15	0.16
COM_INDUSTR_DW	-0.12	0.30	0.20	-0.01	0.39	0.11	0.10	0.18	-0.10	0.18	0.17	0.21	0.42	0.13	0.14	0.43	0.35	-0.21	0.13	0.12
SUM_AGRICULTURE	0.19	0.05	-0.08	-0.11	0.43	0.30	-0.02	0.07	-0.09	0.10	-0.02	0.25	0.32	-0.14	-0.21	0.06	-0.17	-0.09	-0.25	-0.14
ROW_CROP	0.01	0.15	-0.00	-0.00	0.29	0.32	0.14	0.14	0.06	0.18	0.02	0.29	0.29	0.01	-0.05	0.04	-0.09	0.05	-0.13	-0.13
ROW_CROP_DW	0.00	0.15	0.00	0.01	0.27	0.32	0.15	0.12	0.09	0.17	-0.00	0.27	0.27	0.04	-0.03	0.02	-0.08	0.09	-0.12	-0.12
PAST_HAY	0.20	-0.01	-0.17	-0.15	0.41	0.23	-0.11	0.07	-0.20	0.19	0.09	0.24	0.37	-0.19	-0.23	0.11	-0.13	-0.17	-0.23	-0.17
PAST_HAY_DW	0.23	-0.04	-0.16	-0.13	0.39	0.23	-0.12	0.05	-0.20	0.16	0.07	0.20	0.32	-0.18	-0.24	0.07	-0.17	-0.14	-0.26	-0.19
GRASSLAND	0.39	-0.05	0.12	-0.17	0.04	0.33	-0.07	0.02	-0.05	-0.27	-0.12	0.10	0.04	-0.30	-0.30	-0.34	-0.39	0.00	-0.23	-0.14

Stream-Water Relations with Environmental Characteristics

Stepwise multiple-linear regression indicated that higher concentrations of MeHg in unfiltered water from sites in unmined basins (n = 223) were primarily related to higher DOC and THg of unfiltered stream water and, to a lesser extent, higher percentages of MeHg in bed sediment, higher percentages of total wetland (woody and herbaceous) in the basin, and lower pH values of the water (adjusted $r^2 = 0.61$):

$$\begin{aligned} \ln[MeHg_{water}] = & -1.664 + 0.573\ \ln[DOC] \\ & + 0.384\ \ln[THg_{water}] - 0.270\ [pH] \\ & + 0.268\ \ln[MeHg/THg_{BS}] \\ & + 0.015\ \arcsin[L_w], \end{aligned} \qquad (4)$$

where

$MeHg_{water}$ is the MeHg concentration in unfiltered water, in nanograms per liter,

DOC is the dissolved organic carbon concentration in unfiltered water, in milligrams per liter,

$MeHg / THg_{BS}$ is the percentage of MeHg in bed sediment,

THg_{water} is the THg concentration in unfiltered water, in nanograms per liter, pH is the pH value in unfiltered water, and

L_w is the percentage of total wetland in the basin.

MeHg concentrations in unfiltered water correlated positively with concentrations of DOC ($r_s = 0.59$, $p < 0.001$) and UV absorbance ($r_s = 0.67$, $p < 0.001$) (fig. 24A, 24B; table 6). UV absorbance has been suggested as an inexpensive surrogate measure for Hg concentration in water because it correlates highly with DOC and even more highly with the types of DOC thought to complex most strongly with Hg (George R. Aiken, U.S. Geological Survey, oral commun., 2003). The correlation of unfiltered MeHg to SUVA ($r_s = 0.466$, $p < 0.01$) was not as strong. Similar but weaker correlations were found between filtered MeHg concentrations and DOC, UV absorbance, and SUVA. DOC, in turn, correlated positively with hydric soils, total wetness index, total wetlands, and precipitation-weighted atmospheric Hg deposition, and it correlated negatively with average basin elevation and average depth to the seasonally high water table. Spearman correlations between MeHg and THg in water ranged from $r_s = 0.54$ in unfiltered water (fig. 24C) to $r_s = 0.72$ in particulate water samples (table 6). In addition, MeHg and THg in unfiltered and particulate samples increased in relation to total suspended-sediment concentration. A weak negative relation was found between MeHg and pH in unfiltered water (fig. 24D). The percentage of MeHg (percent MeHg/THg) in unfiltered water was positively correlated with percent MeHg in bed sediment (fig. 24E).

MeHg concentrations in unfiltered water were higher at sites in basins with higher percentages of total wetland (fig. 24F) and with both woody wetland and herbaceous wetland (table 6). Increasing percentages of hydric soils were only weakly predictive of unfiltered MeHg. Other LULC and basin-level GIS measured characteristics were limited in their value for explaining Hg in water.

No correlation was found for modeled or actual Hg from atmospheric deposition with unfiltered MeHg; however, this is not surprising, given that water samples were collected only once at each site. The analysis was also hampered for filtered MeHg by many values below reporting limits and by sparse NADP-MDN wet-deposition data for Western States.

Discussion of Findings and Comparison with Other Studies

Our results for total Hg in fish provide evidence that Hg concentrations in freshwater fish across the United States are often greater than levels specified in various criteria for protection of fish-eating wildlife and humans. However, the purpose of our study was to compare sites and explore factors related to fish Hg; it was not intended to be a thorough assessment of fish Hg with respect to fish-consumption-advisory levels. The results presented here paint a picture of Hg in streams across the United States for a broad range of regional and national gradients in Hg source strength and factors thought to influence Hg methylation and bioaccumulation. Sources included atmospheric deposition, urbanization, and gold or Hg mining; however, sampling focused primarily on sites where atmospheric deposition was the Hg source. Hg in fish, bed sediment, and stream water were assessed spatially and with regard to existing guidelines or criteria and possible relations to stream and basin attributes, including chemical and physical characteristics, as well as LULC. To date, there have been no other studies of this scale in the literature that include multimedia sampling of MeHg and THg and, currently, there is no national Hg monitoring network in the United States for fish, bed sediment, and water.

A conceptual model for MeHg bioaccumulation is that as MeHg is formed within the ecosystem through methylation of inorganic Hg, some portion of the MeHg is transferred to stream water, and some portion of MeHg in water is taken up by the base of the aquatic food web through both sorption to detritus and uptake into living algal (periphyton) cells. MeHg is subsequently biomagnified in aquatic food webs

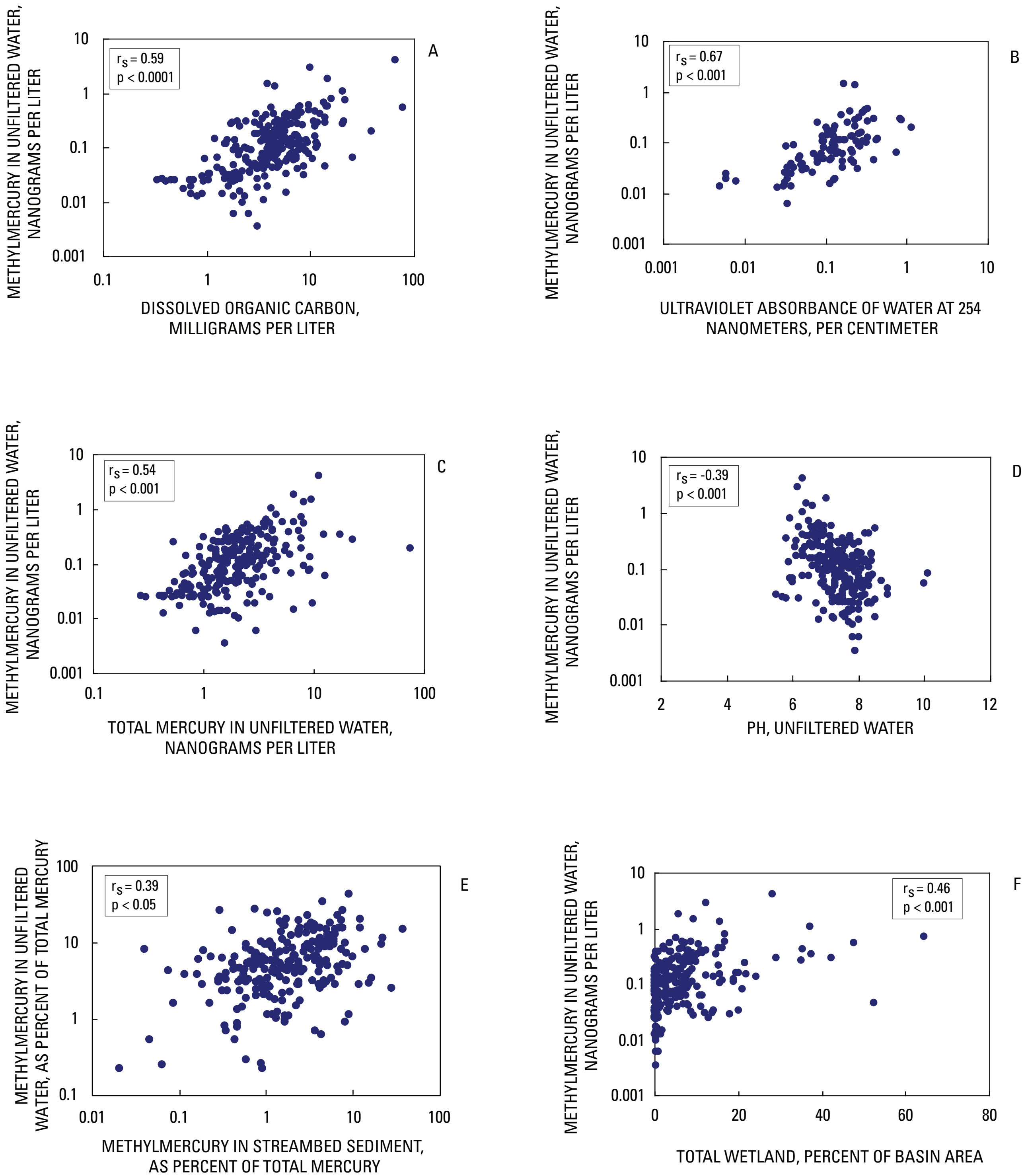

Figure 24. Correlations between mercury in unfiltered water and selected environmental characteristics in unmined basins, 1998–2005. (r_s, Spearman rank correlation coefficients.)

to reach highest concentrations at the apex of the food web. One plausible inference from this conceptual model is that MeHg concentrations in organisms at the top of the aquatic food web are linearly related to concentrations at the base of the food web, which are in turn linearly related to aqueous MeHg concentrations. We examined relations between fish Hg, which is largely MeHg, to MeHg in water. Whereas fish accumulate MeHg over time, MeHg in water is highly variable over time, season, and hydrologic conditions. Our dataset does not capture this variability, so correlations between fish Hg and MeHg measured in this study are confounded by the fact that single, instantaneous (single synoptic) aqueous MeHg measurements are an uncertain estimator of longer-term mean MeHg concentrations in a stream (Paller and others, 2004; Brigham and others, 2009). Chasar and others (2009), using temporally extensive water sampling and more complete assessment of MeHg in aquatic food webs, support the conceptual model that MeHg concentrations in predator fish are related to mean aqueous MeHg concentrations and that trophic transfer (biomagnification) is relatively consistent among diverse stream ecosystems.

Concentrations of fish Hg from our study must be compared to those from other studies with caution, owing to influences of fish species, age, length, weight, sex, and sample cut or type (skin-off fillets, as were most samples in our study, compared to skin-on fillets or whole-body fish). In general, Hg increases with age and size in top-predator fish and can be lower in whole-body fish compared to muscle or fillet. However, the ratio of fillet to whole-body Hg may be relatively consistent for some fish species (Boudou and Ribeyre, 1983; Ribeyre and Boudou, 1984; Goldstein and others, 1996). Differences in Hg relations with feeding habitat, length, and weight have been noted in other large-scale studies, including the historical NCBP (Schmitt and others, 1999), the USGS BEST study (Schmitt, 2002; Schmitt and others, 2004; Hinck and others, 2004a and 2004b, 2006, 2007), and USEPA EMAP (Peterson and others, 2007). For example, Hinck and others (2004b) analyzed whole-body fish from historical stream sites in major river basins of the United States and found that piscivorous fish (bass and northern pikeminnow) in the BEST Columbia River Basin study had higher Hg concentrations than nonpiscivores and that Hg in these fish increased with size.

Fish in streams receiving higher amounts of Hg due to atmospheric load, gold or Hg mining, or urban contamination have been found generally to have higher concentrations of Hg. Hammerschmidt and Fitzgerald (2006) compared a large historical dataset for Hg in largemouth bass (30-40 cm total length) for 25 States with average annual wet atmospheric deposition of Hg from the MDN and the literature for various periods from the 1990s to early 2004. They excluded known point sources and found a positive correlation between statewide average concentrations of Hg in largemouth bass and average annual wet deposition of Hg. Based on USEPA EMAP results, Peterson and others (2007) suggested that atmospheric deposition of Hg was an important source of fish Hg in the western United States. However, at least one recent paper found that effects of atmospheric deposition on fish Hg were lessened by the structure and function of the particular aquatic ecosystem (Rypel and others, 2008). They compared largemouth bass in two river basins in the southeastern United States; atmospheric Hg was not correlated with fish Hg. In our study, we did not find any relation to atmospheric THg except for rock bass. In recent decades, industrial Hg use and atmospheric Hg deposition have decreased in parts of the United States (Engstrom and Swain, 1997). It is, therefore, likely that fish-Hg concentrations are not at a steady state but may be decreasing in the Nation’s waters. The response time for fish Hg with regard to source input, such as from atmospheric deposition, is unknown and is likely dependent on many factors that were incompletely described or unmeasured by this study.

Gold and Hg mining played an important role in higher fish-Hg concentrations at selected sites in this study, overwhelming correlations with other site or basin characteristics. When sites in mined basins were excluded, higher unfiltered MeHg in streams correlated with higher unfiltered THg. Davis and others (2008) examined Hg in largemouth bass and other fish in streams of the Sacramento-San Joaquin Delta of California, an area affected by historical gold and Hg mining. They found that the median fish Hg for largemouth bass (0.53 μg/g ww) reflected this influence. Detailed and accurate data on Hg sources, such as atmospheric deposition, which is sparsely measured in the western United States, as well as gold or Hg mining or other sources of local Hg contamination, are critical to tease apart other environmental characteristics contributing to Hg methylation and fish Hg bioaccumulation.

In this study, the strongest correlations with environmental characteristics were found for largemouth bass, a top-predator/piscivorous fish, but significant correlations were also found for brown and rainbow-cutthroat trout, with selected environmental characteristics that were often different from those found for bass or other sunfish. In the USEPA EMAP study, fish were also grouped by genera or family for comparison to environmental factors (Peterson and others, 2007). Fish Hg for rainbow trout, cutthroat trout, and brown trout genera, as well as for suckers, had the weakest relations, if any, with measured environmental characteristics, whereas top-predator/piscivorous genera, such as pikeminnow, had the strongest. The interspecies differences we observed between fish Hg correlations with environmental characteristics (for example, largemouth and smallmouth bass) suggest caution in generalizing beyond the species level. This concern has been held historically for different groups of biota and other environmental contaminants.

Results of the current study indicate that, if sites in gold or Hg mined basins are excluded from statistical analysis, the most important environmental characteristics for predicting increasing concentrations of unfiltered MeHg in streams are higher concentrations of DOC, unfiltered THg, and bed-sediment MeHg, as well as higher basin percentages of wetland and lower pH. Increased bed-sediment MeHg was correlated with increasing LOI as a measure of sediment organic content, bed-sediment THg, and AVS. The best predictors of increasing fish Hg for largemouth bass were increasing basin percentages of forest and wetland, MeHg in unfiltered water and bed sediment, and decreasing pH and dissolved sulfate. Although less important than water and bed-sediment organic content (as measured by DOC and LOI, respectively), sulfate was a useful characteristic for understanding Hg in fish, bed sediment, and water. Dissolved sulfate concentration negatively correlated with fish Hg for largemouth bass and brown trout. Similarly, atmospheric sulfate deposition positively correlated with fish Hg in rock bass. The roles of pH and sulfate in Hg methylation have been documented in the literature; sulfate is important in Hg methylation by bacteria and, depending on concentration, can have either a positive or negative effect on Hg methylation (Compeau and Bartha, 1983, 1987; Gilmour and others, 1992, 1998; Benoit and others, 2003). The complex nature of sulfate effects may help explain why it was not highly correlated with fish Hg across the broad range of concentrations and environmental conditions found in our study.

Increasing MeHg in water with increasing DOC, as found in our study over a broad range of environmental conditions, confirms similar results found in smaller scale studies with regard to the role of DOC in Hg methylation (St. Louis and others, 1994; Hurley and others, 1995). With the exception of a negative correlation for rock bass, DOC was not correlated with fish Hg, but unfiltered MeHg was found to be positively correlated with fish Hg for all fish species where data were sufficient for this examination. MeHg in unfiltered water was less than 1 ng/L at most sites and, although MeHg in unfiltered water was high for many sites in mined basins, both unfiltered MeHg and fish Hg were high at many other sites that also were high in DOC, such as coastal-plain streams along the eastern and southern United States. These observations underscore the importance of multiple factors that control Hg bioaccumulation. A large source of Hg input to an ecosystem, coupled with a modest capacity of the ecosystem to methylate inorganic Hg, can produce high levels of MeHg in water and fish. In contrast, a modest Hg source input to an ecosystem, such as in ecosystems where atmospheric deposition is thought to be the predominant source, coupled with a large capacity of an ecosystem to methylate inorganic Hg, also can produce high MeHg concentrations in water and fish.

High fish THg concentrations were found at sites that had high percentages of forest and wetland, especially evergreen forest and woody wetland more proximal to stream sites. MeHg in unfiltered water positively correlated with wetland abundance and, as for fish, MeHg relations to woody or herbaceous wetland strengthened when these LULC types were more proximal to stream sites. Wente (2000) showed that proximity-based (distance-weighted) LULC explained more variability in ecosystem integrity than more commonly used standard percentages of LULC, a finding also seen in this study. Other studies have found greater amounts of wetland to be correlated with higher water MeHg (St. Louis and others, 1994, 1996; Hurley and others, 1995; Krabbenhoft and others, 1999; Grigal, 2002; Brigham and others, 2009). Higher rates of Hg methylation in wetlands promote higher MeHg in streams, especially during years of high water yield (Krabbenhoft and others, 1995; Branfireun and others, 1996). Chumchal and others (2008) noted that Hg concentrations in largemouth bass were higher from forested-wetland habitat compared to open-water habitat. Our finding of higher potential methylation rates, based on the MeHg to THg ratio, at sites in basins with primarily undeveloped land in comparison to urban land, agrees with findings of Krabbenhoft and others (1999) who noted that forested and mixed forest/agricultural basins had higher rates than streams in mining and urban basins. Horowitz and Stephens (2008) found that THg in bed sediment was higher at sites in forested basins (≥ 50 percent forested land use) than in basins in other LULC categories. They analyzed data for a suite of trace elements across 1,200 stream sites sampled as part of the NAWQA Program during 1991 to 1999. Evergreen forest canopies have greater effective surface areas than deciduous forest canopies or open (non-forested) land for filtering Hg from atmospheric deposition (Iverfeldt, 1991; Kolka and others, 1999). A study by St. Louis and others (2001) showed that the tree canopies of boreal forests receiving low atmospheric deposition are significant sources of both MeHg and THg via litter fall to the forest floor, wetlands, and potentially to downstream water bodies. This underscores the greater sensitivity and efficiency of these two LULC types with regard to Hg methylation.

Summary and Conclusions

Hg in top-predator fish, bed sediment, and water was examined from streams in diverse settings across the United States during 1998–2005 by the USGS. Most studies of Hg in aquatic environments have focused on lakes, reservoirs, and wetlands because of the predominance of lakes with Hg concerns and the importance of wetlands in Hg methylation. Fewer studies have focused on Hg in streams or rivers. This report describes the occurrence and distribution of THg in stream fish in relation to regional and national gradients of Hg source strength (including atmospheric deposition, gold and Hg mining, urbanization) and other factors that are thought to affect Hg concentrations, including LULC. In addition, concentrations of THg and MeHg in bed sediment and stream water were evaluated in relation to these gradients and to identify ecosystem characteristics that favor the production and bioaccumulation of MeHg.

Site selection targeted environmental settings thought to be important with regard to the source, concentration, or biogeochemical behavior of Hg in aquatic ecosystems. Agricultural, urban, undeveloped (forested, grassland, shrubland, and wetland land cover), and mined (for gold and Hg) settings were of particular interest. Each site was sampled one time during seasonal low flow. Predator fish were targeted for collection, and composited skin-off fillets were analyzed for THg, as most of the Hg found in fish tissue (95–99 percent) is MeHg. Bed sediment and stream water were analyzed for THg, MeHg, and characteristics thought to affect Hg methylation, such as LOI, AVS, pH, DOC, and dissolved sulfate.

Key findings of this report are as follows:

- Hg concentrations in fish at more than two-thirds of the sites exceeded the value of 0.1 µg/g Hg ww that is of concern for the protection of fish-eating mammals, including mink and otters. Fish-Hg concentrations equaling or exceeding the 0.3 µg/g ww USEPA criterion for the protection of human health were found at 27 percent of the sites. The highest concentrations among all sampled sites occurred in fish from blackwater coastal-plain streams draining forested land or wetland in the eastern and southeastern United States, as well as from streams draining gold- or Hg-mined basins in the western United States.

- Across the United States, concentrations of MeHg in unfiltered water and in bed sediment were generally low (median values were 0.11 and 0.51 ng/g, respectively).

- Concentrations of MeHg in unfiltered water from several blackwater coastal-plain streams were similar to those of streams in mined basins, although THg concentrations were significantly lower than in mined basins. This finding emphasizes the importance of the amount of Hg in an ecosystem in combination with the capacity of an ecosystem to methylate inorganic Hg.

- Across all sites, fish Hg was not significantly different between sites in unmined basins compared to mined basins, except for smallmouth bass. This exception was driven by one high outlier from a mined basin.

- Largemouth bass from predominantly undeveloped or mixed-land-use basins were significantly higher in Hg than were largemouth bass from urban basins.

- Length-normalized Hg concentrations in largemouth bass from unmined basins were primarily related to basin percentages of evergreen forest and woody wetland, especially with proximity of these land-cover types to the sampling site. This finding underscores the sensitivity of these land-cover types to Hg bioaccumulation.

- Length-normalized Hg concentrations in largemouth bass were highly correlated with stream water and bed sediment chemistry, and with LULC characteristics, but this was not true for smallmouth bass. This finding warns against interspecies conversions of fish-Hg concentrations because different fish species are influenced by different factors.

- In addition to basin percentages of evergreen forest and woody wetland, increasing concentrations of MeHg in unfiltered stream water, increasing bed sediment MeHg normalized by loss-on-ignition (LOI), and decreasing pH and dissolved sulfate also were important as explanatory variables for Hg concentrations in largemouth bass.

- In contrast to the positive relation for fish Hg with evergreen forest and woody wetland LULC, bed-sediment THg concentrations were higher in urban sites. Higher concentrations of MeHg in bed sediment were found with higher THg, LOI, and AVS; LOI was a strong predictor of bed-sediment THg and MeHg.

- Concentrations of MeHg in unfiltered water were higher with higher DOC and increased DOC complexity (as measured by SUVA), THg in water, percentage of MeHg in bed sediment, and percentage of wetland in the basin.

It is difficult to directly compare fish-Hg concentrations across the Nation by using any compilation of existing fish-Hg data. Increased water sampling over the water cycle, such as was done by Brigham and others (2009), Chasar and others (2009), and Marvin-DiPasquale and others (2009), could increase identification and understanding of factors leading to high Hg bioaccumulation.

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Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.

[**Land-use/land-cover category**: "other" includes water, bare rock, quarry/mine, transitional, tundra, and ice/snow. **Abbreviations:** USGS, U.S. Geological Survey; DMS, degrees-minutes-seconds; km^2, square kilometers; NAD 83, North American Datum 83; *, not determined]

Site number	Site name	USGS station identifier	Latitude (DMS) NAD 83	Longitude (DMS) NAD 83	Drainage area (km^2)	Mined	Land use/land cover (percent of basin area)						Land-use/land-cover category
							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
ACAD.1	Bogue Falaya at Covington, La.	07375170	30 29 59	-090 05 04	*	No	*	*	*	*	*	*	*
ACAD.2	Tangipahoa River at Robert, La.	07375500	30 30 24	-090 21 42	1,675	No	3.3	33.4	58.4	3.0	0.0	1.9	Mixed
ACAD.3	Blind River near Gramercy, La.	07380222	30 06 01	-090 44 07	141	No	6.5	40.5	3.8	46.6	0.0	2.5	Mixed
ACAD.4	Bayou Boeuf at Railroad Bridge at Amelia, La.	073814675	29 40 06	-091 05 59	3,171	No	4.8	37.7	3.6	52.4	0.1	1.5	Mixed
ACAD.5	Bayou Teche at Keystone Lock near St. Martinville, La.	07385700	30 04 16	-091 49 45	181	No	14.6	66.7	6.1	10.6	0.2	1.7	Mixed
ACAD.6	Mermentau River at Mermentau, La.	08012150	30 11 24	-092 35 26	3,576	No	3.2	63.7	20.9	10.0	0.9	1.2	Ag
ACAD.7	Bayou Lacassine near Lake Arthur, La.	08012470	30 04 12	-092 52 44	767	No	2.2	87.6	2.9	6.7	0.2	0.4	Ag
ACAD.8	Whiskey Chitto Creek near Oberlin, La.	08014500	30 41 56	-092 53 35	1,305	No	1.4	8.2	65.8	15.3	0.0	9.4	Undev
ACAD.9	Calcasieu River near Kinder, La.	08015500	30 30 09	-092 54 56	4,442	No	1.8	11.3	64.9	15.5	0.0	6.3	Undev
ACAD.10	Turtle Bayou near Bayou Penchant, La.	293524091041300	29 35 25	-091 04 13	*	No	*	*	*	*	*	*	*
ACAD.11	Bayou Segnette 4.6 mi South of Westwego, La.	294957090095300	29 49 58	-090 09 53	62	No	35.1	0.5	5.1	55.0	0.5	3.8	Urban
ACFB.1	New River near Sumatra, Fla.	02330400	30 02 20	-084 50 38	449	No	0.0	0.3	34.3	64.4	0.0	1.0	Undev
ACFB.2	Peachtree Creek at Atlanta, Ga.	02336300	33 49 10	-084 24 28	222	No	85.3	0.0	14.2	0.0	0.0	0.4	Urban
ACFB.3	Chattahoochee River near Whitesburg, Ga.	02338000	33 28 37	-084 54 03	6,251	Yes	19.2	10.2	66.0	0.7	0.0	3.8	Mixed
ACFB.4	Mulberry Creek at Mountain Hill Road, below Hamilton, Ga.	02341230	32 40 56	-085 00 30	421	No	1.1	7.2	84.6	1.8	0.0	5.2	Undev
ACFB.5	Flint River at Montezuma, Ga.	02349500	32 17 54	-084 02 38	7,575	Yes	4.8	18.4	65.3	7.8	0.0	3.8	Undev
ACFB.6	Cooleewahee Creek near Newton, Ga.	02352980	31 19 49	-084 19 50	400	No	4.5	38.3	33.2	20.1	0.0	3.9	Mixed
ACFB.7	Chickasawhatchee Creek at Elmodel, Ga.	02354500	31 21 02	-084 28 57	818	No	0.9	32.0	37.4	24.2	0.0	5.6	Mixed
ACFB.8	Spring Creek at US Hwy 84 at Brinson, Ga.	02357050	30 58 31	-084 44 44	1,394	No	0.9	52.0	29.9	12.9	0.0	4.3	Ag
ALBE.1	Nottoway River near Sebrell, Va.	02047000	36 46 14	-077 09 58	3,731	No	2.1	20.6	66.4	7.6	0.0	3.3	Undev
ALBE.2	Ahoskie Creek near Poortown, N.C.	02053490	36 17 19	-077 01 31	150	No	3.9	24.6	52.7	16.8	0.0	1.9	Mixed
ALBE.3	Falling River below Hat Creek near Brookneal, Va.	02065000	37 04 54	-078 56 07	575	No	3.0	27.6	65.8	0.8	0.0	2.8	Mixed
ALBE.4	Grindle Creek at US 264 at Pactolus, N.C.	0208412725	35 37 28	-077 13 16	192	No	1.3	38.8	34.7	22.0	0.0	3.2	Mixed
ALBE.5	Flat River at SR 1737 near Red Mountain, N.C.	0208539150	36 14 31	-078 54 21	265	No	4.9	29.8	64.0	0.6	0.0	0.7	Mixed
ALBE.6	Crabtree Creek at US 1 at Raleigh, N.C.	02087324	35 48 40	-078 36 39	315	No	33.7	6.2	55.2	2.1	0.0	2.8	Urban
ALBE.7	Walnut Creek at Sunnybrook Drive near Raleigh, N.C.	02087359	35 45 30	-078 34 59	77	No	61.8	3.2	26.0	2.4	0.0	6.5	Urban
ALBE.8	Contentnea Creek at Hookerton, N.C.	02091500	35 25 44	-077 34 57	1,909	No	4.3	41.9	33.4	19.4	0.0	1.0	Mixed
ALMN.1	Clarion River at Ridgway, Pa.	03029000	41 25 15	-078 44 09	791	No	2.8	6.9	89.0	0.2	0.0	1.1	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
ALMN.2	Allegheny River at New Kensington, Pa.	03049625	40 33 52	-079 46 21	29,728	No	2.5	20.8	74.0	1.0	0.0	1.8	Undev
ALMN.3	Dunkard Creek at Shannopin, Pa.	03072000	39 45 33	-079 58 14	588	No	0.7	20.3	78.2	0.1	0.0	0.8	Undev
ALMN.4	Tenmile Creek near Amity, Pa.	03072815	40 01 11	-080 12 19	134	No	2.3	44.2	53.4	0.0	0.0	*	Mixed
ALMN.5	Youghiogheny River at Sutersville, Pa.	03083500	40 14 24	-079 48 23	4,429	No	3.6	26.4	67.2	0.7	0.0	2.0	Mixed
CACI.1	North Canadian River near Calumet, Okla.	07239450	35 37 01	-098 03 55	34,332	No	0.4	43.4	1.0	0.1	54.7	0.4	Mixed
CACI.2	North Canadian River at Britton Rd at OKC, Okla.	07241520	35 33 56	-097 22 02	35,478	No	1.2	43.6	1.1	0.1	53.5	0.5	Mixed
CAZB.1	Verde River above W. Clear Creek, near Camp Verde, Ariz.	09505570	34 30 20	-111 50 08	11,211	Yes	1.1	0.4	44.6	0.0	53.1	0.7	Undev
CAZB.2	West Clear Creek near Hwy 260, Ariz.	343104111461300	34 31 04	-111 46 16	665	No	0.0	0.0	86.6	0.0	13.4	*	Undev
CAZB.3	Wet Beaver Creek at Beaver Creek Campground, Ariz.	344010111424300	34 40 10	-111 42 46	299	No	0.0	0.0	79.4	0.0	20.6	*	Undev
CAZB.4	Verde River above Perkinsville diversion, Ariz.	345338112124500	34 53 38	-112 12 48	7,587	Yes	0.8	0.3	34.3	0.0	63.7	0.9	Undev
CCYK.1	Crab Creek at Rocky Ford Road near Ritzville, Wash.	12464770	47 18 10	-118 22 09	1,188	No	1.2	66.6	4.0	0.3	27.4	0.4	Ag
CCYK.2	Umtanum Creek near mouth at Umtanum, Wash.	12484550	46 51 26	-120 29 50	137	No	0.0	2.7	6.4	0.0	90.8	0.1	Undev
CCYK.3	S F Ahtanum Creek above Conrad Ranch near Tampico, Wash.	12500900	46 29 31	-120 57 27	48	No	0.0	0.0	79.0	0.0	16.7	4.3	Undev
CCYK.4	Satus Creek at gage at Satus, Wash.	12508620	46 16 25	-120 08 36	1,458	No	0.1	0.7	29.4	0.1	69.4	0.4	Undev
CCYK.5	Yakima River at Kiona, Wash.	12510500	46 15 12	-119 28 41	14,536	Yes	2.1	15.0	36.2	0.2	41.9	4.7	Mixed
CCYK.6	Rock Creek below Cottonwood Creek near Revere, Wash.	13349700	47 06 16	-117 47 17	1,767	No	1.3	81.2	2.9	0.1	13.6	0.9	Ag
CCYK.7	Frenchmannhills at Road I, near George, Wash.	470012119410300	47 00 12	-119 41 03	297	No	2.8	80.8	0.1	0.6	15.2	0.5	Ag
CHEY.1	Moreau River near Whitehorse, S. Dak.	06360500	45 15 21	-100 50 35	12,657	No	0.1	18.1	0.3	0.7	79.5	1.3	Undev
CHEY.2	Cheyenne River near Hot Springs S. Dak.	06400500	43 18 19	-103 33 45	22,592	Yes	0.1	1.2	7.9	1.0	89.4	0.4	Undev
CHEY.3	Cheyenne River at Redshirt, S. Dak.	06403700	43 40 23	-102 53 38	26,563	Yes	0.2	2.7	8.7	0.9	86.9	0.6	Undev
CHEY.4	Cheyenne River near Wasta, S. Dak.	06423500	44 04 52	-102 24 05	32,865	Yes	0.5	3.9	12.9	0.9	80.4	1.4	Undev
CHEY.5	Belle Fourche River at Belle Fourche, S. Dak.	06429000	44 40 30	-103 51 22	8,602	Yes	0.4	6.5	10.9	2.3	79.4	0.6	Undev
CHEY.6	Belle Fourche River below Nisland, S. Dak.	06436100	44 40 12	-103 29 32	11,888	Yes	0.4	8.5	18.1	2.8	69.7	0.5	Undev
CHEY.7	Whitewood Creek above Lead, S. Dak.	06436150	44 18 07	-103 46 59	22	No	0.2	0.0	85.7	3.1	11.0	*	Undev
CHEY.8	Whitewood Creek at Deadwood, S. Dak.	06436170	44 22 48	-103 43 27	105	Yes	3.3	0.0	78.6	1.6	13.9	2.6	Undev
CHEY.9	Whitewood Creek above Whitewood, S. Dak.	06436180	44 26 32	-103 37 46	147	Yes	2.6	1.7	76.5	1.9	15.4	1.9	Undev
CHEY.10	Whitewood Creek above Vale, S. Dak.	06436198	44 37 04	-103 28 54	267	Yes	1.9	15.5	46.7	5.0	30.0	1.1	Undev
CHEY.11	Belle Fourche River at Vale, S. Dak.	06436250	44 38 10	-103 25 39	12,787	Yes	0.4	8.6	17.8	2.9	69.5	0.7	Undev
CHEY.12	Belle Fourche River near Sturgis, S. Dak.	06437000	44 30 47	-103 08 13	15,021	Yes	0.4	9.7	15.3	3.1	70.9	0.7	Undev
CHEY.13	Belle Fourche River near Elm Springs, S. Dak.	06438000	44 22 11	-102 33 58	18,309	Yes	0.3	10.1	13.6	2.9	72.0	1.1	Undev

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									Forest	Wetland	Shrub/grassland		
CHEY.14	Cheyenne River near Plainview, S. Dak.	06438500	44 31 46	-101 55 49	55,527	Yes	0.4	6.7	12.6	1.6	77.4	1.3	Undev
CHEY.15	Cheyenne River at Cherry Creek, S. Dak.	06439300	44 35 59	-101 29 53	61,041	Yes	0.4	7.0	11.5	1.4	78.4	1.3	Undev
CHEY.16	Cheyenne River near Eagle Butte, S. Dak.	06439500	44 41 47	-101 13 03	62,787	Yes	0.4	7.2	11.2	1.4	78.6	1.3	Undev
CHEY.17	Yellow Creek at mouth, at Lead, S. Dak.	442023103451600	44 20 23	-103 45 18	55	Yes	1.7	0.0	82.3	2.0	11.7	2.3	Undev
CHEY.18	Whitetail Creek below Kirk Power Plant, at Lead, S. Dak.	442034103453100	44 20 34	-103 45 33	18	Yes	4.9	0.0	71.5	0.8	15.8	6.9	Undev
CHEY.19	West Strawberry Creek above Grizzly Gulch, near Lead, S. Dak.	442042103434600	44 20 42	-103 43 48	5	No	0.0	0.0	94.6	0.3	5.1	*	Undev
CHEY.20	Deadwood Creek above Central City, S. Dak.	442148103471000	44 21 48	-103 47 12	9	Yes	0.0	0.0	87.2	1.3	11.4	0.1	Undev
CNBR.1	Dismal River near Thedford, Nebr.	06775900	41 46 43	-100 31 31	72	No	0.0	1.1	12.3	12.1	72.0	2.5	Undev
CNBR.2	Middle Loup River at St. Paul, Nebr.	06785000	41 12 13	-098 26 46	20,918	No	0.2	14.6	2.2	2.4	79.5	1.1	Mixed
CNBR.3	North Loup River at Taylor, Nebr.	06786000	41 46 37	-099 22 45	6,088	No	0.0	2.2	0.4	5.4	90.8	1.2	Undev
CNBR.4	Calamus River near Harrop, Nebr.	06787000	41 56 49	-099 23 10	1,794	No	0.0	1.5	0.2	8.0	88.3	2.1	Undev
CNBR.5	Cedar River near Spalding, Nebr.	06791500	41 42 41	-098 26 49	1,947	No	0.0	10.9	0.9	6.6	80.4	1.2	Undev
CNBR.6	Maple Creek near Nickerson, Nebr.	06800000	41 33 37	-096 32 27	954	No	0.4	96.7	1.0	0.2	1.4	0.3	Ag
CNBR.7	Elkhorn River at Waterloo, Nebr.	06800500	41 17 36	-096 17 02	17,989	No	0.8	67.8	1.7	7.3	21.6	0.9	Ag
CNBR.8	Salt Creek at Greenwood, Nebr.	06803555	40 57 56	-096 27 16	2,724	No	5.7	72.8	2.5	1.0	16.9	1.0	Mixed
CONN.1	Priest Brook near Winchendon, Mass.	01162500	42 40 57	-072 06 54	50	No	2.7	4.5	78.7	12.2	0.0	1.9	Undev
CONN.2	Green River at Stewartville, Mass.	01170095	42 42 42	-072 40 07	107	No	0.3	6.1	90.7	2.3	0.0	0.6	Undev
CONN.3	Connecticut River at Thompsonville, Conn.	01184000	41 59 14	-072 36 19	25,049	Yes	5.0	8.4	78.7	4.6	0.2	3.1	Undev
CONN.4	Broad Brook at Broad Brook, Conn.	01184490	41 54 50	-072 33 00	38	No	13.1	39.0	41.8	5.2	0.0	0.9	Mixed
CONN.5	Pequabuck River at Forestville, Conn.	01189000	41 40 23	-072 54 02	116	No	34.6	7.9	49.8	5.0	0.0	2.7	Urban
CONN.6	Hockanum River near East Hartford, Conn.	01192500	41 46 59	-072 35 14	191	No	42.7	11.2	36.6	7.0	0.0	2.5	Urban
CONN.7	Konkapot River at Hartsville-Mill River Road, near Mill River, Mass.	01198158	42 07 46	-073 15 50	90	No	4.0	5.4	86.1	0.9	0.0	3.7	Undev
CONN.8	Norwalk River at South Wilton, Conn.	01209700	41 09 49	-073 25 09	85	No	50.2	2.8	39.8	5.8	0.0	1.4	Urban
COOK.1	South Fork Campbell Creek near Anchorage, Alaska	15274000	61 10 00	-149 46 22	76	No	*	*	*	*	*	*	*
COOK.2	Chester Creek at Arctic Boulevard at Anchorage, Alaska	15275100	61 12 17	-149 53 51	71	No	*	*	*	*	*	*	*
COOK.3	Deshka River near Willow, Alaska	15294100	61 46 03	-150 20 21	1,531	No	*	*	*	*	*	*	*
COOK.4	Johnson River above Lateral Glacier near Tuxedni Bay, Alaska	15294700	60 05 39	-152 54 46	64	No	*	*	*	*	*	*	*
COOK.5	Costello Creek near Colorado, Alaska	631018149323700	63 16 16	-149 32 45	60	Yes	*	*	*	*	*	*	*
DELR.1	West Branch Delaware River at Walton, N.Y.	01423000	42 09 58	-075 08 24	860	No	1.3	23.1	75.2	0.1	0.0	0.2	Undev
DELR.2	Lackawaxen River at Hawley, Pa.	01431500	41 28 34	-075 10 20	749	No	1.6	18.7	74.1	2.7	0.0	3.0	Undev
DELR.3	Delaware River at Port Jervis, N.Y.	01434000	41 22 14	-074 41 51	7,968	No	1.9	10.6	83.5	1.4	0.0	2.5	Undev

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
DELR.4	Neversink River near Claryville, N.Y.	01435000	41 53 24	-074 35 24	172	No	0.3	0.5	99.1	0.0	0.0	0.1	Undev
DELR.5	Neversink River at Godeffroy, N.Y.	01437500	41 26 28	-074 36 07	794	No	4.9	2.9	87.7	1.4	0.0	3.0	Undev
DELR.6	Bush Kill at Shoemakers, Pa.	01439500	41 05 17	-075 02 16	306	No	3.7	0.4	84.1	9.4	0.0	2.4	Undev
DELR.7	Flat Brook near Flatbrookville, N.J.	01440000	41 06 22	-074 57 09	168	No	1.5	7.0	87.4	3.1	0.0	1.0	Undev
DELR.8	Brodhead Creek at Minisink Hills, Pa.	01442500	40 59 55	-075 08 34	675	No	8.5	7.2	79.6	3.0	0.0	1.6	Mixed
DELR.9	Little Lehigh Creek at East Texas, Pa.	01451425	40 32 34	-075 33 46	131	No	8.6	67.5	23.1	0.3	0.0	0.5	Mixed
DELR.10	Jordan Creek near Schnecksville, Pa.	01451800	40 39 42	-075 37 37	136	No	1.8	64.9	32.5	0.3	0.0	0.3	Ag
DELR.11	Lehigh River at Glendon, Pa.	01454700	40 40 09	-075 14 11	3,519	No	10.0	23.0	60.4	3.5	0.0	3.1	Mixed
DELR.12	Pidcock Creek near New Hope, Pa.	01462100	40 19 46	-074 56 13	36	No	0.6	38.6	58.8	1.7	0.0	0.3	Mixed
DELR.13	Delaware River at Trenton, N.J.	01463500	40 13 18	-074 46 41	17,580	No	5.3	16.4	73.0	2.5	0.0	2.8	Mixed
DELR.14	Shabakunk Creek near Lawrenceville, N.J.	01463810	40 15 19	-074 44 16	33	No	66.5	14.1	14.9	4.2	0.0	0.3	Urban
DELR.15	Pine Run at Chalfont, Pa.	01464710	40 17 20	-075 12 10	33	No	19.1	45.7	33.5	0.3	0.0	1.5	Mixed
DELR.16	Little Neshaminy Creek at Valley Road near Neshaminy, Pa.	01464907	40 13 45	-075 07 11	72	No	37.2	31.2	30.4	0.2	0.0	1.0	Mixed
DELR.17	Pennypack Creek at Paper Mill, Pa.	01467040	40 08 24	-075 04 27	61	No	81.9	4.0	13.0	0.4	0.0	0.6	Urban
DELR.18	South Branch Pennsauken Creek at Cherry Hil, N.J.	01467081	39 56 30	-075 00 04	23	No	72.7	12.1	9.5	5.3	0.0	0.4	Urban
DELR.19	Cooper River at Haddonfield, N.J.	01467150	39 54 11	-075 01 17	47	No	69.5	6.5	17.1	3.5	0.0	3.5	Urban
DELR.20	Tulpehocken Creek near Bernville, Pa.	01470779	40 24 48	-076 10 18	179	No	4.6	81.9	12.5	0.4	0.0	0.6	Ag
DELR.21	Wyomissing Creek at West Reading, Pa.	01471520	40 19 41	-075 56 40	42	No	38.2	23.3	37.8	0.3	0.0	0.4	Urban
DELR.22	Hay Creek near Birdsboro, Pa.	01471668	40 15 04	-075 48 49	57	No	0.7	21.2	75.4	1.1	0.0	1.6	Undev
DELR.23	Manatawny Creek near Pottstown, Pa.	01471980	40 16 22	-075 40 48	222	No	2.2	41.3	54.9	0.9	0.0	0.7	Mixed
DELR.24	Pigeon Creek near Parker Ford, Pa.	01472100	40 11 48	-075 35 12	37	No	6.0	45.0	48.8	0.1	0.0	0.1	Mixed
DELR.25	French Creek near Phoenixville, Pa.	01472157	40 09 05	-075 36 05	152	No	1.8	34.1	62.7	0.9	0.0	0.5	Mixed
DELR.26	Stony Creek at Sterigere Street at Norristown, Pa.	01473470	40 07 38	-075 20 42	49	No	46.6	27.7	24.4	0.2	0.0	1.1	Mixed
DELR.27	Wissahickon Creek at mouth, Philadelphia, Pa.	01474000	40 00 55	-075 12 25	165	No	61.8	9.9	26.8	0.4	0.0	1.1	Urban
DELR.28	Schuylkill River at Philadelphia, Pa.	01474500	39 58 04	-075 11 19	4,896	Yes	13.8	37.3	45.6	0.7	0.0	2.6	Mixed
DELR.29	Darby Creek at Foxcroft, Pa.	01475430	39 59 45	-075 21 21	41	No	64.3	10.9	24.5	0.2	0.0	0.1	Urban
DELR.30	Darby Creek near Darby, Pa.	01475510	39 55 44	-075 16 21	98	No	78.3	6.0	15.3	0.3	0.0	0.1	Urban
DELR.31	Crum Creek at Goshen Road near Whitehorse, Pa.	01475845	39 59 24	-075 26 15	33	No	33.3	19.5	46.9	0.3	0.0	*	Urban
DELR.32	Ridley Creek near Media, Pa.	01476470	39 55 57	-075 24 42	71	No	21.0	27.4	51.3	0.1	0.0	0.2	Mixed
DELR.33	Raccoon Creek near Swedesboro, N.J.	01477120	39 44 26	-075 15 33	67	No	6.9	65.7	23.2	3.8	0.0	0.3	Mixed
DELR.34	East Branch Brandywine Creek near Dorlan, Pa.	01480665	40 03 08	-075 43 27	87	No	2.5	51.8	44.3	0.2	0.0	1.1	Ag
GAFL.1	St. Marys River at Boulogne, Fla.	02231220	30 46 36	-081 58 43	3,311	No	1.6	1.5	48.6	37.2	1.6	9.5	Undev
GAFL.2	Little Wekiva River near Longwood, Fla.	02234998	28 42 13	-081 23 31	115	No	72.9	7.1	4.1	5.3	1.3	9.2	Urban
GAFL.3	Blackwater Creek near Cassia, Fla.	02235200	28 52 28	-081 29 23	298	No	3.0	18.6	34.4	28.1	5.7	10.2	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

[**Land-use/land-cover category**: "other" includes water, bare rock, quarry/mine, transitional, tundra, and ice/snow. **Abbreviations:** USGS, U.S. Geological Survey; DMS, degrees-minutes-seconds; km^2, square kilometers; NAD 83, North American Datum 83; *, not determined]

Site number	Site name	USGS station identifier	Latitude (DMS) NAD 83	Longitude (DMS) NAD 83	Drainage area (km^2)	Mined	Land use/land cover (percent of basin area)						Land-use/land-cover category
							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
GAFL.4	Withlacoochee River at US 84, near Quitman, Ga.	02318500	30 47 35	-083 27 13	3,864	No	3.0	49.7	25.5	15.2	0.3	6.3	Mixed
GAFL.5	Santa Fe River near Fort White, Fla.	02322500	29 50 56	-082 42 54	2,592	No	2.8	14.6	47.0	18.1	10.6	6.9	Undev
GAFL.6	Steinhatchee River near Cross City, Fla.	02324000	29 47 12	-083 19 17	791	No	0.1	0.2	41.0	42.4	0.1	16.1	Undev
GAFL.7	Econfina River near Perry, Fla.	02326000	30 10 15	-083 49 26	556	No	0.3	3.1	35.1	47.6	3.3	10.5	Undev
GRSL.1	Cub River near Richmond, Utah	10102200	41 55 35	-111 51 13	577	No	1.0	33.9	21.7	0.7	42.3	0.4	Ag
GRSL.2	Weber River near Coalville, Utah	10130500	40 53 43	-111 24 07	1,108	Yes	1.2	5.1	60.7	0.0	31.2	1.8	Undev
GRSL.3	Jordan River at 1700 South at Salt Lake City, Utah	10171000	40 44 01	-111 55 24	9,096	Yes	6.0	7.3	41.7	0.5	39.4	5.1	Mixed
HDSN.1	Hudson River near Winebrook Hills, N.Y.	01311951	43 57 30	-074 05 38	224	No	0.2	0.1	94.8	1.8	0.0	3.0	Undev
HDSN.2	Hudson River near Newcomb, N.Y.	01312000	43 57 58	-074 07 51	495	No	0.3	0.1	92.1	3.3	0.0	4.2	Undev
KANS.1	Kill Creek at 95 St near Desoto, Kans.	06892360	38 57 24	-094 58 25	124	No	18.1	65.3	12.0	0.8	2.5	1.4	Mixed
KANS.2	Cedar Creek near Desoto, Kans.	06892495	38 58 41	-094 55 22	151	No	11.2	59.9	22.3	1.1	3.5	2.0	Mixed
KANS.3	Mill Creek at Johnson Drive, Shawnee, Kans.	06892513	39 01 45	-094 49 02	150	No	34.5	43.0	16.3	1.1	2.7	2.3	Mixed
KANS.4	Indian Creek at State Line Rd, Leawood, Kans.	06893390	38 56 18	-094 36 28	167	No	58.2	32.6	5.7	1.2	1.4	0.9	Mixed
LERI.1	Clinton River at Sterling Heights, Mich.	04161820	42 36 52	-083 01 36	803	No	29.0	26.7	25.4	10.8	0.0	8.2	Mixed
LERI.2	Cuyahoga River near Newburgh Heights, Ohio	04208504	41 27 45	-081 40 51	2,044	No	29.1	25.5	36.2	6.2	0.0	2.9	Mixed
LERI.3	Grand River at Harpersfield, Ohio	04211820	41 45 19	-080 56 54	1,431	No	1.2	41.6	40.4	15.7	0.0	1.1	Mixed
LINJ.1	Swan River at East Patchogue N.Y.	01305500	40 46 01	-072 59 37	21	No	79.1	1.2	18.8	0.6	0.0	0.3	Urban
LINJ.2	Passaic River near Millington, N.J.	01379000	40 40 48	-074 31 44	140	No	25.9	11.3	40.7	21.5	0.0	0.7	Urban
LINJ.3	Raritan River at Queens Bridge at Bound Brook, N.J.	01403300	40 33 34	-074 31 40	2,074	No	17.5	34.1	42.0	5.0	0.0	1.4	Mixed
LINJ.4	Bound Brook at Middlesex, N.J.	01403900	40 35 06	-074 30 28	126	No	74.9	1.0	18.2	5.6	0.0	0.3	Urban
LINJ.5	Great Egg Harbor River near Sicklerville, N.J.	01410784	39 44 01	-074 57 04	39	No	36.1	14.5	33.3	14.8	0.0	1.3	Urban
LINJ.6	Muddy Run at Centerton, N.J.	01411700	39 31 28	-075 10 08	98	No	4.4	65.8	22.1	6.4	0.0	1.3	Ag
MISE.1	Hatchie River at Bolivar, Tenn.	07029500	35 16 31	-088 58 36	3,837	No	1.3	27.6	64.3	4.8	0.0	2.0	Mixed
MISE.2	Wolf River at LaGrange, Tenn.	07030392	35 01 57	-089 14 48	543	No	0.3	31.9	57.8	8.7	0.0	1.3	Mixed
MN.1	St. Croix River near Danbury, Wis.	05333500	46 04 34	-092 14 49	4,092	No	0.4	6.7	76.7	8.7	0.4	7.1	Undev
MN.2	Rush Creek near Rush City, Minn.	05339720	45 39 19	-092 53 56	156	No	2.9	51.3	16.4	20.1	0.0	9.2	Ag
MN.3	Sunrise River at Sunrise, Minn.	05340195	45 32 48	-092 51 23	781	No	2.6	53.4	17.6	21.0	0.1	5.4	Ag
MN.4	St Croix River at Nevers Dam site, near Wolf Creek, Wis.	05340420	45 32 13	-092 43 28	15,737	No	0.8	22.2	52.9	19.0	0.5	4.6	Undev
MN.5	St Croix River at Franconia, Minn.	05340552	45 21 40	-092 42 05	16,026	No	0.8	23.0	52.4	18.7	0.5	4.6	Undev
MN.6	Apple River at County Road H near Balsam Lake, Wis.	05341111	45 26 16	-092 21 58	327	No	0.0	42.0	46.2	5.1	0.2	6.4	Mixed
MN.7	Apple River above 05341499 at Park in Somerset, Wis.	05341498	45 07 40	-092 40 31	1,346	No	0.7	62.4	28.1	3.4	0.2	5.3	Ag

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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Site number	Site name	USGS station identifier	Latitude (DMS) NAD 83	Longitude (DMS) NAD 83	Drainage area (km^2)	Mined	Land use/land cover (percent of basin area)						Land-use/land-cover category
							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
MN.8	St. Croix River at Prescott, Wis.	05344490	44 44 57	-092 48 17	19,814	No	1.1	32.7	45.6	15.6	0.4	4.6	Mixed
MOBL.1	Coosa River near Rome, Ga.	02397000	34 12 01	-085 15 24	10,461	Yes	4.1	13.8	78.8	0.2	0.0	3.1	Undev
MOBL.2	Cahaba Valley Creek at Cross Creek Road at Pelham, Ala.	0242354750	33 18 48	-086 48 23	66	No	11.9	9.8	76.7	0.2	0.0	1.4	Mixed
MOBL.3	Shades Creek at Samford Univ at Homewood, Ala.	02423581	33 27 40	-086 47 36	56	No	53.3	3.6	40.8	0.3	0.0	2.0	Urban
MOBL.4	Alabama River at Claiborne, Ala.	02429500	31 32 49	-087 30 45	56,921	Yes	3.0	16.3	73.1	4.1	0.0	3.6	Undev
MOBL.5	Town Creek at Tupelo, Miss.	02434000	34 17 40	-088 42 33	283	No	1.0	51.3	45.9	0.3	0.0	1.5	Ag
MOBL.6	Tombigbee R below Coffeeville L&D near Coffeeville, Ala.	02469762	31 45 26	-088 07 30	47,833	No	2.2	22.0	63.6	8.0	0.0	4.2	Undev
MOBL.7	Satilpa Creek near Coffeeville, Ala.	02469800	31 44 40	-088 01 21	423	No	0.1	1.5	91.2	3.6	0.0	3.6	Undev
MOBL.8	Chickasaw Creek near Kushla, Ala.	02471001	30 48 11	-088 08 36	324	No	1.3	9.6	81.4	3.5	0.0	4.3	Undev
NECB.1	Souadabscook Stream at Carmel, Maine	01037110	44 48 03	-069 03 10	56	No	2.8	10.5	71.0	11.3	0.1	4.3	Undev
NECB.2	Marsh Stream near Monroe, Maine	01037230	44 36 01	-069 02 22	101	No	1.3	10.2	85.3	2.0	0.4	0.8	Undev
NECB.3	Deer Meadow Brook near Newcastle, Maine	01038100	44 02 23	-069 35 10	17	No	0.4	5.4	88.0	5.2	0.0	1.0	Undev
NECB.4	Fifteenmile Stream at East Benton, Maine	01049135	44 34 59	-069 27 54	171	No	1.2	19.3	71.4	6.7	0.0	1.3	Undev
NECB.5	Kennebec River at North Sidney, Maine	01049265	44 28 20	-069 41 02	14,015	No	1.4	5.6	79.4	3.7	0.4	9.5	Undev
NECB.6	Bond Brook at Augusta, Maine	01049318	44 19 22	-069 46 30	54	No	17.0	20.2	57.7	4.2	0.0	0.9	Mixed
NECB.7	Togus Stream at Togus, Maine	01049550	44 15 58	-069 41 53	88	No	4.3	11.6	73.7	3.5	0.0	6.9	Undev
NECB.8	Taylor Brook at Poland Rd near Auburn, Maine	01058710	44 04 47	-070 14 44	48	No	16.0	17.7	58.0	2.6	0.0	5.6	Mixed
NECB.9	Little River near Lisbon Falls, Maine	01059295	44 00 17	-070 02 02	59	No	1.0	15.8	81.3	1.3	0.0	0.5	Undev
NECB.10	Androscoggin River near Lisbon Falls, Maine	01059300	43 59 00	-070 02 28	8,849	Yes	1.9	5.3	83.5	3.4	0.2	5.7	Undev
NECB.11	Pleasant River at Popeville, Maine	01064110	43 47 12	-070 25 16	121	No	14.0	10.0	65.4	3.9	0.0	6.6	Mixed
NECB.12	Stoudwater River near South Gorham, Maine	01064154	43 39 22	-070 24 00	45	No	14.1	14.4	67.4	4.0	0.0	0.1	Mixed
NECB.13	Nonesuch River near Scarborough, Maine	01064195	43 36 58	-070 21 19	47	No	14.4	5.1	74.0	6.2	0.0	0.2	Mixed
NECB.14	Mousam River near Sanford, Maine	01068900	43 25 54	-070 45 40	112	No	17.9	5.9	65.7	3.3	0.0	7.2	Mixed
NECB.15	Little River near Lebanon, Maine	01072540	43 24 21	-070 51 03	46	Yes	2.4	8.6	84.7	3.8	0.0	0.4	Undev
NECB.16	Little River near Berwick, Maine	01072550	43 19 07	-070 51 53	133	Yes	2.1	6.6	84.1	7.0	0.0	0.2	Undev
NECB.17	Great Works River near North Berwick, Maine	01072650	43 19 03	-070 44 20	60	No	12.7	8.5	72.3	4.5	0.0	2.1	Mixed
NECB.18	Isinglass River, Batchelder Rd, near Ctr Strafford, N.H.	01072845	43 15 15	-071 06 10	59	No	4.8	3.9	73.9	8.8	0.0	8.6	Undev
NECB.19	Bellamy River at Bellamy Rd, near Dover, N.H.	01072904	43 10 49	-070 53 22	68	No	11.1	10.1	63.6	9.8	0.0	5.4	Mixed
NECB.20	Lamprey River below Cotton Road, near Deerfield Center, N.H.	01073260	43 05 00	-071 14 00	83	No	3.7	6.4	80.2	8.4	0.0	1.3	Undev
NECB.21	Pawtuckaway River at Folsum Mill Lane, near Epping, N.H.	01073392	43 02 36	-071 07 39	59	No	2.5	2.7	79.6	8.2	0.0	7.0	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
NECB.22	North River at NH 152, near Nottingham, N.H.	01073458	43 05 53	-071 03 34	75	No	5.4	4.4	77.8	10.4	0.0	2.0	Mixed
NECB.23	Little River at Cartland Rd, at Lee, N.H.	010734833	43 07 07	-071 01 20	52	No	3.4	4.4	76.8	11.5	0.0	3.9	Undev
NECB.24	Little Suncook River at Black Hall Rd, at Epson, N.H.	01089743	43 13 26	-071 20 46	101	No	4.6	6.4	73.4	8.1	0.0	7.5	Undev
NECB.25	Black Brook at Dunbarton Road, near Manchester, N.H.	01090477	43 01 31	-071 30 17	54	No	2.0	11.3	77.7	6.0	0.0	3.0	Undev
NECB.26	Baboosic Brook at Bedford Road, near Merrimack, N.H.	01094005	42 53 36	-071 30 51	73	No	10.7	9.8	72.0	3.6	0.0	3.9	Mixed
NECB.27	Pennichuck Brook at US 3, near Nashua, N.H.	01094161	42 47 36	-071 28 14	66	No	21.2	8.1	59.0	7.7	0.0	4.0	Mixed
NECB.28	Stillwater River near Sterling, Mass.	01095220	42 24 39	-071 47 28	79	No	6.0	8.8	74.2	8.1	0.0	2.9	Mixed
NECB.29	Mulpus Brook at Hazen Road near Shirley, Mass.	01095917	42 34 26	-071 37 28	41	No	12.0	9.5	67.7	5.6	0.0	5.2	Mixed
NECB.30	Nissitissit River at Bond Street, at Brookline, N.H.	0109650060	42 43 59	-071 39 51	71	No	3.7	3.3	84.3	5.7	0.2	2.7	Undev
NECB.31	Stony Brook at School Street at Chelmsford, Mass.	01096544	42 37 04	-071 24 08	108	No	23.2	5.8	55.2	9.0	0.0	6.7	Mixed
NECB.32	Beaver Brook at North Pelham, N.H.	010965852	42 46 58	-071 21 13	122	No	38.5	7.2	49.2	2.7	0.0	2.4	Urban
NECB.33	Assabet River at Allen Street at Northborough, Mass.	01096710	42 19 46	-071 37 48	76	No	36.6	1.9	48.9	8.6	0.0	4.1	Urban
NECB.34	Elizabeth Brook off White Pond Road near Stow, Mass.	01096945	42 25 36	-071 29 07	49	No	12.2	10.9	70.5	3.9	0.0	2.4	Mixed
NECB.35	Fort Pond Brook at River Road near South Acton, Mass.	01097270	42 27 34	-071 26 34	54	No	23.0	5.2	63.3	5.8	0.0	2.8	Mixed
NECB.36	Sudbury River at Concord Street at Ashland, Mass.	01097476	42 15 45	-071 27 48	90	No	20.4	5.5	60.1	8.7	0.0	5.3	Mixed
NECB.37	Merrimack River below Concord River at Lowell, Mass.	01100000	42 38 45	-071 17 54	11,983	Yes	11.5	6.7	71.6	4.6	0.1	5.5	Mixed
NECB.38	Spicket River at Bridge Street, at Salem, N.H.	011005372	42 47 16	-071 11 59	123	No	20.8	6.4	64.4	3.5	0.0	4.9	Mixed
NECB.39	Shawsheen River near Tewksbury, Mass.	01100610	42 35 59	-071 11 34	145	No	64.6	0.3	25.7	7.6	0.0	1.7	Urban
NECB.40	Little River at Rt 121, at Westville, N.H.	01100684	42 49 04	-071 06 48	54	No	30.8	5.8	56.2	5.9	0.0	1.3	Urban
NECB.41	Powwow River at Whitehall Rd, at South Hampton, N.H.	01100842	42 52 21	-070 57 41	126	No	13.2	6.5	65.5	8.2	0.0	6.6	Mixed
NECB.42	Parker River at Byfield, Mass.	01101000	42 45 10	-070 56 44	55	No	15.2	4.7	64.4	12.4	0.2	3.1	Mixed
NECB.43	Ipswich River at South Middleton, Mass.	01101500	42 34 10	-071 01 37	115	No	45.5	0.6	34.9	16.2	0.0	2.8	Urban
NECB.44	Saugus River at Saugus Ironworks at Saugus, Mass.	01102345	42 28 10	-071 00 25	60	No	67.8	0.0	18.8	9.1	0.0	4.3	Urban
NECB.45	Aberjona River at Winchester, Mass.	01102500	42 26 50	-071 08 20	60	No	79.2	0.0	13.8	4.4	0.0	2.6	Urban
NECB.46	Charles River at Maple St. at North Bellingham, Mass.	011032058	42 07 11	-071 27 10	54	No	31.5	6.0	53.0	6.5	0.2	2.8	Urban
NECB.47	Charles River above Watertown Dam at Watertown, Mass.	01104615	42 21 53	-071 11 23	695	No	40.4	4.3	45.5	6.5	0.1	3.2	Urban

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/ grassland		
NECB.48	Neponset River at Norwood, Mass.	01105000	42 10 39	-071 12 03	85	No	41.3	2.3	45.2	9.6	0.0	1.5	Urban
NECB.49	East Branch Neponset River at Canton, Mass.	01105500	42 09 16	-071 08 45	73	No	52.0	0.2	36.4	7.4	0.0	4.0	Urban
NECB.50	Monatiquot River at River Street at Braintree, Mass.	01105581	42 13 12	-070 59 56	71	No	55.4	0.5	32.2	8.5	0.0	3.3	Urban
NECB.51	Matfield River at N. Central St. at E. Bridgewater, Mass.	01106468	42 02 01	-070 58 21	80	No	66.6	0.2	26.5	5.0	0.1	1.7	Urban
NECB.52	Wading River near Norton, Mass.	01109000	41 56 51	-071 10 36	113	No	25.6	4.2	59.3	8.9	0.1	1.9	Urban
NECB.53	Middle River off Sutton Lane at Worcester, Mass.	01109595	42 14 19	-071 49 28	125	No	32.5	5.9	48.3	6.8	0.1	6.3	Urban
NECB.54	Quinsigamond River at North Grafton, Mass.	01110000	42 13 49	-071 42 39	66	No	53.9	0.7	30.7	7.7	0.3	6.7	Urban
NECB.55	Mill River at Summer Street near Blackstone, Mass.	01112262	42 02 27	-071 30 56	74	No	13.6	9.4	66.8	7.4	0.1	2.8	Mixed
NECB.56	Blackstone River at Manville, R.I.	01112900	41 58 16	-071 28 12	1,115	No	22.7	6.3	60.1	6.8	0.2	4.0	Mixed
NROK.1	Clark Fork at Turah Bridge near Bonner, Mont.	12334550	46 49 34	-113 48 51	9,521	Yes	0.6	5.1	51.7	0.8	40.3	1.4	Undev
NROK.2	Clark Fork at St. Regis, Mont.	12354500	47 18 07	-115 05 14	27,820	Yes	0.6	5.2	63.2	0.7	27.5	2.9	Undev
NROK.3	Middle Fork Flathead River near West Glacier, Mont.	12358500	48 29 43	-114 00 36	2,939	No	0.2	0.1	75.9	0.3	14.3	9.3	Undev
NROK.4	Flathead River at Perma, Mont.	12388700	47 22 03	-114 35 06	21,787	Yes	0.5	7.0	65.6	0.4	18.6	8.0	Undev
NROK.5	South Fork Coeur d'Alene River near Pinehurst, Idaho	12413470	47 33 07	-116 14 11	738	Yes	2.4	0.1	83.2	0.1	12.7	1.4	Undev
NVBR.1	East Fork Carson River below Markleeville Creek near Markleeville, Calif.	10308200	38 42 53	-119 45 54	716	Yes	0.0	0.0	58.0	0.0	37.0	4.9	Undev
NVBR.2	East Fork Carson River near Dresslerville, Nev.	10309010	38 52 42	-119 41 22	970	Yes	0.0	0.0	52.7	0.0	43.4	3.8	Undev
NVBR.3	West Fork Carson River at Woodfords, Calif.	10310000	38 46 11	-119 50 02	169	Yes	0.0	0.0	60.1	0.0	37.7	2.2	Undev
NVBR.4	Carson River at Deer Run Road near Carson City, Nev.	10311400	39 10 53	-119 41 42	24,83	Yes	2.4	6.0	34.0	0.2	55.1	2.3	Undev
NVBR.5	Carson River at Dayton, Nev.	10311700	39 14 16	-119 35 16	28,00	Yes	2.2	5.4	33.5	0.2	56.6	2.3	Undev
NVBR.6	Carson River near Fort Churchill, Nev.	10312000	39 17 30	-119 18 40	3,801	Yes	1.7	4.3	26.2	0.1	65.4	2.3	Undev
NVBR.7	Carson River below Carson Diversion Dam near Fallon, Nev.	10312158	39 29 33	-118 59 31	4,669	Yes	1.5	3.8	21.3	0.3	69.3	3.8	Undev
NVBR.8	Carson River at Tarzyn Road near Fallon, Nev.	10312275	39 33 32	-118 43 34	*	Yes	*	*	*	*	*	*	*
NVBR.9	Truckee River below Viking Plant near Verdi, Nev.	10347335	39 31 18	-119 58 29	2,576	Yes	4.0	0.0	57.6	0.1	16.5	21.7	Undev
NVBR.10	Truckee River near Sparks, Nev.	10348200	39 31 03	-119 44 30	2,763	Yes	5.0	0.1	54.8	0.1	19.7	20.3	Mixed
NVBR.11	Truckee River at Clark, Nev.	10350500	39 33 56	-119 29 10	4,310	Yes	5.9	1.2	39.0	0.1	40.2	13.5	Mixed
OAHU.1	Waikele Stream at Waipahu, Oahu, Hawaii	16213000	21 23 00	-158 00 39	118	No	*	*	*	*	*	*	*
OAHU.2	Kawainui Canal at Kailua, Oahu, Hawaii	16264800	21 24 26	-157 45 22	28	No	*	*	*	*	*	*	*
PODL.1	Christina River at Coochs Bridge, Del.	01478000	39 38 15	-075 43 40	54	No	37.2	34.0	27.2	1.0	0.0	0.7	Mixed
PODL.2	Nassawango Creek near Snow Hill, Md.	01485500	38 13 44	-075 28 17	142	No	2.5	23.2	54.3	16.9	0.0	3.2	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
PODL.3	Nanticoke River near Bridgeville, Del.	01487000	38 43 42	-075 33 43	187	No	4.4	54.7	27.1	13.7	0.0	0.1	Ag
PODL.4	Deep Creek at Old Furnace, Del.	01487100	38 39 59	-075 30 52	88	No	2.5	36.2	47.2	14.0	0.0	0.1	Mixed
PODL.5	Marshyhope Creek near Adamsville, Del.	01488500	38 50 59	-075 40 23	125	No	0.9	59.2	27.8	12.0	0.0	0.1	Ag
PODL.6	Chesterville Branch near Crumpton, Md.	01493112	39 15 25	-075 56 25	17	No	0.4	90.8	4.5	3.8	0.0	0.6	Ag
PODL.7	South Fork South Branch Potomac River near Moorefield, W. Va.	01608000	39 00 44	-078 57 22	718	No	0.2	9.9	88.9	0.1	0.0	0.8	Undev
PODL.8	Rock Creek at Joyce Rd Washington, D.C.	01648010	38 57 37	-077 02 30	169	No	61.3	18.0	18.3	1.6	0.0	0.8	Urban
PUGT.1	North Fork Skokomish River below Staircase Rapids near Hoodsport, Wash.	12056500	47 30 51	-123 19 48	147	No	0.0	0.0	89.7	0.0	5.0	5.2	Undev
PUGT.2	Big Soos Creek above Hatchery near Auburn, Wash.	12112600	47 18 44	-122 09 55	173	No	39.0	3.4	46.6	0.8	6.0	4.2	Urban
PUGT.3	Taylor Creek near Selleck, Wash.	12117000	47 23 11	-121 50 46	45	No	0.1	0.0	94.6	0.0	0.3	5.0	Undev
PUGT.4	Mercer Creek near Bellevue, Wash.	12120000	47 36 10	-122 10 51	38	No	80.5	0.2	14.4	0.3	3.8	0.9	Urban
PUGT.5	North Creek below Penny Creek near Bothell, Wash.	12125900	47 49 12	-122 12 46	31	No	68.0	1.0	23.9	1.3	5.0	0.8	Urban
PUGT.6	Thornton Creek near Seattle, Wash.	12128000	47 41 44	-122 16 34	29	No	94.4	0.0	3.6	0.2	1.6	0.1	Urban
RIOG.1	Saguache Creek near Saguache, Colo.	08227000	38 09 48	-106 17 26	1,327	Yes	0.0	0.8	51.5	0.0	44.2	3.5	Undev
RIOG.2	Rio Chama near La Puente, N. Mex.	08284100	36 39 46	-106 38 00	1,222	Yes	0.4	3.9	52.9	0.1	41.8	0.9	Undev
SACR.1	Cottonwood Creek near Cottonwood, Calif.	11376000	40 23 14	-122 14 19	2,313	Yes	0.3	2.5	48.0	0.0	48.0	1.2	Undev
SACR.2	Colusa Basin Drain at Road 99E near Knights Landing, Calif.	11390890	38 48 45	-121 46 27	4,238	Yes	1.0	56.5	6.9	1.7	32.9	1.0	Ag
SACR.3	Sacramento Slough near Knights Landing, Calif.	11391100	38 46 45	-121 38 19	3,329	Yes	3.5	60.7	15.1	4.1	15.3	1.3	Ag
SACR.4	Sacramento River at Freeport, Calif.	11447650	38 27 22	-121 30 05	61,693	Yes	2.1	13.1	52.2	0.8	29.7	2.2	Mixed
SACR.5	Putah Creek below Road 95A near Davis, Calif.	383213121505701	38 32 13	-121 51 01	1,668	Yes	0.5	3.7	50.0	0.1	42.0	3.7	Undev
SACR.6	Miners Ravine near Roseville, Calif.	384537121145801	38 45 37	-121 14 58	50	Yes	12.5	34.5	27.3	0.0	25.1	0.5	Mixed
SACR.7	Secret Ravine near Roseville, Calif.	384544121151201	38 45 44	-121 15 12	50	Yes	9.8	37.7	18.0	0.0	33.9	0.6	Mixed
SACR.8	Coon Creek near Auburn, Calif.	385824121122501	38 58 24	-121 12 25	86	Yes	6.9	18.1	51.6	0.0	22.9	0.5	Mixed
SACR.9	Bear River at Hwy 70 near Rio Oso, Calif.	385821121323201	38 58 21	-121 32 36	1,096	Yes	5.0	10.0	59.5	0.2	23.8	1.5	Mixed
SANJ.1	Salt Slough at Hwy 165 near Stevinson, Calif.	11261100	37 14 52	-120 51 08	1,,274	No	1.8	75.1	0.1	10.2	10.9	2.0	Ag
SANJ.2	Merced River at River Road Bridge near Newman, Calif.	11273500	37 21 04	-120 57 43	3621	Yes	1.2	13.7	47.8	0.2	33.0	4.1	Ag
SANJ.3	San Joaquin River at Patterson Br near Patterson, Calif.	11274570	37 29 51	-121 04 59	9,801	Yes	2.0	31.4	22.6	2.3	39.0	2.7	Mixed
SANJ.4	Tuolumne River at Hickman near Waterford, Calif.	11289800	37 38 08	-120 45 18	4,052	Yes	1.9	0.6	56.4	0.0	28.6	12.3	Undev
SANJ.5	San Joaquin River near Vernalis, Calif.	11303500	37 40 34	-121 15 59	19,030	Yes	2.7	22.5	33.7	1.3	34.8	5.1	Mixed
SANJ.6	Cosumnes River at Michigan Bar, Calif.	11335000	38 30 01	-121 02 43	1,389	Yes	0.9	3.2	76.1	0.0	19.2	0.5	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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									Forest	Wetland	Shrub/grassland		
SANJ.7	Merced River at Mcconnell State Park near Livingston, Calif.	372450120423300	37 24 50	-120 42 37	3,214	Yes	0.6	5.0	53.8	0.2	35.7	4.6	Undev
SANJ.8	Stanislaus River at Riverbank, Calif.	374419120570701	37 44 19	-120 57 11	2,704	Yes	1.7	2.4	66.4	0.0	23.2	6.3	Undev
SANT.1	Saluda River near Silverstreet, S.C.	02167500	34 10 58	-081 43 36	4,214	Yes	10.1	18.0	67.6	0.5	0.0	3.8	Mixed
SANT.2	South Fork Edisto River at Springfield, S.C. on SC39	02172654	33 28 42	-081 18 49	1,389	No	1.6	31.3	49.7	7.8	0.0	9.6	Mixed
SANT.3	South Fork Edisto River near Canaan, S.C. on SSR39	02173052	33 18 51	-080 57 51	2,197	No	1.5	35.9	43.4	11.0	0.0	8.2	Mixed
SANT.4	North Fork Edisto River near Fairview Crossroads, S.C.	02173180	33 43 03	-081 21 25	371	No	2.1	25.4	58.8	7.6	0.0	6.2	Mixed
SANT.5	North Fork Edisto River near Branchville, S.C.	02173700	33 17 21	-080 52 51	1,968	No	3.0	29.7	51.7	9.2	0.0	6.3	Mixed
SANT.6	Edisto River near Cottageville, S.C.	02174175	33 03 17	-080 26 57	5,347	No	1.9	30.8	47.3	13.5	0.0	6.5	Mixed
SANT.7	Edisto River near Givhans, S.C.	02175000	33 01 41	-080 23 29	7,077	No	2.0	31.8	44.8	15.5	0.0	5.9	Mixed
SOCA.1	Santa Ana River at MWD Crossing, Calif.	11066460	33 58 07	-117 26 54	2,136	Yes	20.0	4.6	27.4	0.1	45.6	2.4	Urban
SOCA.2	Santa Ana River below Prado Dam, Calif.	11074000	33 53 00	-117 38 43	3,727	Yes	25.4	8.6	19.1	0.4	44.0	2.5	Urban
SOCA.3	Santa Ana River at Hamner Rd near Norco, Calif.	335645117332701	33 56 45	-117 33 30	2,510	Yes	23.0	6.1	24.1	0.2	44.3	2.3	Mixed
SOCA.4	Mill Creek at Chino Corona Rd near Norco, Calif.	335645117365301	33 56 45	-117 36 56	225	No	42.7	18.4	7.6	0.0	28.8	2.5	Urban
SOCA.5	South Fork Santa Ana River near SF Campground near Angelus Oaks, Calif.	341014116494801	34 10 14	-116 49 51	19	No	0.7	0.0	75.0	0.3	17.1	7.0	Undev
SOFL.1	Kissimmee River at S-65E near Okeechobee, Fla.	02273000	27 13 33	-080 57 45	5,876	No	10.7	18.3	10.0	29.1	20.9	11.0	Mixed
SOFL.2	Cypress Creek Canal near Rock Island Road., near Margate, Fla.	261345080131700	26 13 46	-080 13 16	6	No	93.4	0.8	0.1	3.1	0.0	2.6	Urban
SOFL.3	Hillsborough Canal near Powerline Road., near Deerfield Beach, Fla.	261937080091200	26 19 38	-080 09 11	6	No	85.9	2.1	0.9	4.7	0.0	6.5	Urban
SOFL.4	Boynton Canal near I-95, near Boynton Beach, Fla.	263218080032800	26 32 19	-080 03 27	18	No	72.8	5.4	2.0	6.8	1.8	11.2	Urban
SPLT.1	Clear Creek above Johnson Gulch near Idaho Springs, Colo.	06718300	39 44 47	-105 26 10	693	Yes	1.3	0.0	57.6	0.0	13.3	27.8	Undev
SPLT.2	North St. Vrain Creek near Allens Park, Colo.	06721500	40 13 08	-105 31 42	84	No	0.1	0.0	48.5	0.0	6.3	45.1	Undev
SPLT.3	St. Vrain Creek at Lyons, Colo.	06724000	40 13 05	-105 15 36	560	Yes	1.2	0.5	63.2	0.0	17.1	18.1	Undev
SPLT.4	Big Thompson River at Estes Park, Colo.	06733000	40 22 42	-105 30 50	355	No	2.2	1.2	55.1	0.0	9.7	31.7	Undev
SPLT.5	Cache La Poudre River at mo of cn, near Ft Collins, Colo.	06752000	40 39 52	-105 13 28	2,731	Yes	0.4	0.9	61.8	0.0	31.0	5.9	Undev
SPLT.6	South Platte River at North Platte, Nebr.	06765500	41 07 05	-100 46 24	63,678	Yes	3.4	26.1	14.7	0.3	52.7	2.8	Mixed
SPLT.7	James Creek near Jamestown, Colo.	400630105215801	40 06 30	-105 21 58	44	Yes	1.2	0.9	77.9	0.0	19.8	0.2	Undev
SPLT.8	Big Thompson below Moraine Park near Estes Park, Colo.	402114105350101	40 21 14	-105 35 03	103	No	0.1	2.1	45.9	0.0	5.8	46.2	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

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							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/ grassland		
TENN.1	Sequatchie River near Whitwell, Tenn.	03571000	35 12 24	-085 29 50	1,001	No	2.2	20.1	77.1	0.2	0.0	0.3	Undev
TENN.2	Indian Creek near Madison, Ala.	03575830	34 41 50	-086 42 00	127	No	4.5	57.7	37.0	0.7	0.0	0.2	Ag
TENN.3	Buffalo River near Flat Woods, Tenn.	03604000	35 29 45	-087 49 58	1,163	No	2.1	22.3	71.2	0.8	0.0	3.6	Undev
TRIN.1	Clear Creek near Sanger, Tex.	08051500	33 20 10	-097 10 46	763	No	0.2	37.9	15.2	0.0	45.8	0.9	Mixed
TRIN.2	White Rock Creek at Greenville Ave., Dallas, Tex.	08057200	32 53 21	-096 45 24	173	No	61.2	29.2	5.2	0.0	4.1	0.4	Mixed
TRIN.3	Trinity River below Dallas, Tex.	08057410	32 42 27	-096 44 09	16,227	No	12.0	38.3	13.5	0.7	31.4	4.2	Mixed
TRIN.4	East Fork Trinity River at McKinney, Tex.	08058900	33 14 38	-096 36 32	435	No	1.5	66.3	16.5	0.0	14.6	1.0	Ag
TRIN.5	Chambers Creek near Rice, Tex.	08064100	32 11 55	-096 31 13	2,136	No	2.6	77.1	12.3	0.1	5.5	2.5	Ag
TRIN.6	Upper Keechi Creek near Oakwood, Tex.	08065200	31 34 12	-095 53 18	391	No	1.9	59.2	35.5	2.7	0.0	0.7	Ag
TRIN.7	Trinity River near Crockett, Tex.	08065350	31 20 19	-095 39 23	35,967	No	8.2	50.6	18.8	1.9	16.1	4.4	Mixed
TRIN.8	Bedias Creek near Madisonville, Tex.	08065800	30 53 05	-095 46 40	856	No	1.8	75.8	12.4	9.5	0.0	0.5	Ag
TRIN.9	Menard Creek near Rye, Tex.	08066300	30 28 53	-094 46 47	384	No	1.8	9.4	85.2	1.8	0.0	1.9	Undev
UCOL.1	Colorado River below Baker Gulch near Grand Lake, Colo.	09010500	40 19 33	-105 51 24	163	Yes	0.3	0.0	63.7	0.0	9.8	26.1	Undev
UCOL.2	French Gulch at Breckenridge, Colo.	09046530	39 29 35	-106 02 41	29	Yes	5.7	0.0	63.1	0.0	6.5	24.7	Mixed
UCOL.3	Dry Creek at Begonia Road, near Delta, Colo.	09149480	38 38 45	-108 02 56	448	No	0.0	12.5	34.1	0.0	53.2	0.1	Ag
UCOL.4	Red Mountain Creek above Crystal Lake near Ironton, Colo.	375732107394000	37 57 32	-107 39 42	47	Yes	0.0	0.1	38.1	0.0	17.9	43.9	Undev
UCOL.5	Snake River below mouth of Peru Creek, Colo.	393557105530000	39 35 57	-105 53 02	84	Yes	0.0	0.0	27.6	0.0	14.2	58.2	Undev
UIRB.1	Pitner Ditch near La Crosse, Ind.	05517120	41 19 02	-086 50 55	113	No	1.2	92.2	4.4	0.3	1.8	0.1	Ag
UIRB.2	Des Plaines River at Russell, Ill.	05527800	42 29 21	-087 55 35	318	No	5.8	77.7	10.4	1.6	3.2	1.1	Mixed
UIRB.3	Salt Creek at Western Springs, Ill.	05531500	41 49 33	-087 54 01	291	No	81.5	2.2	8.0	2.5	3.6	2.2	Urban
UIRB.4	Mukwonago River at Mukwonago, Wis.	05544200	42 51 24	-088 19 40	191	No	7.7	56.6	24.8	5.0	2.1	3.8	Mixed
UIRB.5	Nippersink Creek above Wonder Lake, Ill.	05548105	42 23 07	-088 22 10	219	No	5.6	86.2	5.2	1.4	0.8	0.7	Mixed
UMIS.1	Shingle Creek at Queen Ave in Minneapolis, Minn.	05288705	45 03 00	-093 18 37	73	No	70.1	2.6	6.1	11.0	0.0	10.1	Urban
UMIS.2	Nine Mile Creek nearJames Circle at Bloomington, Minn.	05330902	44 48 26	-093 18 06	116	No	79.6	0.0	6.9	7.6	0.0	5.9	Urban
UMIS.3	St. Croix River near Woodland Corner, Wis.	05331775	46 07 00	-092 07 54	1,121	No	0.4	2.6	80.5	7.3	0.3	9.0	Undev
UMIS.4	Namekagon River at Leonards, Wis.	05331833	46 10 17	-091 19 46	333	No	0.2	4.3	71.7	16.2	0.4	7.2	Undev
UMIS.5	Kettle River below Sandstone, Minn.	05336700	46 06 20	-092 51 51	2,252	No	1.0	19.1	41.8	35.1	0.3	2.8	Undev
UMIS.6	Wood River at State Highway 70 at Grantsburg, Wis.	05338975	45 46 22	-092 42 30	414	No	0.7	44.2	36.9	7.5	5.0	5.7	Mixed
UMIS.7	Kinnickinnic River near River Falls, Wis.	05342000	44 49 50	-092 44 00	449	No	2.1	86.9	10.1	0.3	0.3	0.2	Ag
WHMI.1	Little Miami River at Milford, Ohio	03245500	39 10 17	-084 17 53	3,115	No	11.6	71.6	15.6	0.2	0.0	1.0	Mixed

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									Forest	Wetland	Shrub/grassland		
WHMI.2	East Fork Little Miami River near Williamsburg, Ohio	03246400	39 03 32	-084 03 05	607	No	2.5	84.2	12.6	0.1	0.0	0.5	Ag
WHMI.3	Fall Creek at Millersville, Ind.	03352500	39 51 07	-086 05 15	772	No	12.0	79.1	6.8	0.8	0.0	1.4	Mixed
WHMI.4	White River near Centerton, Ind.	03354000	39 29 51	-086 24 02	6,325	No	16.6	75.7	5.8	0.8	0.0	1.1	Mixed
WHMI.5	Big Walnut Creek near Roachdale, Ind.	03357330	39 48 58	-086 45 12	340	No	1.0	95.0	3.7	0.3	0.0	*	Mixed
WHMI.6	Sugar Creek at New Palestine, Ind.	03361650	39 42 51	-085 53 08	246	No	3.5	91.0	4.6	0.7	0.0	0.2	Ag
WHMI.7	Clifty Creek at Hartsville, Ind.	03364500	39 16 29	-085 42 06	228	No	0.6	94.8	4.1	0.5	0.0	0.1	Ag
WHMI.8	Muscatatuck River near Deputy, Ind.	03366500	38 48 15	-085 40 26	755	No	3.4	53.1	37.1	3.0	0.0	3.4	Ag
WHMI.9	Beaver Creek at Squirt Run near Shoals, Ind.	383915086474901	38 39 15	-086 47 49	186	No	3.6	21.1	74.5	0.2	0.0	0.6	Undev
WHMI.10	South Fork Salt Creek at Maumee Road near Robinson Cem, Ind.	390219086164901	39 02 19	-086 16 49	256	No	0.5	25.4	73.5	0.2	0.0	0.4	Mixed
WHMI.11	Great Miami River below Hamilton, Ohio	392246084340100	39 22 46	-084 34 01	9,404	No	9.8	79.0	10.1	0.3	0.0	0.8	Mixed
WHMI.12	Whitewater River near Nulltown, Ind.	393259085101200	39 32 59	-085 10 12	1,369	No	2.9	86.7	9.4	0.9	0.0	0.2	Ag
WHMI.13	Holes Creek in Huffman Park at Kettering, Ohio	393944084120700	39 39 44	-084 12 07	52	No	65.4	27.4	6.5	0.3	0.0	0.4	Mixed
WHMI.14	Stillwater River on Old Springfield Road near Union, Ohio	395433084175300	39 54 33	-084 17 53	1,672	No	2.8	90.6	6.0	0.3	0.0	0.2	Ag
WHMI.15	Great Miami River near Tipp City, Ohio	395534084091400	39 55 34	-084 09 14	2,958	No	4.3	85.5	8.6	0.4	0.0	1.1	Ag
WHMI.16	Mad River near Hwy. 41 near Springfield, Ohio	395650083504400	39 56 50	-083 50 44	802	No	4.8	80.2	14.5	0.3	0.0	0.3	Ag
WILL.1	Middle Fork Willamette River near Oakridge, Oreg.	14144800	43 35 49	-122 27 24	669	No	0.0	0.0	88.4	0.3	4.8	6.5	Undev
WILL.2	Row River above Pitcher Creek near Dorena, Oreg.	14154500	43 44 09	-122 52 24	547	Yes	0.6	0.1	94.2	0.0	3.2	2.0	Undev
WILL.3	Lookout Creek near Blue River, Oreg.	14161500	44 12 34	-122 15 24	62	No	0.0	0.0	97.0	0.0	2.3	0.7	Undev
WILL.4	East Fork Dairy Creek near Meacham Corner, Oreg.	14205400	45 40 50	-123 04 16	88	No	0.0	0.8	91.9	0.0	0.2	7.0	Undev
WILL.5	Beaverton Creek at SW 216th Ave, near Orenco, Oreg.	14206435	45 31 14	-122 53 58	96	No	67.8	10.5	16.2	0.2	4.7	0.6	Urban
WILL.6	Fanno Creek at Durham, Oreg.	14206950	45 24 12	-122 45 17	81	No	75.7	6.2	12.1	0.4	4.8	0.9	Urban
WILL.7	Johnson Creek at Milwaukie, Oreg.	14211550	45 27 10	-122 38 35	137	No	59.3	18.3	18.2	0.1	3.7	0.4	Urban
WILL.8	Calapooya Creek near Nonpareil, Oreg.	432454123124801	43 24 53	-123 12 52	255	Yes	0.5	2.6	89.4	0.0	6.8	0.7	Undev
WILL.9	Coast Fork Willamette River near London, Oreg.	433855123045401	43 38 54	-123 04 58	195	Yes	0.7	1.7	88.0	0.0	7.5	2.0	Undev
WILL.10	Horse Creek below Foley Springs at McKenzie Bridge, Oreg.	440944122091401	44 09 43	-122 09 18	388	No	0.0	0.0	91.9	0.3	2.6	5.2	Undev
WILL.11	Quartz Creek near Blue River, Oreg.	441120122195001	44 11 19	-122 19 54	9	Yes	0.0	0.0	93.9	0.0	4.3	1.7	Undev
WILL.12	North Santiam River near Marion Forks, Oreg.	443003122000801	44 30 02	-122 00 12	55	No	0.0	0.0	86.1	0.9	7.7	5.4	Undev
WILL.13	Canal Creek near Cascadia, Oreg.	443516122204701	44 35 15	-122 20 51	61	Yes	0.0	0.0	92.9	0.0	4.5	2.6	Undev
WILL.14	Breitenbush River below Breitenbush Hot Springs near Detroit, Oreg.	444649121594701	44 46 48	-121 59 51	161	No	0.0	0.0	87.7	0.2	5.6	6.5	Undev

Table 7. Land-use/land-cover characterization of U.S. streams sampled for mercury, 1998–2005.—Continued

[**Land-use/land-cover category**: "other" includes water, bare rock, quarry/mine, transitional, tundra, and ice/snow. **Abbreviations:** USGS, U.S. Geological Survey; DMS, degrees-minutes-seconds; km^2, square kilometers; NAD 83, North American Datum 83; *, not determined]

Site number	Site name	USGS station identifier	Latitude (DMS) NAD 83	Longitude (DMS) NAD 83	Drainage area (km^2)	Mined	Land use/land cover (percent of basin area)						Land-use/land-cover category
							Urban	Agri-culture	Undeveloped			Other	
									Forest	Wetland	Shrub/grassland		
WILL.15	Upper Clackamas River at Two Rivers C.G., Oreg.	450156122033100	45 01 55	-122 03 35	408	No	0.0	0.0	88.3	0.1	3.7	7.9	Undev
WILL.16	Oak Grove Fork at Rainbow Campground, Oreg.	450448122023000	45 04 47	-122 02 34	365	Yes	0.1	0.0	87.1	0.5	3.0	9.4	Undev
WMIC.1	Pine River near Tipler, Wis.	04063660	45 53 37	-088 33 31	543	No	0.1	1.9	58.6	35.3	0.4	3.7	Undev
WMIC.2	Popple River near Fence, Wis.	04063700	45 45 49	-088 27 49	363	No	0.1	3.4	57.5	37.5	0.6	0.9	Undev
WMIC.3	South Branch Oconto River near Breed, Wis.	04070720	45 03 40	-088 31 24	370	No	0.0	4.3	77.3	14.2	1.6	2.6	Undev
WMIC.4	Evergreen River below Evergreen Falls near Langlade, Wis.	04075365	45 03 57	-088 40 34	167	No	0.2	11.3	75.7	9.1	3.4	0.4	Undev
WMIC.5	Milwaukee River at Milwaukee, Wis.	04087000	43 06 00	-087 54 32	1,805	No	10.8	65.2	16.4	5.3	0.8	1.5	Mixed
WMIC.6	Oak Creek at South Milwaukee, Wis.	04087204	42 55 30	-087 52 12	67	No	51.0	34.6	9.9	1.3	2.7	0.3	Mixed
WMIC.7	Root River near Franklin, Wis.	04087220	42 52 25	-087 59 45	128	No	62.0	20.6	13.4	1.1	1.2	1.7	Urban
WMIC.8	Poplar Creek near Waukesha, Wis.	05543796	43 02 39	-088 09 59	64	No	47.1	27.4	18.2	2.6	2.9	1.7	Mixed
YELL.1	Bighorn River at Kane, Wyo.	06279500	44 45 31	-108 10 53	40,825	Yes	0.2	3.8	9.2	0.7	80.6	5.5	Mixed
YELL.2	Tongue River at State Line near Decker, Mont.	06306300	45 00 32	-106 50 10	3763	Yes	0.8	9.1	28.3	2.0	58.2	1.6	Undev
YELL.3	Yellowstone River near Sidney, Mont.	06329500	47 40 42	-104 09 24	17,7139	Yes	0.2	8.4	14.0	0.6	72.4	4.4	Mixed
YELL.4	Shoshone River at mouth, near Kane, Wyo.	445221108122601	44 52 21	-108 12 28	7,711	Yes	0.3	7.2	28.3	0.6	56.0	7.5	Mixed

Appendix 1. Definitions for variable abbreviations used in tables 5 and 6.

[**Acronyms:** MDN, Mercury Deposition Network; PRISM, Parameter-elevation Regressions on Independent Slopes Model]

Abbreviation	Description
	Stream water
DOC	Dissolved organic carbon concentration
UV	Ultraviolet absorbance at 254 nm
SUVA	Specific UV absorbance at 254 nm, divided by the DOC concentration
SS_conc	Suspended sediment concentration
UMeHg	Unfiltered water, methylmercury concentration
UTHg	Unfiltered water, total mercury concentration
UMeHg/UTHg	Unfiltered water, ratio of methylmercury concentration to total mercury concentration
FMeHg	Filtered water, methylmercury concentration
FTHg	Filtered water, total mercury concentration
PMeHg	Particulate fraction, water, methylmercury concentration
PTHg	Particulate fraction, water, total mercury concentration
	Bed sediment
SMeHg/LOI	Bed sediment, methylmercury concentration normalized by loss-on-ignition
SMeHg	Bed sediment, methylmercury concentration
STHg/LOI	Bed sediment, total mercury concentration normalized by loss-on-ignition
STHg	Bed sediment, total mercury concentration
SMeHg/STHg	Bed sediment, ratio of methylmercury concentration to total mercury concentration
LOI	Loss-on-ignition
AVS	Acid volatile sulfide concentration
	Atmospheric deposition
SULF.DEP	Atmospheric deposition, sulfate
ADRY.SEI	Atmospheric deposition, dry, modeled Hg concentration
ATOT.SEI	Atmospheric deposition, wet + dry, modeled Hg concentration
AWET.MDN	Atmospheric deposition, wet, measured mercury concentration, MDN data
AWET.PRE	Atmospheric deposition, wet, precipitation-weighted from PRISM
PREC.PR	Mean annual precipitation (1961–90) from PRISM
WTDEPAVE	Average depth to seasonally high water table
	Other
POPDEN00	Population density, 2000 U.S. Census
ELEV.AVG	Mean basin elevation
HYDRIC SOILS	Hydric soils
PET	Potential evapotranspiration, mean annual
AET	Actual evapotranspiration, mean annual

Appendix 1. Definitions for variable abbreviations used in tables 5 and 6.—Continued

[MDN, Mercury Deposition Network; PRISM, Parameter-elevation Regressions on Independent Slopes Model]

Abbreviation	Description
	Land use/land cover
SUM_FOREST	Sum forest land in basin: evergreen, deciduous, mixed
EVR_FOREST	Evergreen forest land, percent of basin area
EVR_FOREST_DW	Distance weighted evergreen forest land in basin
SUM_WETLAND	Sum wetland in basin: woody and herbaceous
WOODWETLAND	Woody wetlands, percent of basin area
WOODWETLAND_DW	Distance weighted woody wetlands in basin
HERBWETLAND	Herbaceous wetlands, percent of basin area
HERBWETLAND_DW	Distance weighted herbaceous wetlands in basin
SUM_UNDEVELOPED	Sum undeveloped land in basin: forest, grassland, shrubland, tundra, wetland
SUM_URBAN	Sum urban land in basin: residential, commercial/industrial
RES_L_URBAN	Low intensity residential land, percent of basin area
RES_L_URBAN_DW	Distance weighted low intensity residential land in basin
RES_H_URBAN	High intensity residential land, percent of basin area
RES_H_URBAN_DW	Distance weighted high intensity residential land in basin
COM_INDUSTR	Commercial/industrial/transportation land, percent of basin area
COM_INDUSTR_DW	Distance weighted commercial/industrial/transportation land in basin
SUM_AGRICULTURE	Sum agricultural land in basin: row crop, small grains, fallow, pasture/hay, orchards/vineyards
ROW_CROP	Row crop land, percent of basin area
ROW_CROP_DW	Distance weighted row crop land in basin
PAST_HAY	Pasture/hay land, percent of basin area
PAST_HAY_DW	Distance weighted pasture/hay land in basin
GRASSLAND	Grasslands (herbaceous) land, percent of basin area

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