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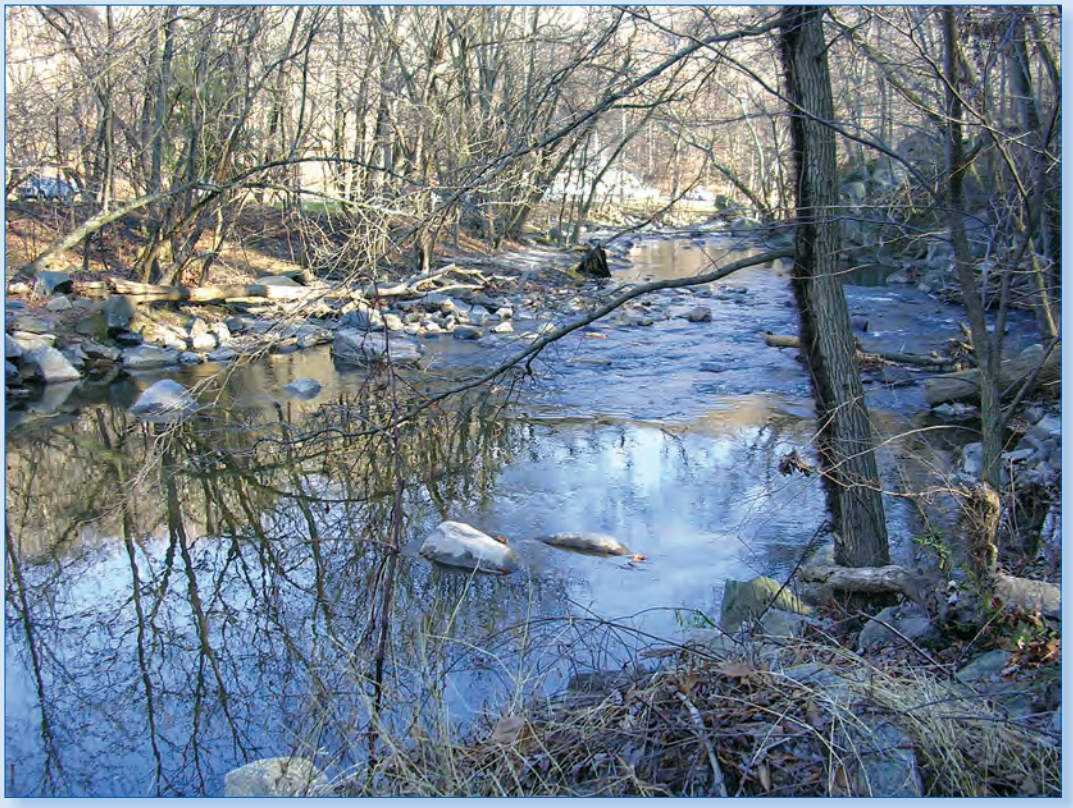
Chemical and Ecological Health of White Sucker (*Catostomus commersoni*) in Rock Creek Park, Washington, D.C., 2003–04



Scientific Investigations Report 2006–5140

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

Cover. Rock Creek downstream from Joyce Road in Washington, D.C. during base-flow conditions. (Photograph by Cherie V. Miller)

Chemical and Ecological Health of White Sucker (*Catostomus commersoni*) in Rock Creek Park, Washington, D.C., 2003–04

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DIRK KEMPTHORNE, Secretary

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	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:

$$°F=(1.8\times°C)+32$$

Concentrations of chemical constituents in fish tissue and bed sediment are given in percent weight, micrograms per kilogram (µg/kg) or picograms per gram (pg/g). Fish tissue results are reported on a wet-weight basis and bed sediment results are reported on a dry-weight basis.

Chemical and Ecological Health of White Sucker (*Catostomus commersoni*) in Rock Creek Park, Washington, D.C., 2003–04

By Cherie V. Miller[1], Holly S. Weyers[1], Vicki S. Blazer[2], and Mary E. Freeman[3]

Abstract

Several classes of chemicals that are known or suspected contaminants were found in bed sediment in Rock Creek, including polyaromatic hydrocarbons (PAHs), phthalate esters, organochlorine pesticides, dioxins and furans, trace metals and metalloids (mercury, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, silver, and zinc), and polychlorinated biphenyls (total PCBs and selected aroclors). Concentrations of many of these chemicals consistently exceeded threshold- or chronic-effects guidelines for the protection of aquatic life and often exceeded probable effects levels (PELs). Exceedance of PELs was dependent on the amount of total organic carbon in the sediments.

Concurrent with the collection of sediment-quality data, white sucker (*Catostomus commersoni*) were evaluated for gross-external and internal-organ anomalies, whole-body burdens of chemical contaminants, and gut contents to determine prey. The histopathology of internal tissues of white sucker was compared to contaminant levels in fish tissue and bed sediment. Gut contents were examined to determine preferential prey and thus potential pathways for the bioaccumulation of chemicals from bed sediments. Male and female fish were tested separately. Lesions and other necroses were observed in all fish collected during both years of sample collection, indicating that fish in Rock Creek have experienced some form of environmental stress. No direct cause and effect was determined for chemical exposure and compromised fish health, but a substantial weight of evidence indicates that white sucker, which are bottom-feeding fish and low-order consumers in Rock Creek, are experiencing some reduction in vitality, possibly due to immunosuppression. Abnormalities observed in gonads of both sexes of white sucker and observations of abnormal behavior during spawning indicated some interruption in reproductive success.

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Introduction

Rock Creek, a small tributary to the Potomac River, is an important stream in the Washington, D.C. metropolitan corridor and is a vital resource to Rock Creek Park. The upper watershed of Rock Creek extends primarily into suburban areas and some agricultural land in Maryland. The mouth of the creek is at the Potomac River, a major tributary to the Chesapeake Bay Estuary. Flowing from a developed and urbanized watershed, Rock Creek is vulnerable to multiple stressors including toxic chemical contaminants from development and agriculture that can accumulate in bed sediment and biota, and physical changes to the stream that have potentially degraded the habitat. In-stream structures such as dams and weirs have altered the hydrology of the stream and may affect the migration and breeding behavior of fish. From 2004 to the present, the dams and weirs within the park area of Rock Creek were mitigated or removed, and a fish ladder was completed in the spring of 2006 (fig. 1).

Previous studies have demonstrated that anthropogenic chemicals are present in the water column and bed sediment of Rock Creek and that the biological habitat is degraded (Sherman and Horner, 1935; CH2M Hill, 1977; Anderson and others, 2002). In 1999–2000, the U.S. Geological Survey (USGS) partnered with the National Park Service (NPS) to conduct a study of potential chemical contamination in Rock Creek. Rock Creek Park is managed on a continual basis by the NPS and the Maryland National Capital Planning Commission. The results of chemical testing in the stream indicated that some chemicals persist in the bed sediment and water column at levels that exceed guidelines for the protection of health in the aquatic biota. Organochlorine insecticides were detected in the water column throughout the year. Bed sediments had accumulated a number of different classes of compounds including polyaromatic hydrocarbons (PAHs), phthalate esters, organochlorine (OC) pesticides, trace metals and metalloids (mercury, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, silver, and zinc), and polychlorinated biphenyls (PCBs). The current study focuses on the health and diet of white sucker (*Catostomus*

Figure 1. Fish ladder on Rock Creek just upstream from Peirce Mill. [Construction for this ladder was begun after field sampling for this study and was completed in spring 2006.]

commersoni), a common species of bottom-feeding fish in Rock Creek, to determine if exposure to these chemicals is having an observable effect. White sucker were evaluated for physical health, whole-body burdens of chemical contaminants, and gut contents to determine preferential prey and thus potential trophic pathways for ingestion and bioaccumulation of toxic chemicals. Fish were collected during three different sampling rounds and tested for PAHs, PCBs (Aroclor mixtures), trace metals, OC pesticides, phthalate esters, and dioxins and furans. The histopathology of internal tissues was compared to contaminant levels in whole fish. Male and female fish were tested separately. This report describes the results of chemistry and fish-health assessment and infers possible effects of chemicals in bed sediment on the aquatic faunal community. Specifically, this report presents evidence that fish in Rock Creek are affected by chemical contaminants that may compromise fish health, but these effects are moderate and vary temporally, possibly enhanced by shifts in the hydrology and physical environment of the stream. The results from this study emphasize the importance of making observations over multiple years and variable hydrologic conditions (fig. 2).

Previous Investigations

One of the earliest published reports on the water quality of Rock Creek was by Sherman and Horner (1935), who documented contamination as indicated by biological oxygen demand (BOD) and coliform bacteria in the stream from the Maryland/Washington, D.C. boundary to the mouth of the Potomac River. On the basis of Sherman and Horner's recommendations, improvements to sewer infrastructures were instituted, and as documented by CH2M Hill (1977; 1979), stream conditions have been improved, but the stream remains affected by pollution. Bacteria and other indicators of sewage pollution persist, particularly in the lower reaches of the stream. In 1979, CH2M Hill conducted a survey of undocumented outfalls on the main stem and tributaries of Rock Creek and documented a number of such outfalls that were discharging waters with elevated levels of fecal coliforms and chemical oxygen demand (COD). Concentrations of iron, lead, zinc, and mercury in bed sediment also were measured in that survey, but none of those concentrations exceeded any action levels for that time period. Concentrations of metals generally were similar to those measured in the current study. CH2M Hill documented sewage-treatment plants that were overcommitted and thus subject to combined sewage overflows during storm events. At least one landfill in Montgomery County above Washington, D.C., was found to be contributing leachate to Rock Creek. Assemblages of indicator species of macroinvertebrates, macrophytes, and fish documented in the CH2M Hill study corroborated observations of mild to moderate pollution in Rock Creek.

From 1992 through 1996, the USGS National Water-Quality Assessment (NAWQA) Program performed an assessment of the Potomac River Basin for the occurrence of

Figure 2. Rock Creek at Joyce Road during a high-flow event.

selected contaminants in surface waters, bed sediment, and fish tissue (Ator and others, 1998; Zappia, 1996). Although no samples were collected from Rock Creek during that study, the streambed sediments at a number of other sites on the Potomac River and its tributaries were found to contain contaminants such as chlordane, DDT, PCBs, mercury, and lead that were bioavailable and incorporated into the food chain.

The Montgomery County Department of Environmental Protection, Streams and Watershed Program (1997) evaluated the general health of the County's waters and biological habitat. At that time, they determined that "the overall resource condition for Rock Creek was fair to poor." The Montgomery County Government is continuing to assess the status of biological communities and general stream health in Rock Creek in Montgomery County as part of a watershed restoration feasibility study. Similar studies are being conducted by the city of Rockville, Maryland, and the National Naval Medical Center in Bethesda, Maryland, which is making efforts to restore Stoney Creek, a tributary on this section of Federal land.

The Washington, D.C. Department of Health (DCDOH) conducts monthly fish-shocking surveys in the southern portion of Rock Creek from March through December. These surveys, which focus on alewife and blueback herring, measure gross parameters such as weight, length, and sex of the fish. The DCDOH will continue to study these species to document the effects of the removal of a fish passage within Rock Creek Park.

Severe adverse effects on fish health have been observed in the Anacostia River, a tributary of the Potomac River adjacent to Rock Creek that has higher-density-urban land use. Pinkney and others (2001, 2004) used ethoxyresorufin *o*-deethylase (EROD) assays in liver tissue to indicate exposure of brown bullhead (*Ameiurus nebulosus*) to PAH compounds. They documented serious health effects such as skin and liver tumors and barbe malformations from exposures to these and other contaminants in the Anacostia River. Hepatosomatic indicies (HIS; ratios of liver to body weight in fish) were positively correlated to concentrations of PAH metabolites in bile and with chlordane concentrations in muscle tissue.

The USGS conducted sampling for water and sediment quality within Rock Creek Park, during 1999–2000 (Anderson and others, 2002). In a temporal assessment of water quality at one site on the main stem of Rock Creek, four insecticides—chlorpyrifos, diazinon, carbaryl, and malathion—were found year-round to exceed published guidelines for the protection of aquatic life. Several major classes of chemicals also were found in samples of bed sediment from three locations that were sampled within the main stem of Rock Creek. Most of the chemicals and compounds analyzed were detected in the bed sediment. Eight trace metals, 14 PAHs, 6 OC pesticides (including some legacy compounds that are no longer in use), total PCBs, and 1 phthalate compound were found to exceed published guidelines for the protection of aquatic life (U.S. Environmental Protection Agency, 1999; Canadian Council of Ministers of the Environment, 1999; International Joint Commission of the United States and Canada, 1989).

Description of Study Area

Rock Creek travels approximately 33 miles from its headwaters near Laytonsville, Maryland, to the Potomac River (fig. 3). The lower third of the Rock Creek watershed is within the city limits of Washington, D.C., and is influenced by physical and chemical urban effects. The upper watershed is in Montgomery County, Maryland, and is a mixture of urban/suburban and agricultural land use. On the basis of surveys of land cover in 1997 by the Maryland Office of Planning, the upper Rock Creek Basin is approximately 54 percent urban/suburban and 18 percent agricultural, whereas the lower part of the basin in the Washington, D.C. area is approximately 61 percent urban/suburban (Duigon and others, 2000; Vogelmann and others, 2001). Population over the entire Potomac River Basin has increased approximately 44 percent from 1970 to 1990 (Ator and others, 1998), and this growth has been most intense in a corridor north of Washington, D.C., which includes the Rock Creek watershed. The percent of impervious surface in the Lower Rock Creek study area may be as high as 55 percent (Jeffrey Runde, National Park Service, written commun., 2006). The NPS maintains a public 18-hole golf course within the boundaries of Rock Creek Park; chemical use at the course is strictly controlled and monitored by the Park Service. The principal pesticides used on the golf course include manzeneb, chlorothalonil, chlorpyrifos, and glyphosphate (Anderson and others, 2002). The National Zoological Park is within the lower Rock Creek watershed, downstream from the current study area (fig. 4).

All fish were collected in a 200-foot reach adjacent to the millrace at Peirce Mill in Rock Creek, Washington, D.C. (USGS Station 01648016, fig. 5). White sucker occupy an important niche for bottom feeders in Rock Creek and spawn at or near Peirce Mill in early spring. Habitat in this section of Rock Creek is composed of pools and gentle riffles. The riverbed by Peirce Mill is mainly sand and gravel with some cobbles. Fine sediments have accumulated in the bends, pools, and other areas of low stream energy. A fish ladder was installed in the main stem of Rock Creek just upstream of Peirce Mill, but construction did not begin until after all field activities for this project had been completed.

The annual mean-daily discharge for the period of record at the USGS gaging station on Rock Creek at Sherrill Drive (Station 01648000, fig. 6), approximately 2 miles upstream of Peirce Mill, is 63.1 ft^3/s (cubic feet per second). Discharges for Rock Creek at Sherrill Drive during the period of study ranged from a minimum of 0.97 ft^3/s in 2002, which was a severe drought year, to a maximum of 997 ft^3/s in 2003, which was a much wetter than average year (James and others, 2003).

Ecology of White Sucker in Rock Creek

White sucker are common benthivorous fish in North America and occupy a dominant niche for benthic predators in the Rock Creek ecosystem. Feeding activities of white sucker go through several stages during their life cycle. The mouth moves from a terminal position in larval fish to an inferior position with specialized protractile lips that limit the feeding strategies in the adult to benthic foraging. These fish are successful in a wide range of environmental conditions, particularly due to their thermoregulatory behavior and resistance to some chemicals (Logan and others, 1991). Habitats include most stream and brook environments, but adult white sucker prefer reaches with rocky or sandy bottoms. Although adult white sucker are predominantly omnivorous benthic feeders, they are flexible and opportunistic, and will feed on zooplankton when they present a readily available food supply. Chironomid larvae are the preferred prey for white sucker (Marin, 1983; Stewart, 1926; Saint-Jacques and others, 2000). Annual surveys of benthic macroinvertebrates in Rock Creek by the DCDOH have shown that larvae of chironomids (midges) and hydropsychidae (caddis flies) are the dominant fauna in bed sediment in Rock Creek (Clarence Dickens, Washington, D.C. Department of Health, written commun., 2004).

Methods of Investigation

Fish and bed sediment were collected and analyzed during three different sampling events during 2003–04 in Rock Creek at Peirce Mill in Washington, D.C. The USGS field crews were assisted in the collection of fish samples by DCDOH personnel, who regularly make surveys of fish populations in Rock Creek.

Collection of Field Data

White suckers in Rock Creek were collected by backpack electroshocking. The size of the study area and the number of fish collected were limited in an attempt to minimize damage to fish populations by overcollection. Migration patterns of the collected fish were not documented. Fish were kept alive in aerated holding tanks for 1 to 4 hours before processing. Samples of fish were collected twice during spring spawning in 2003 and 2004 to target the peak reproduction periods for the fish, and once in fall 2003 for comparison. At each site, fish were first measured for total mass and length, examined for visible external lesions and abnormalities, and then dissected. External surfaces were examined for tumors, deformities, lesions, parasites, and scale loss. The fish peritoneal cavity was exposed for dissection by cutting from the vent to the pectoral fins, and gross internal abnormalities were observed and documented. The gonads were dissected from the other viscera and removed for weighing. Small

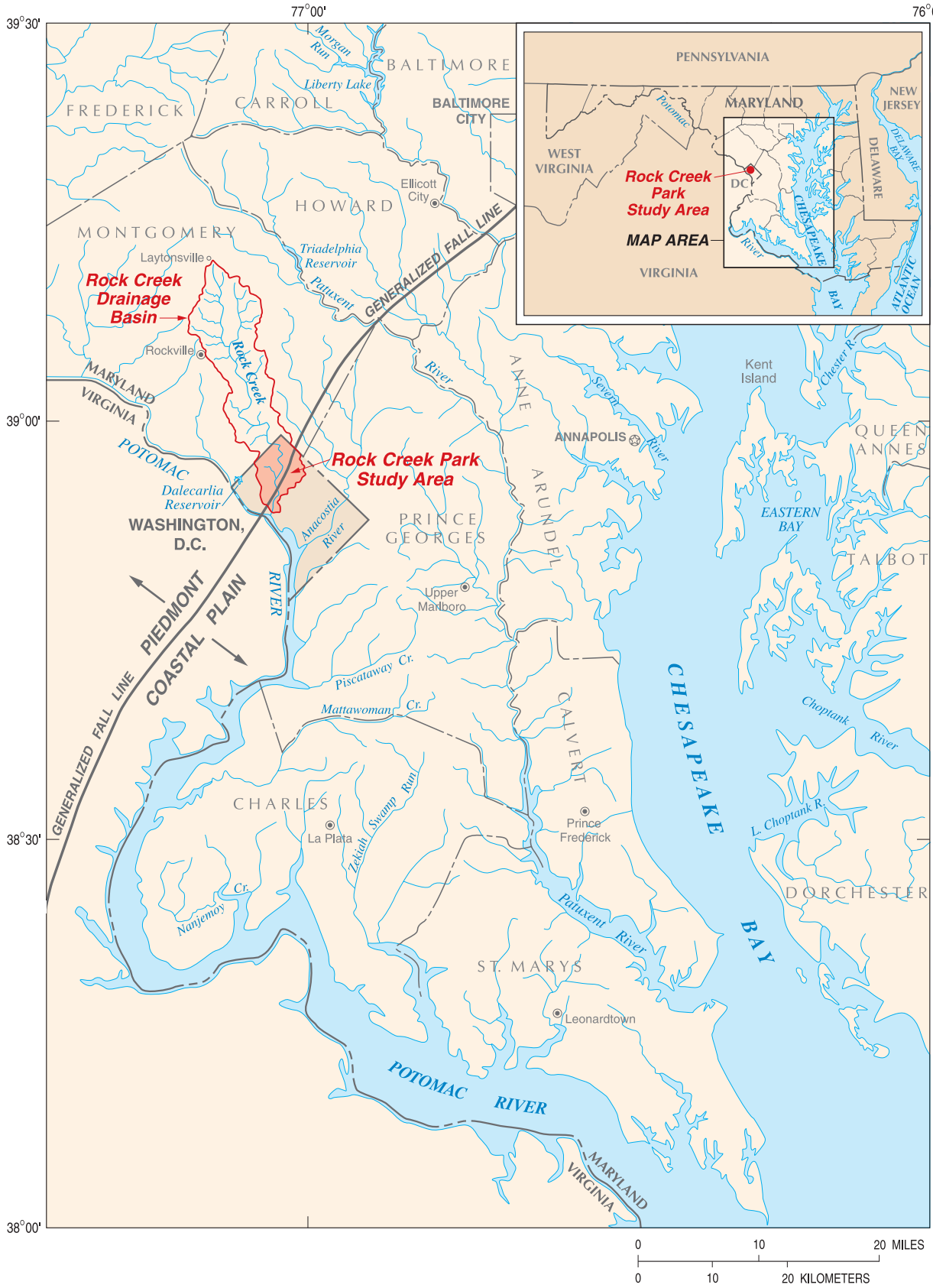

Figure 3. Location of Rock Creek drainage basin and Rock Creek Park study area, Washington, D.C.

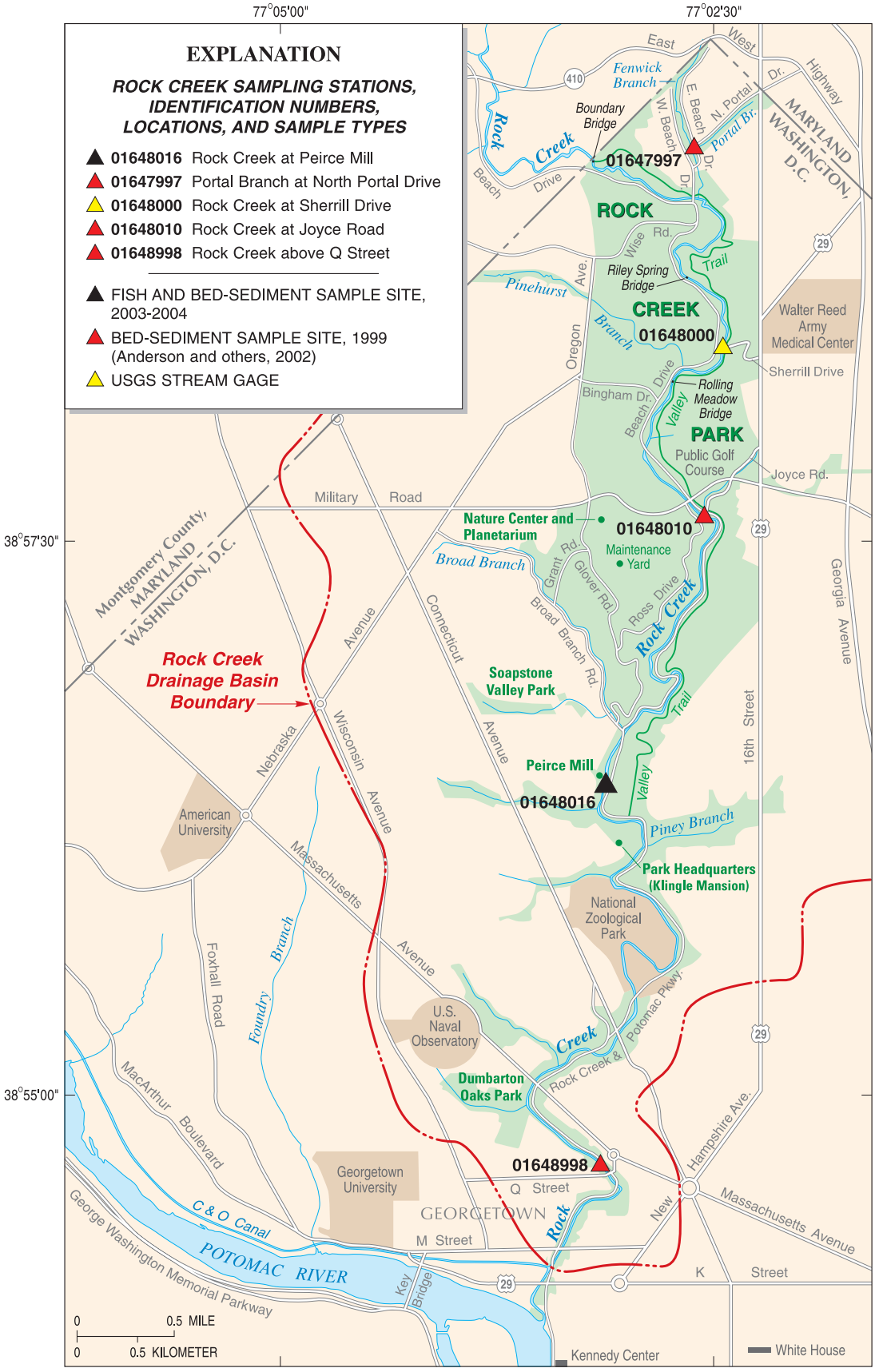

Figure 4. U.S. Geological Survey sampling stations within the Rock Creek Park study area, Washington, D.C.

Figure 5. Rock Creek at Peirce Mill, Washington, D.C. (Station 01648016). [The open pool adjacent to the millrace is where white sucker are commonly observed spawning in the spring. Fish were collected in a 200-foot reach of the stream around this site.]

Figure 6. U.S. Geological Survey stream-gaging station on Rock Creek at Sherrill Drive (Station 01648000).

samples of tissue were removed from the liver, gonads, kidney, and gills (figs. 7 and 8). Any abnormalities on the fish were observed grossly and sub-specimens were placed in plastic containers with Z-Fix solution for fixation. Whole stomachs were removed and stored in plastic containers with 10 percent formalin for later identification of gut contents. All remaining tissues were returned to the carcass for chemical analysis. Fish were handled with clean nitrile gloves and on clean dissection boards before finally being transferred to baked glass jars for analyses of tissue chemistry. Samples were sent overnight on ice to the Severn Trent Laboratories (STL) in Denver, Colorado, and stored at 4 ºC (degrees Celsius) at this facility or shipped on to STL Sacramento in Sacramento, California, or STL Burlington in Colchester, Vermont, for analysis. Samples for histopathology were transported to the USGS National Fish Health Research Laboratory at the Leetown Science Center in Kearneysville, West Virginia, and stored at room temperature until processed. Samples of fish gut for prey identification were stored in formalin at room temperature and shipped at a later date to the USGS Patuxent Wildlife Research Center Field Station in Athens, Georgia.

In spring and fall 2003, fish filets were collected for chemical analyses, but in spring 2004, whole fish were analyzed. Analyses of filets are better indicators of potential human health effects as this is the only tissue normally consumed by humans. Most organic contaminants, however, tend to accumulate in lipids and other fatty tissues such as liver and gonads. Thus, analyses of whole fish are better indicators of bioaccumulation of contaminants and for the potential transfer of contaminants to higher trophic levels in the food chain. Differences in fish size, type of tissue collected, and hydrology in each of the three sampling periods precluded comparisons of results between sampling events. Fish size also differed by gender, so each gender was analyzed separately.

Samples of bed sediment were collected twice, once in spring 2003 and once in spring 2004. Bed sediment was collected as a composite of surficial fine sediment in a low-energy bend of the riverbed adjacent to Peirce Mill. Samples were not collected from areas where the bottom was coarse sand or rocky material. Sediment was collected in a baked glass jar using a stainless-steel spoon that had been washed in liquinox and warm tap water followed by a rinse with ultrapure deionized water. These samples were immediately placed on ice and shipped overnight to STL in Denver, Colorado. After initial processing at STL Denver, some of the bed-sediment samples were then sent on to STL Sacramento or to STL Burlington.

Chemical Analyses of Bed Sediment and Fish Tissue

Samples of bed sediment and fish tissue were analyzed for selected chemicals at the STL laboratories. The methods, references, and STL locations where each analysis was performed are listed in table 1. Individual fish were used when they were large enough for a complete analysis. Smaller fish carcasses were composited to collect enough material for some analyses. Fish samples were homogenized in a clean blender at the laboratory before subsamples were extracted for each analysis. All analytical results for fish tissue are reported as wet weight, and concentrations in bed sediment are reported as dry weight for consistency with the established literature.

Samples for analysis of trace metals in both tissue and bed sediment were refluxed with concentrated nitric acid, followed by vigorous oxidation with 30 percent hydrogen peroxide, and finally diluted with deionized water. Digestates were analyzed for trace metals by direct-injection Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Samples for mercury were analyzed separately; bed sediment and fish tissue were digested in Teflon bombs with concentrated nitric and sulfuric acid and then analyzed for total mercury by Cold-Vapor Atomic Absorption Spectrometry.

Samples for most organic compounds were extracted ultrasonically using methylene chloride for PAHs and phthalate ester, hexane/acetone for OC pesticides, and hexane for PCBs. Extracts were cleaned as needed for interferences in individual samples and analyzed by Gas Chromatography-Mass Spectrometry (GC-MS). PCBs are reported as Aroclor mixtures and as total PCBs.

Polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) were analyzed by High Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS). All samples were fortified with isotopically labeled standards before soxhlet extraction with toluene. Extracts were cleaned as needed for interferences in individual samples.

More detailed summaries of laboratory analyses and quality-assurance results are available by request from the USGS Maryland-Delaware-D.C. Water Science Center in Baltimore, Maryland.

Quality Assurance for Chemical Analyses

Method blanks were analyzed concurrently for all methods at STL. With the exception of some metals, method blanks showed non-detections for the analytes. For most of the metals found in method blanks, the concentrations were considerably less than 10 percent of the environmental concentrations. Exceptions were the concentrations of mercury, chromium, and nickel in several tissue blanks. The results of the analyses of method blanks are presented with the data, and data are coded as “estimated” where concentrations of the analyte of interest in the blanks were greater than 10 percent of the environmental concentrations.

Many of the methods used in this study are “information rich,” meaning that often the chemical can be detected below the reporting level, but that the precision on these low-level detections is less than optimal. Detections that are below the reporting levels are presented in this report, but are coded to

Figure 7. Fish dissection at Rock Creek; removal of filets from white sucker.

Figure 8. Fish dissection at Rock Creek; removal of tissues for histopathology and analysis of gut contents.

Table 1. Locations of laboratories and methods used for analysis of fish and bed-sediment chemistry.

[STL, Severn Trent Laboratory; HRGC/HRMS, High Resolution Gas Chromatography/Mass Spectrometry; ICP-MS, Inductively Coupled Plasma Emission Spectroscopy/Mass Spectrometry; PAH, polyaromatic hydrocarbon; PCB, Polychlorinated Biphenyl; GC/MS, Gas Chromatography/Mass Spectrometry]

Analysis	Laboratory	Preparation methods	Analytical methods	References
Dibenzodioxins and Dibenzofurans by HRGC/HRMS	STL Sacramento	8290	8290	SW846[1]
Metals by ICP-MS	STL Denver	3050B	6020	SW846
Mercury by cold vapor in tissue	STL Denver	245.6	245.6	MCAWW[2]
Mercury by cold vapor in solids	STL Denver	7471A	7471A	SW846
PCB alaclors by GC/MS	STL Denver	3550B/366	8082	SW846
Organochlorine pesticides by GC/MS	STL Denver	3550	8081A	SW846
Semivolatile organic compounds (PAHs and phthalate esters) by GC-MS in tissue	STL Burlington	3550B/3660B	8270C	SW846
Semivolatile organic compounds (PAHs and phthalate esters) by GC-MS in solids	STL Denver	3550B/3620B	8270C	SW846
Percent moisture	STL Sacramento	D2216-90	D2216-90	ASTM[3]
Percent lipids	STL Denver	823R95007	Extracted residue	SW846

[1] U.S. Environmental Protection Agency, 1986.

[2] U.S. Environmental Protection Agency, 1983.

[3] American Society for Testing and Materials (ASTM), 2000.

qualify these data and should be considered to have less confidence in the reported values.

Surrogate organic compounds were added to samples before analysis to determine the recovery of similar compounds in the natural environmental matrices. The recoveries of these surrogate compounds are presented with the data and should be considered when evaluating the concentrations of the target analytes. In several cases for PAH compounds, the surrogate recoveries were outside of the established control limits. These samples were analyzed at a higher dilution, yielding similar results. For organochlorine pesticides, surrogate recoveries could not be calculated due to dilution effects and interfering analytes, so these data should be considered as estimates only.

On May 12, 2004, field replicates of whole-fish tissue, two samples of male fish and two samples of female fish were collected to determine the reproducibility of tissue chemistry data. Replicate values are presented with environmental data.

Histopathology of Fish

Pieces of fish tissue were routinely processed for histology (Luna, 1992). Each piece was dehydrated with a series of alcohols and organic solvent, followed by infiltration with paraffin. Once the paraffin had hardened, the blocks were sectioned at 6 microns, dried on glass slides, voided of paraffin with organic solvent, and stained with hematoxylin and eosin (H&E).

Gut Analysis for Diet of White Sucker

Contents were removed from the foregut (April 2003 and May 2004 samples, n=37) or from the entire intestinal tract (September 2003 samples, n=8) for identification. Enumerations of organisms were therefore not compared, as differences were likely biased by the amount of gut that was collected. Gut contents were examined with a dissecting microscope (10–40X magnification) and all individual prey items present were counted as whole animals or as head capsules. Animals were identified to the lowest taxon practicable, usually to the level of family or order, using the classifications of Merritt and Cummins (1996). The biomass of gut contents was not determined.

Calculation of Biota-Sediment Accumulation and Toxic Equivalency Factors

Organic chemicals that are introduced to a river ecosystem are commonly hydrophobic and will tend to partition into and accumulate in lipids and other fatty tissues in the biota. The Biota-Sediment-Accumulation Factors (BSAF) quantifies the steady-state accumulation of non-polar organic chemicals from bed sediment to the total-extractable lipid fraction in an organism. A BSAF was calculated for each chemical that was found in both the fish tissue and the bed sediment in Rock Creek. The concentration of total organic carbon was mea-

sured in the 2004 bed sediment sample and was 1.0 percent by dry weight.

$$BSAF = \frac{C_{fish}\ (ww) \ / \ L_{fish}\ (\%\ ww)}{C_{BS}\ (dw) \ / \ TOC_{BS}\ (\%\ dw)} \qquad (1)$$

where BSAF is unitless, and

C_{fish} = the contaminant concentration in fish tissue [wet weight (ww) in micrograms per kilogram (µg/kg) or picograms per kilogram (pg/kg)],

L_{fish} = the concentration of total lipids in fish tissue (ww percent),

C_{BS} = the concentration of the same contaminant in bed sediment [dry weight (dw) in µg/kg or pg/kg],

and

TOC_{BS} = the concentration of total organic carbon (dw percent).

Bioaccumulation of chemicals is largely a function of the concentration of the chemical in bed sediment, the composition, length, and complexity of the food web, the hydrophobicity (K_{ow}) of the chemical, and the rate of metabolism of the chemical within the organism. Ideally, at equilibrium, the BSAF should be between 1 and 1.7, depending on the relative solubilities of organic fractions, but biomagnification can occur under the right conditions.

There are numerous different chemical structures or congenors of dioxins and furans, and the toxicity of each species is highly variable. Toxicity is generally expressed as a single value for the group of measured dioxins and furans, and is calculated as the sum of the weighted toxicity of each congenor. Toxic Equivalents for total dioxin and furans (TEQs) are expressed as the 2,3,7,8-TCDD equivalent, which is the most toxic congenor of the group. The TEQ is calculated as the sum of the concentrations of each congenor multiplied by a Toxics Equivalency Factor (TEF) for that congenor, which was developed by the World Health Organization (Van den Berg and others, 1998). TEFs have been developed for different groups of fauna; the values from Van den Berg and others (1998) for fish are listed in table 2. TEFs are not available for all congenors of dioxins and furans and for the calculations in this study, an assumption was made to apply the TEF to the total subgroup of each set of chemical isomers when not all congenors were reported. However, to be conservative, this assumption was applied with the lowest TEF for that subgroup. For example, the TEF of 0.01 was used for total HxCDF (hexachlorodibenzofurans) rather than the three individual congenors that also were reported for this group.

Table 2. Toxic Equivalency Factors (TEFs) developed by the World Health Organization to calculate the cumulative toxicity of chlorinated dibenzodioxin (CDD) and chlorinated dibenzofuran (CDF) compounds.

[Van den Berg and others, 1998; Congenor names are defined in appendix A5; <, less than]

Dioxin or Furan Congenor	TEF for fish
2,3,7,8-TCDD	1
1,2,3,7,8-PentaCDD	1
1,2,3,4,7,8-HexaCDD	0.5
1,2,3,6,7,8-HexaCDD	0.01
1,2,3,7,8,9-HexaCDD	0.01
1,2,3,4,6,7,8-HeptaCDD	0.001
OctaCDD	< 0.0001
2,3,7,8-TetraCDF	0.05
1,2,3,7,8-PentaCDF	0.05
2,3,4,7,8-PentaCDF	0.5
1,2,3,4,7,8-HexaCDF	0.1
1,2,3,6,7,8-HexaCDF	0.1
1,2,3,7,8,9-HexaCDF	0.1
2,3,4,6,7,8-HexaCDF	0.1
1,2,3,4,6,7,8-HeptaCDF	0.01
1,2,3,4,7,8,9-HeptaCDF	0.01
OctaCDF	< 0.0001

Evaluation of Bed Sediment and Fish

Fish-tissue samples from white sucker were evaluated both physically and chemically to determine if there was evidence of stress on this species of fish. Fish health was evaluated at both the individual and population level. Bed-sediment chemistry was analyzed to compare to the results of fish health, and contents of fish stomachs were identified to determine potential trophic pathways for transfers of chemical contaminants from bed sediments to the fish.

Chemical Analyses of Bed Sediment and Fish Tissue

Results of chemical testing of bed sediment in Rock Creek corroborated results from an earlier study by USGS (Anderson and others, 2002). Differences in the concentrations of potential contaminants from each study could not be accurately determined due to the low number of samples collected and differences in collection methods. However, within ranges of natural and analytical variability, the results are similar. Results of all chemical analyses are presented in appendix A. For comparison, appendix B summarizes selected guidelines and criteria to assess the potential toxicity of bed sediment and the safety for fish health and human consumption.

Chemical and toxicological properties vary widely among individual organic contaminants. Higher-molecular-weight PAH compounds such as benzo(a)pyrene, pyrene, and chrysene persist longer in the environment because they partition more easily into organic fractions and are more slowly metabolized. Higher-molecular-weight PAH compounds also are more toxic and thus create a greater hazard to the benthic community in Rock Creek. Lower-molecular-weight PAH compounds such as anthracene, phenanthrene, and fluorine tend to be more water soluble and biodegradable, and as expected, were found less frequently and in lower concentrations than the higher-weight PAH compounds in Rock Creek bed sediment. PAH compounds were not found in fish tissue, but this was not unexpected due to very efficient metabolism of PAHs by fish. Phthalate esters are less easily metabolized in fish than are PAHs, and bis(2-ethylhexyl) phthalate, a chemical commonly used in a number of industrial applications, was detected consistently in both bed sediment and fish tissue at Rock Creek.

A number of OC pesticide compounds were detected in bed sediment in Rock Creek as well as in fish tissue. DDT and its degradates (DDD and DDE) were detected at all stations where bed sediment was collected in the 1999–2000 study and at the Peirce Mill site in 2004, but the DDT compounds were not detected in bed sediment at Peirce Mill in the sample collected in 2003. DDT and degradates were detected in fish tissue each time that fish were collected, indicating that this pesticide and its degradation products continue to persist and accumulate in biota. Other pesticides that were detected consistently in both bed sediment and fish tissue included chlordanes, dieldrin, and heptachlor epoxide (a degradate of heptachlor). Concentrations of all OC pesticides were higher and more consistently detected in whole fish than in filets.

Fish tissue and bed sediment were tested for total PCBs and concentrations of selected aroclors. In the 1999–2000 USGS study, total PCBs were analyzed and found in bed sediment. In the 2003–04 study, samples were analyzed for selected individual aroclors that were not detected in bed sediment, but Aroclor 1254 was found consistently in fish tissue, particularly in the samples collected in 2004, when whole fish were analyzed. Aroclor 1254 is one of the most common mixtures of PCBs and is used in a number of industrial applications, including hydraulic fluids, cutting oils, sealants, inks, adhesives, electrical transformers, and vacuum pumps. This mixture has been shown to be persistent in the environment, resistant to degradation, to bioaccumulate, and in some cases to cause endocrine disruption in a variety of biota. Concentrations of Aroclor 1254 in samples of whole fish tissue collected in 2004 ranged from 68 to 270 µg/kg (wet weight).

Dioxins and furans were detected at various levels in each sample of bed sediment and fish tissue, but the highest concentrations occurred in the less toxic forms of these chemicals. TEQs for dioxin and furan compounds were calculated for each sample and are reported with the data in appendix A5. The TEQ in bed sediment was 13 pg/g (picograms per gram) as TCDD in 2003 and 1.0 pg/g in 2004. The TEQ in fish tissue was 0.03 to 0.04 pg/g as TCDD in fish filets in 2003, and 0.1 to 0.4 pg/g as TCDD in whole fish in 2004. Dioxins and furans were not analyzed in the earlier USGS study.

Except for PAHs, the organic chemical compounds that were analyzed in this study do not occur naturally. True background concentrations are therefore expected to be zero, although this concentration is very difficult to find even in pristine environments. Concentrations found in bed sediment and fish tissue in Rock Creek represent exposures typical of other urban streams in the United States and in the Chesapeake Bay watershed (Schmitt and others, 2002; McGee and others, 1999; Pinkney and others, 2001, 2004).

Trace metals are naturally occurring constituents and were detected in all samples of bed sediment and fish tissue, usually at levels that could be considered background, or at levels that would be expected in urban settings. Concentrations of metals in sediment are highly variable as they are dependent on the percentage of fine materials such as clays and organic particles in the samples. No estimates of size fractionation were made and total organic carbon (TOC) was not measured in all years, but some comparisons can be made. When concentrations of trace metals measured in 2003 and 2004 are normalized to TOC and compared to concentration ratios at all three sites in the 1999–2000 study, they were similar. The ratios of metals to TOC collected at Peirce Mill in 2004 are well within three standard deviations of the concentrations collected at multiple sites in the 2002 study, and therefore are representative of concentrations of metals in fine material in Rock Creek. Levels of metals in fish were comparable to those found in other studies, such as those of farmed and wild salmon from the Atlantic and Pacific Oceans (Foran and others, 2004) and carp and bass from the Mississippi River Basin (Schmitt and others, 2002). All concentrations of metals in tissue were less than 1,000 µg/kg except for copper and zinc. Concentrations of copper in whole fish in 2004 ranged from 1,100 to 2,300 µg/kg. Concentrations of zinc ranged from 5,300 to 10,000 µg/kg in filets and 14,000 to 25,000 in whole fish in 2004. Not unexpectedly, concentrations of all metals in fish tissue, except mercury, were highest in 2004, when whole fish rather than filets were analyzed. Concentrations of mercury were similar in filets and whole fish, and ranged from 27 to 83 µg/kg in both years.

Gross Fish Health Assessment

A total of 17 white suckers were examined in spring 2003 (late April), 8 were examined in fall 2003 (September) and 20 were examined in spring 2004 (early May). A summary of gross characteristics by sex is presented in table 3. Gonadosomatic index (GSI) is the ratio of the mass of the gonads to the mass of entire fish and is used as an index of fecundity. The index is expected to change during ontogenesis, with maxima in mature individuals and during spawning. GSI also is higher for mature females than mature males, due to morphologic differences in the gonads. In Rock Creek, the ratios were

Table 3. Summary of gross-health characteristics for white sucker collected in Rock Creek at Peirce Mill, Washington D.C.

[n, number of samples; cm, centimeters; g, grams; GSI, gonadosomatic index; —, insufficient data to calculate]

Collection date	Sex	n	Length (mean; range in cm)	Weight (mean; range in g)	Mean GSI[1]
April 28, 2003	Male	7	32; 28–36	368; 200–500	.035
	Female	10	31; 29–35	333; 250–490	.144
Sept. 9, 2003	Male	5	23; 21–26	139; 96–187	—
	Female	3	25; 19–34	173; 78–381	—
May 12, 2004	Male	7	23; 19–28	126; 77–213	.020
	Female	12	30; 22–40	357; 128–750	.140

[1] GSI, gonadosomatic index = mass of gonads/mass of whole fish.

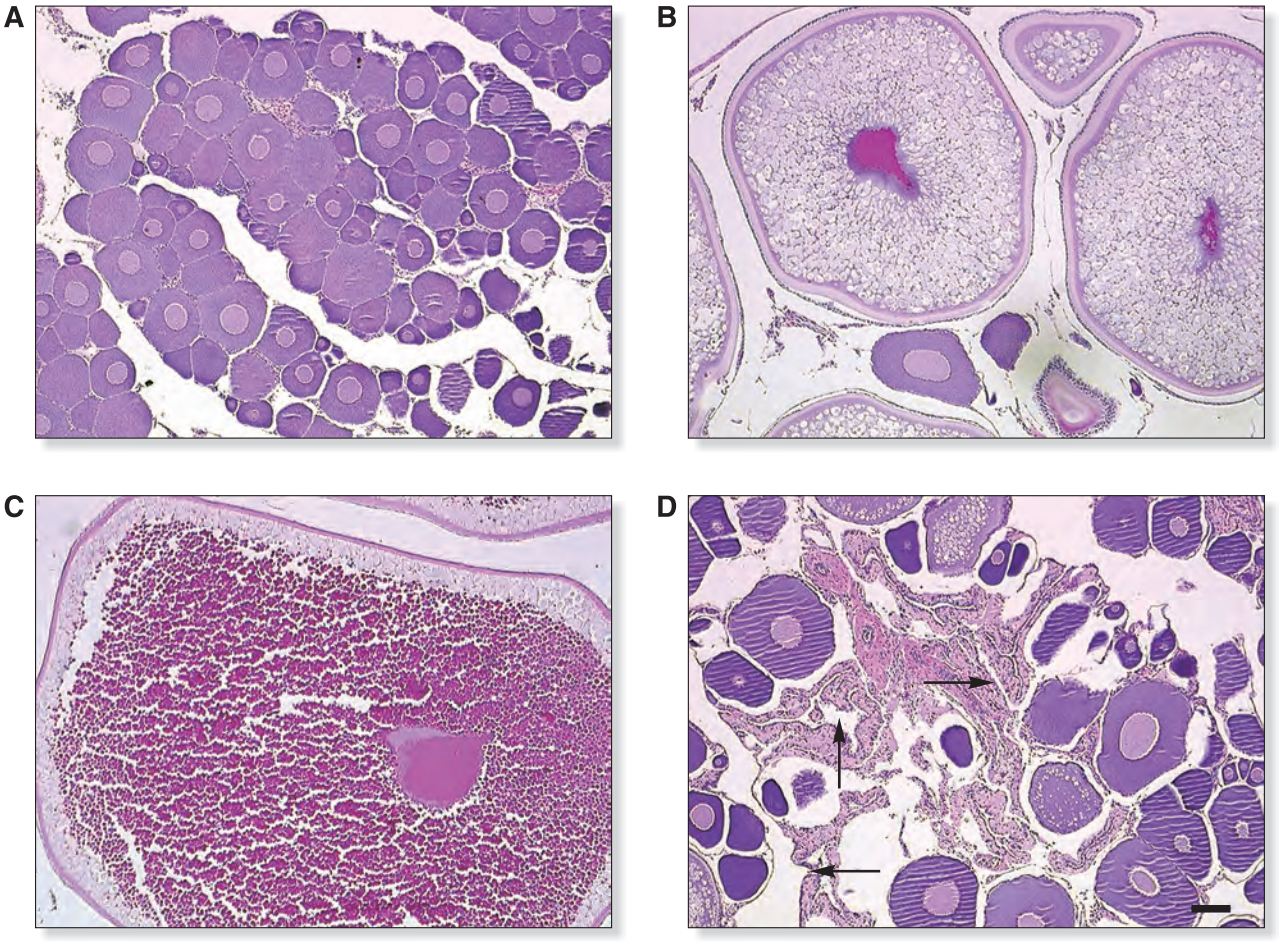

Figure 9. Microscopic appearance of female white sucker gonads illustrating *A*, The early pre-vitellogenic, stage 1. *B*, Early vitellogenic or cortical alvelolar, stage 2. *C*, The late vitellogenic, stage 3. In one fish *D*, post-ovulatory follicles, stage 5 (arrows) were observed. [H&E stain; bar equals 100 micrometers]

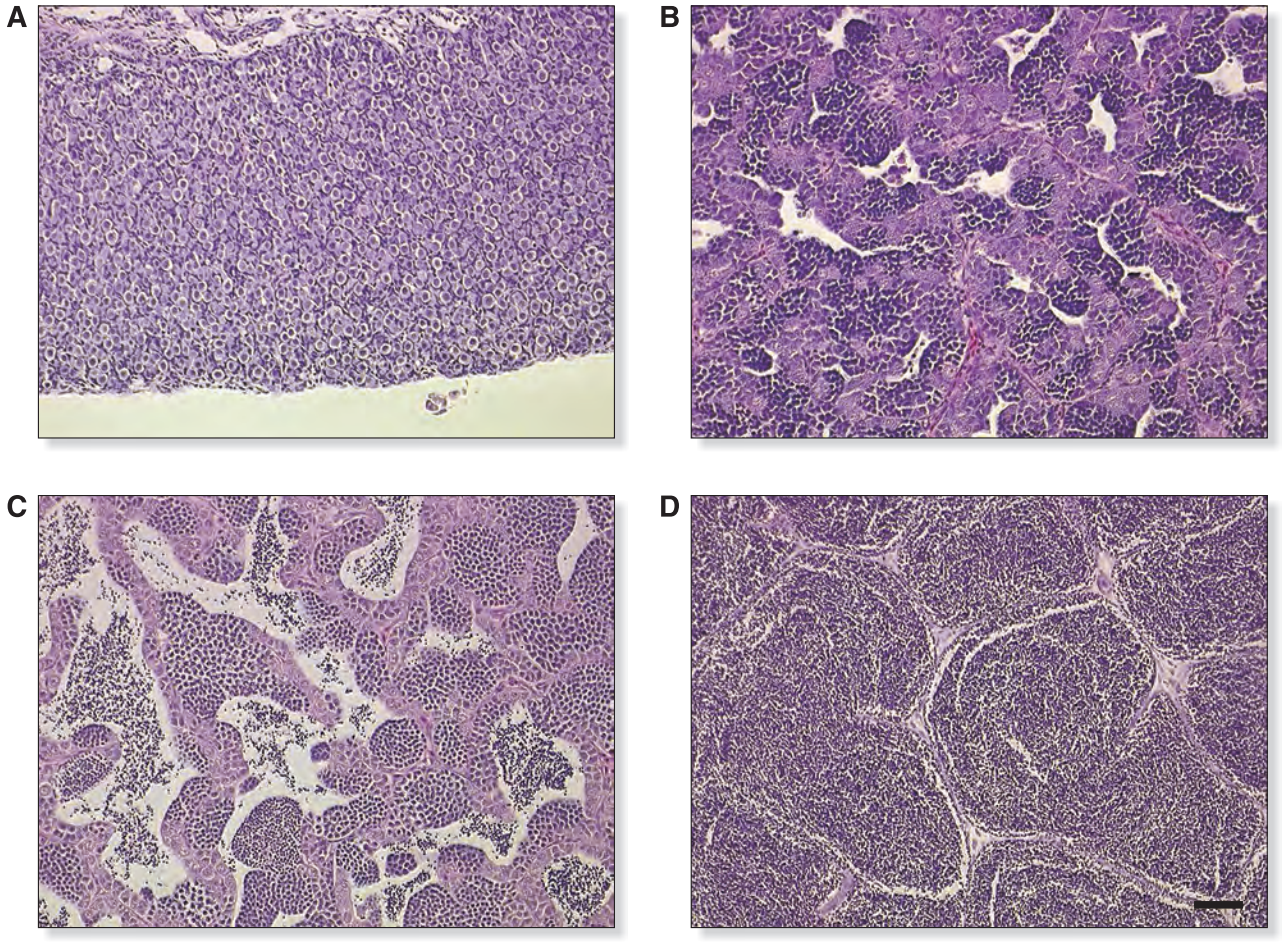

Figure 10. Microscopic appearance of male white sucker gonads illustrating *A*, Stage 0, undeveloped gonads, containing primarily spermatogonia. *B*, Stage 1, containing spermatocytes and spermatids. *C*, Stage 2 with approximately equal numbers of spermatocytes, spermatids, and spermatozoa. *D*, Stage 3, containing primarily mature spermatozoa. [H&E stain; bar equals 50 micrometers]

calculated only during the two spring spawning seasons when fish were sampled. The GSIs for female white sucker were indistinguishable between years, and healthy mature egg sacks were observed in females for both years. For male white sucker, however, there was a significant difference in the mean GSI between the 2 years ($p = 0.05$, two-tailed Student's t test = 2.15, with 12 degrees of freedom). In 2004, the GSIs were lower than those observed in 2003, and fish were not observed exhibiting typical spawning behavior—groups of male fish were not swimming beside a female attempting to spawn. Stewart (1926) observed in Michigan that ripe females were not observed until late April whereas ripe males were observed as early as March. This sequence allows the timing of sexual maturity to correctly overlap and ensures reproductive success, but is the reverse of what was observed in Rock Creek in 2004.

During both spring sampling rounds, more females were collected than males. The females collected during both years were similar in size (lengths and weights), but the males collected in 2003 were significantly larger than those collected in 2004. In spring 2003, one male was stage 2 (testes containing many spermatocytes and spermatids), whereas in 2004 one male and one female were stage 1 (immature gonads), and one female was stage 5 (postspawn). The majority of sucker gonads collected in the spring were stage 3 or prespawn with vitellogenic eggs (fig. 9) in the females and stage 3 or containing primarily spermatozoa (fig. 10) in the males. Four gonads in spring 2003 had grossly observable black spots, and one in spring 2004 had fibrotic reddened lesions.

The external abnormalities observed in the fish examined included frayed gills, abnormal gill cartilage, white spots on gills, raised white cysts on the fins, frayed fins, healed

areas on the body surface, red areas on the opercle and body surface (some ulcerated, some raised), and a missing eye. The incidence of external abnormalities differed among sample collections, with no external lesions observed in the fall 2003 collection. The percentage of fish with any external lesion was 76 percent in spring 2003 and 45 percent in spring 2004. Gill lesions were much greater in 2003 (59 percent) than in 2004 (5 percent), while body surface and fin abnormalities were similar between the years (table 4).

Histologically, most of the external lesions were parasite-induced (figs. 11 A–B) or wounds. Parasites included the parasitic protozoan *Ichthyopthirius multifilis* (fig. 11A) and a myxosporidian parasite (fig. 11B). In spring 2003, however, seven of the abnormal gills were due to abnormal cartilage (fig. 11C).

Liver lesions observed microscopically included many changes that have previously been associated with contaminant exposure: bile-duct proliferation (fig. 12A), in which the epithelium of the bile ducts sometimes contained rodlet cells (fig. 12B), altered foci (fig. 12C), ceroid/lipofuscin accumulation within hepatocytes (fig. 12D), adenoma (not pictured) and cholangiocarcinoma (figs. 12E–F).

During sample collection, two changes were noted in the kidneys of some fish and these occurred only in spring 2004. Nephrocalcinosis (fig. 13A) was noted in 7 out of 20 (35.0 percent) white suckers and hyaline droplet formation within tubular epithelium of the kidney (fig. 13B) was observed in 12 out of 20 white suckers (60.0 percent).

Analyses of Fish Gut

Dietary composition was similar in fish guts among all three sampling events. The primary diet was chironomid midge larvae with some remains of other benthic macroinvertebrates, including cranefly larvae (family Tipulidae), caddisfly larvae (Hydropsychidae), mayfly larvae (Ephemeroptera), mite larvae (Acarina), copepods, and other dipterans (table 5). Some specimens were in pupae stage. Algae also were found in the guts of a number of the fish. Samples collected on May 12, 2004 included the foregut rather than just the stomach, and so contained more material, but the composition of prey was similar. One notable difference between sampling events was the occurrence of potential parasites in 7 of the 14 fish collected on April 28, 2003. One oddity of note was that all fish guts collected were filled with an unidentified "fluffy" material. When the guts were empty of prey, this material was white; when full, it was green, likely from bile. The source or consequences of this material are unknown, but it is likely some form of detrital material ingested from the stream.

Table 4. Occurrence of lesions and other tissue abnormalities observed in white sucker collected in Rock Creek at Peirce Mill, Washington, D.C.

[n, number of fish; BS, body surface; BD, body deformities (one missing eye and one deformed body)]

(a) Locations of lesions

		n	Gill	Fin	BS	BD	Liver	Gonad	Kidney	Gut
Spring 2003	Male	7	3	1	1	0	4	1	0	0
	Female	10	7	3	1	2	2	3	1	1
Fall 2003	Male	5	0	0	0	0	0	0	0	0
	Female	3	0	0	0	0	0	0	0	0
Spring 2004	Male	7	1	3	3	0	1	1	0	0
	Female	12	0	1	2	0	3	0	0	3
	Unknown[2]	1	0	0	0	0	1	0	0	0

(b) Summary of incidence (proportions in percent)

	Proportion of any fish with lesions	Gill abnormalities	Body surface lesions[1]	Fin abnormalities
Spring 2003	76	59	35	24
Fall 2003	0	0	0	0
Spring 2004	45	5	35	20

[1] Body surface includes abnormalities on opercule, eye, and the whole of the body surface.

[2] One fish in spring 2004 could not be identified for gender.

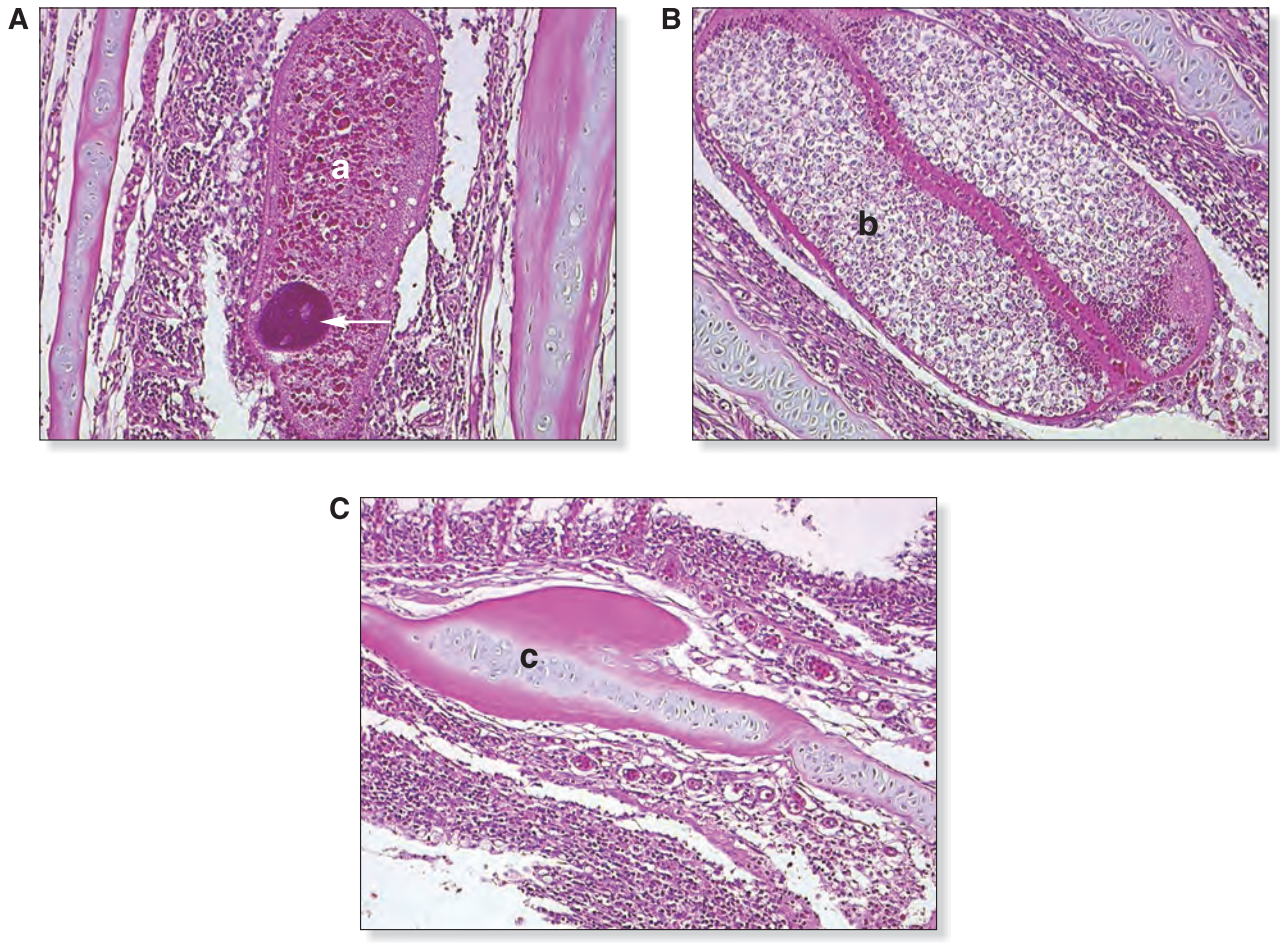

Figure 11. Microscopic appearance of gill lesions illustrating *A*, The ciliated parasite *Icthyopthirius multifilis* (a) with typical nucleus (arrow). *B*, A myxosporidian cyst (b). *C*, Abnormal cartilage (c). [H&E stain]

Ecological Health in Riverine Faunal Communities

In 1999–2000, the USGS completed a survey of chemicals in water and bed sediment in Rock Creek (Anderson and others, 2002). Results from that study indicated that the aquatic ecosystem of the creek was exposed to low but persistent levels of a broad suite of chemical contaminants. Many of these contaminants were found to exceed guidelines for the protection of aquatic life. In some cases, concentrations were in excess of probable-effects levels (PELs), which are more likely to cause problems during short-term or episodic exposures, than lower chronic-effects levels [interim sediment-quality guidelines (ISQGs) or threshold-effects levels (TELs)] that may cause observable toxicity over long-term exposures. A follow-up analysis was conducted in the current study to determine if negative effects due to chemical exposures were observed in the biota. Summaries of significant results from the current study are presented as "exceedance ratios" of guidelines for the protection of aquatic health in tables 6A and 6B. The numbers are the ratios of the concentration of each chemical in bed sediment normalized to guidelines developed by the Canadian Council of Ministers of the Environment (2003) or MacDonald (1994). Guidelines used for this analysis are presented in appendix B. A value of 1 would indicate that a chemical was found at the concentration of the guideline, a value of 2 would be twice the guideline, and so forth. These ratios are presented for both chronic- and probable-effects levels. Some of the variability between years is due to differences in the TOC content of each sample. These ratios also are compared to the occurrences of each chemical in fish tissue. Filets were tested in 2003 and whole fish were tested in 2004.

PAH compounds were commonly detected in bed sediment, and frequently exceeded guidelines for aquatic health, but were virtually undetected in fish tissue, because

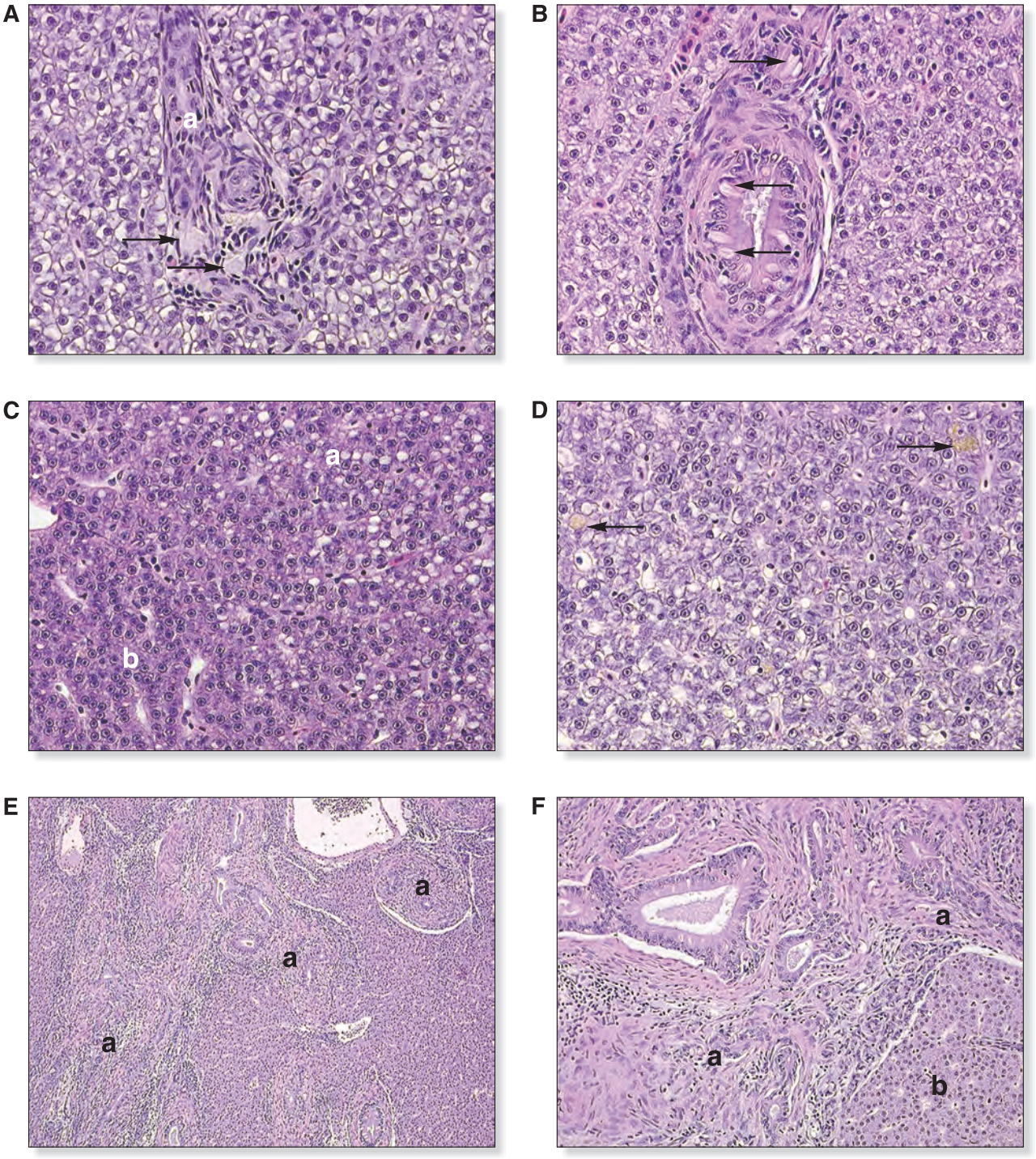

Figure 12. Microscopic liver lesions observed in white sucker from Rock Creek. *A*, Proliferation of bile ducts (a) as well as the presence of ceroid/lipofuscin accumulations (arrows) were noted. *B*, Epithelium of the bile ducts sometimes contained rodlet cells (arrows). *C*, Altered foci (a) of hepatocytes that blend imperceptibly into the normal hepatic tissue (b) were observed. *D*, Many of the livers had ceroid/lipofuscin deposits (arrows) observed within the hepatocytes. *E* and *F*, A cholangiocarcinoma was observed in one fish with proliferating neoplastic bile ducts (a) extending into the hepatic parenchyma (b).

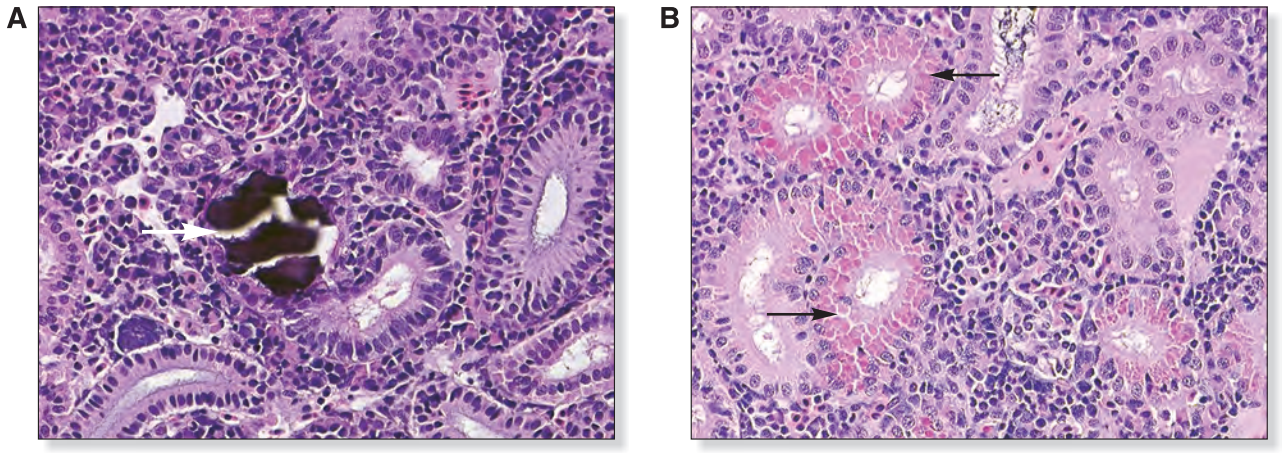

Figure 13. Histological changes noted in kidney of white sucker collected in spring 2004. *A*, Nephrocalcinosis or calcified areas (arrow) were observed replacing some kidney tubules. *B*, Haline droplet formation (arrows) was observed within the tubular epithelium of the kidney.

Table 5. Gut contents in white sucker collected in Rock Creek at Peirce Mill, Washington, D.C., in 2003–04.

[The samples from September 2003 included the intestines with the stomach; n, number of samples]

April 28, 2003 n=17 (14 empty)	September 9, 2003 n=8 (4 empty)	May 12, 2004 n=20 (6 empty)
Insecta	Insecta	Insecta
Diptera	Diptera	Diptera
Chironomidae	Chironomidae	Chironomidae
Larvae	Larvae	Larvae
Pupae	Pupae	Pupae
Cases	Tipulidae	Tipulidae
Algae	Larvae	Larvae
Possible parasites	Pupae	Other Diptera
	Psychodidae	Pupae or adults
	Larvae	Trichoptera
	Other Diptera	Hydropsychidae
	Trichoptera	Larvae
	Hydropsychidae	Ephemeroptera
	Larvae	Nymphs
	Ephemeroptera	Probable Baetidae
	Nymphs	Copepoda
	Hymenoptera	Algae
	Formicidae	Fish scale
	Coleoptera	
	Larvae	
	Acarina	
	Copepoda	
	Algae	

Table 6A. Summary of chemical testing on bed sediment and fish tissue collected in Rock Creek at Peirce Mill, Washington, D.C., 2003–04.

[ISQG, interim sediment-quality guideline; PEL, probable effects level; TEL, threshold effects level; BSAF, biotic sediment accumulation factor; exceedance factors for organic compounds in bed sediment are calculated as the ratio of the concentration of each chemical normalized to guidelines for the protection of aquatic life (appendix B). The guidelines for both the ISQG and PEL were used for each chemical (Canadian Council of Ministers, 2003), except that the ratios for bis(2-ethylhexyl)phthalate were calculated based on guidelines (TEL and PEL) from MacDonald (1994). A plus sign (+) for the incidence of detection indicates that the chemical also was detected in fish tissue; a minus sign (-) indicates that the chemical concentration was less than the detection limit. The BSAF is an estimate of the degree that the chemical has transferred and bioaccumulated from bed sediment to benthic organisms. Ranges of values for BSAF are presented in the tables; —, not determined; ND, not detected in bed sediment]

	Sediment exceedance ratios (ISQG/PEL or TEL/PEL, unitless)		Incidence of detection in fish		BSAF (unitless)
	2003	2004	2003 (filets)	2004 (whole fish)	2004
Pesticides					
Chlordanes	3.1/1.6	1.9/1.0	+	+	1–2
DDD	ND	0.3/0.1	+	-	—
DDE	ND	1.7/0.4	+	-	—
DDT	ND	5.0/1.3	+	+	0.7–2.5
Dieldrin + Aldrin	ND	1.5/0.7	+	+	0.7–3.7
Heptachlor/Heptachlor Epoxide	ND	ND	-	+	—
Aroclor 1254	ND	ND	+	+	—
Dioxins/Furans	15/0.6	1.2/0.05	+	+	0.005–0.5
Polyaromatic Hydrocarbons					
Benzo(a)anthracene	30/2.4	7.3/0.6	-	-	—
Benzo(a)pyrene	31/1.3	8.2/0.3	-	-	—
Chrysene	25/1.6	5.4/0.4	-	-	—
Fluoranthene	26/1.2	6.6/0.3	-	-	—
Fluorene	ND	ND	-	-	—
2-Methylnaphthalene	ND	ND	-	-	—
Naphthalene	ND	ND	-	-	—
Phenanthrene	26/2.1	7.4/0.6	-	-	—
Pyrene	36/2.2	10/0.6	-	-	—
Phthalate Esters					
Bis(2-ethylhexyl)phthalate	17/1.2	2.4/0.2	+	+	2.0–3.8

Table 6B. Exceedance ratios for trace metals and metaloids in bed sediment collected in Rock Creek at Peirce Mill, Washington, D.C., 2003–04.

[Ratios are calculated as the concentration of each element normalized to guidelines for the protection of aquatic life (appendix B). ISQG, interim sediment-quality guideline; PEL, probable effects level; the guidelines for the ISQG and PEL were used for each chemical (Canadian Council of Ministers, 2003)]

Trace metals/metaloids	Sediment exceedance ratio (ISQG/PEL, unitless)	
	2003	2004
Arsenic	1.0/0.3	0.3/0.1
Cadmium	1.5/0.3	0.2/< 0.1
Chromium	3.5/1.4	0.7/0.3
Copper	2.8/0.5	0.4/0.1
Lead	2.5/1.0	0.5/0.2
Mercury (total)	0.6/0.2	0.1/< 0.1
Zinc	2.0/0.8	0.5/0.2

they are metabolized very efficiently in fish. Of some concern are the high values in sediment of exceedance factors for ISQGs for all of the PAHs and phthalate esters, and the fact that most of the PAHs found were of the higher molecular weight and more toxic congenors. By comparison, average concentrations of total PAHs in other tributaries of the Chesapeake Bay range from about 300 µg/kg (an overall background for the Bay) to 30,000 µg/kg in the Anacostia River and 300,000 µg/kg in the Elizabeth River (Walker and others, 2004; Wade and others, 1994). Both the Anacostia and Elizabeth Rivers are considerably more contaminated than Rock Creek and are considered "Areas of Concern" for the Chesapeake Bay. The PELs for PAHs were exceeded in Rock Creek in 2003, and concentrations were on the order of half the PEL in 2004. PAH compounds have been shown to have a direct impact on fish health, and studies on the Anacostia River, an adjacent and more highly contaminated tributary, have directly linked the occurrence of PAHs with observed immunosuppression in bullhead catfish (Pinkney and others, 2001, 2004). There was some evidence of compromised fish health in Rock Creek, with lesions on both external surfaces and internal organs, and in some cases with liver lesions that have previously been associated with contaminant exposures, but no conclusive evidence is available at this time to directly link these observations to PAH exposure in Rock Creek. Comparison of fish health between years suggests that fish had more lesions in 2003 than in 2004, which is the reverse of the overall observed concentrations of PAHs. However, interannual differences in the concentrations of PAHs were not observed when normalized to total organic carbon. Therefore, temporal differences in PAHs may be an artifact of differences in the amounts of fines and organic carbon in the samples.

It is interesting to note that most of the observations of OC pesticides in Rock Creek are coming from legacy chemicals that are no longer licensed for use. The use of DDT was banned in the United States in 1972, chlordane and heptachlor in 1988, and dieldrin, endosulfan, and aldrin in the late 1980s, but these compounds and/or their degradates persist in the natural environment. The BSAF values for these chemicals in white sucker in Rock Creek indicate that they are still accumulating in biota. White sucker are in the middle of the food chain, and because of the persistence of OC pesticides, they have the potential to accumulate to higher concentrations in top-level carnivores, such as bass, perch, pickerel, and piscivorous birds. For example, Rattner and others (1993, 1994, 1996, 1997) have shown that reproductive success in black-crowned night herons in parts of the Chesapeake Bay around Washington, D.C. and Baltimore Harbor, is severely affected by the same suite of OC pesticides as well as by other contaminants such as dioxins and furans.

Dioxins and furans were found in Rock Creek fish tissue at relatively low concentrations, with higher concentrations occurring mainly in the less-toxic congenors. The TEQs in bed sediment were higher and were generally at or above the chronic- or threshold-effects levels. The BSAFs were very low (0.005 to 0.5), indicating that while these chemicals were elevated in bed sediment, they are not bioaccumulating or magnifying in the biota. Sources of dioxins and furans are mainly from combustion emissions and impurities in agrochemicals (Vulykh and Shatalov, 2001). This group of chemicals is persistent and bioaccumulative in the environment, and the most toxic congenor, TCDD, has been linked in the literature to a number of toxic responses including immunosuppression, carcinogenicity, and endocrine disruption. Concentrations of dioxins and furans detected in samples of bed sediment and fish tissue at Rock Creek were lower than those in other studies that have been shown to cause severe effects (Yao and others, 2002; Geisy and others, 1997; MacDonald and others, 1997; Braune and Simon, 2003). In both years of this study, the concentrations of dioxins and furans were above or near chronic-effects levels in bed sediment and were detected in fish tissue, indicating that these compounds are a persistent, but perhaps not a major stressor of fish health.

Concentrations of trace metals in bed sediment and fish tissue in Rock Creek were similar to those observed in other studies, both in this region and in other regions of the country, and can be considered within the background levels for urban and suburban streams across the country. Concentrations did approach probable-effects levels and were consistently above threshold-effects levels for all sediment samples collected in Rock Creek. Trace metals are thus an additional, but perhaps not major stressor for benthic organisms in Rock Creek. Levels of metals were not as high as those observed in other more contaminated areas in the Chesapeake Bay, such as Baltimore Harbor (McGee and others, 1999).

When data for detectable concentrations of chemicals were available for both bed sediment and fish tissue, the calculated BSAFs are shown in the last column of table 6A. These factors are reasonable estimates of the bioaccumulation of a particular chemical from bed sediment into the food chain, and possibly of biomagnification if the factors are high. The accumulation of chemical contaminants in organisms is a function of a number of different factors or processes, including the concentration of the pollutant in the environment, characteristics of the physical environment, reservoirs such as bed sediment in which most of the contaminant may reside, location of the organism within the food chain and the complexity of that food chain, uptake mechanisms for the chemical such as ingestion and absorption through membranes, physiological and ecological health of the organism, and the properties of the chemical that determine partitioning between aqueous and non-polar phases. In Rock Creek, the major repository of chemical contaminants is the bed sediment of the river, so that primary areas of uptake are expected to focus on benthic organisms. Normal ranges for BSAF are on the order of 1 or 2 (U.S. Environmental Protection Agency, 2000; Thorsen and others, 2004), and values determined at Rock Creek were close to this range, indicating that biomagnification may not be a significant or important process for any of the chemicals tested. Evaluation of the diet of white sucker showed that the primary route of accumulation of chemical contaminants was from the ingestion of chironomid larvae and other benthic

invertebrates as well as the inadvertent ingestion of sediment during foraging. White sucker are not high in the food chain, however, and might not be optimal indicators for the transfer and magnification of contaminants up the chain. Animals at higher trophic levels in Rock Creek, such as bass, perch, pickerel, or piscivorous birds and mammals were not evaluated in the current study.

There was a large difference in the incidence of lesions, both external and internal, between the spring and fall samplings, but differences due to seasonal variations in hydrology and breeding function cannot be inferred because the average fish size in each of the populations was different. The fish collected in the fall were smaller than those found in the spring, and may represent a younger population of fish that had accumulated less toxic chemicals over their lifespan. There also were significant differences in fish health between spawning seasons in 2003 and 2004. More lesions on fish were observed in 2003, but reproduction was less successful in 2004, when the GSI was lower for male white sucker, and it appeared that typical spawning behavior was not occurring. Some of these differences might be attributed to differences in flow conditions, but both 2003 and 2004 were above-average years for flow conditions as compared to a severe drought that occurred during the 1999–2000 study. Increased energy from higher flows in the river may have further stressed white sucker and cannot be ruled out as a possible contributing factor to compromised fish health, but it is also likely that the high incidence of lesions on fish tissue was influenced by immunosuppression from chemical exposures. Evidence from other studies on urban streams provides strong support for the relation between the occurrence of the same chemical contaminants found in Rock Creek and negative effects on biota such as immunosuppression and reproductive dysfunction (Bevans and others, 1996; Schmitt and others, 2002).

Summary

In 1999–2000 and 2003–04, the U.S. Geological Survey partnered with the National Park Service to study potential chemical contaminants and their effects on fish in Rock Creek, a small tributary to the Potomac River in Washington, D.C. The results of chemical testing in the stream indicated that some of these chemicals persist in the bed sediment and water column at levels that exceed guidelines for the protection of health in the aquatic biota. Organochlorine insecticides were detected in the water column throughout the year. Bed sediment had accumulated a number of different classes of compounds including PAHs, phthalate esters, organochlorine pesticides, heavy metals including lead and mercury, and PCBs. White sucker (*Catostomus commersoni*) were evaluated in 2003–04 for health, whole-body burdens of chemical contaminants, and for gut contents to determine preferential prey and thus potential trophic pathways for ingestion and bioaccumulation of toxic chemicals.

Rock Creek is generally thought to be a moderately affected urban stream with issues related to geomorphology and chemical pollution from development in the urban Washington, D.C. corridor. Much of the lower portion of Rock Creek is buffered by parkland that is managed by the National Park Service and the Maryland National Capital Planning Commission. The upper portion of the watershed includes urban, suburban, and agricultural land use, but in recent years, there have been shifts in some areas towards using "low-impact development" or LID. Rock Creek is not as highly impacted as the adjacent Anacostia River, which is a Chesapeake Bay Program "Region of Concern," but current and previous studies by the U.S. Geological Survey have documented moderate levels of contaminants in the water column and bed sediment of Rock Creek as well as in the tissue of a common benthivorous fish and have found evidence of some disease in the fish. This report presents evidence that fish in Rock Creek are affected by chemical contaminants that may compromise fish health, but these effects are moderate and vary temporally, possibly enhanced by shifts in the hydrology and physical environment. In summary:

1. Observations of chemicals in bed sediment in Rock Creek corroborated results from an earlier U.S. Geological Survey study. A suite of chemicals including polyaromatic hydrocarbon and phthalate compounds, organochlorine pesticides, polychlorinated biphenyls, dioxins and furans, and trace metals occurred persistently in bed sediment and at concentrations that approached and often exceeded guidelines for the protection of aquatic health. Both chronic- and probable-effects levels were exceeded for some chemicals.

2. Observed higher-than-average flows in Rock Creek in 2003 and 2004 also may have stressed fish populations, and must be considered when evaluating the impact of chemical pollutants.

3. White sucker (*Catostomus commersoni*), a benthic-feeding fish, are showing signs of health stress in some years. This is true for individual fish as well as at the population level in Rock Creek. Observations of gonadosomatic indices and behavior during spawning indicate reproductive success may have been compromised, at least in 2004. Necroses in the liver, gonads, and other organs also were observed.

4. Health effects in fish in Rock Creek were significant, but were not as severe as those found in the adjacent Anacostia River, which has a much more intense urban exposure.

5. Contaminants in bed sediment are moving into the food chain in Rock Creek. For white sucker, benthic macroinvertebrates and in particular chironomid larvae were the most common food source. The potential transfer of chemicals from white sucker to higher levels of the food chain was not examined during the current study.

Rock Creek at Peirce Mill, Washington, D.C. (Station 01648016) looking upstream from the millrace at the fish ladder.

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Appendixes A–B

Appendix A1. Results of analyses for polycyclic aromatic hydrocarbons and phthalate esters in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.

[In 2003, filets from all fish collected were sorted by sex and then composited. In 2004, whole fish were collected. When individual fish were too small, multiple fish were composited into one sample and the sample numbers identify the individual fish analyzed for that sample (e.g. WS38.44 is a composite of fish WS38 and WS44). Quality-control data are included in this table. µg/kg, micrograms per kilogram; <, less than; E, estimated result—compound was detected, but value was less than the reporting level; NA, not applicable; --, undetermined; values above the detection limits are reported in **BOLD**; %, percent]

	Date	Percent lipids	Phenol in µg/kg	4-Methyl-phenol in µg/kg	Naph-thalene in µg/kg	Dimethyl phthalate in µg/kg	Acenaph-thylene in µg/kg	Acenaph-thene in µg/kg	Diethyl-phthalate in µg/kg	Fluorene in µg/kg	Phenan-threne in µg/kg	Anthra-cene in µg/kg	Carbazole in µg/kg	Di-n-butyl phthalate in µg/kg
							Fish tissue							
Male fish filets, composite	4/28/2003	0.56	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Female fish filets, composite	4/28/2003	E 0.060	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Male fish filets, composite	9/9/2003	1.2	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340
Female fish filets, composite	9/9/2003	0.6	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340	<340
Whole female fish (WS26)	5/12/2004	3.0	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
Whole female fish (WS29)	5/12/2004	2.4	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
Whole male fish (WS33)	5/12/2004	4.6	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	**E 56**	<1,100	<1,100	<1,100	<1,100	<1,100
Whole male fish (WS38.44 composite)	5/12/2004	2.1	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
							Bed sediment							
Bed sediment	4/28/2003	NA	<1,600	**6,400**	<1,600	<1,600	<1,600	<1,600	<1,600	<1,600	**E 1,100**	<1,600	**E 210**	<1,600
Bed sediment	5/12/2004	NA	<470	<470	<470	<470	<470	<470	<940	<470	**E 310**	<470	<470	<470
							Quality-control samples							
Tissue method blank	4/28/2003	<0.10	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Soil method blank	4/28/2003	NA	<330	<330	<330	<330	<330	<330	<660	<330	<330	<330	<330	<330
Tissue method blank	9/9/2003	<0.01	<330	<330	<330	<330	<330	<330	<660	<330	<330	<330	<330	<330
Soil method blank	5/12/2004	NA	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Tissue method blank	5/12/2004	E 0.066	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330

Appendix A1. Results of analyses for polycyclic aromatic hydrocarbons and phthalate esters in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.—Continued

	Date	Fluoranthene in µg/kg	Pyrene in µg/kg	Butyl benzyl phthalate in µg/kg	Benzo(a) anthracene in µg/kg	Chrysene in µg/kg	bis(2-Ethylhexyl) phthalate in µg/kg	Di-n-octylphthalate in µg/kg	Benzo(b) fluoranthene in µg/kg	Benzo(k) fluoranthene in µg/kg	Benzo(a) pyrene in µg/kg	Indeno (1,2,3-cd) pyrene in µg/kg	Dibenz(a,h) anthracene in µg/kg
							Fish tissue						
Male fish filets, composite	4/28/2003	<330	<330	<330	<330	<330	**E 74**	<330	<330	<330	<330	<330	<330
Female fish filets, composite	4/28/2003	<330	<330	<330	<330	<330	**E 140**	<330	<330	<330	<330	<330	<330
Male fish filets, composite	9/9/2003	<340	<340	<340	<340	<340	**E45**	<340	<340	<340	<340	<340	<340
Female fish filets, composite	9/9/2003	<340	<340	<340	<340	<340	**E 88**	<340	<340	<340	<340	<340	<340
Whole female fish (WS26)	5/12/2004	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
Whole female fish (WS29)	5/12/2004	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
Whole male fish (WS33)	5/12/2004	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
Whole male fish (WS38.44 composite)	5/12/2004	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100	<1,100
							Bed sediment						
Bed sediment	4/28/2003	**2,900**	**1,900**	<1,600	**E 940**	**E 1,400**	**3,100**	<1,600	**1,700**	**E 750**	**E 1,100**	**E 890**	< 1,600
Bed sediment	5/12/2004	**730**	**550**	<470	**E 230**	**E 310**	**E 440**	<470	**E 290**	**E 300**	**E 260**	**E 150**	<470
							Quality-control samples						
Tissue method blank	4/28/2003	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Soil method blank	4/28/2003	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Tissue method blank	9/9/2003	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Soil method blank	5/12/2004	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330
Tissue method blank	5/12/2004	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330	<330

Appendix A1. Results of analyses for polycyclic aromatic hydrocarbons and phthalate esters in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.—Continued

	Date	Benzo(ghi) perylene	2-Fluorophenol, surrogate % recovery	Phenol-d5, surrogate % recovery	Nitrobenzene-d5, surrogate % recovery	2-Fluorobiphenyl, surrogate % recovery	2,4,6-Tribromophenol, surrogate % recovery	Terphenyl-d14, surrogate % recovery
					Fish tissue			
Male fish filets, composite	4/28/2003	<330	90	85	102	103	104	129
Female fish filets, composite	4/28/2003	<330	84	74	108	102	100	140*
Male fish filets, composite	9/9/2003	<340	83	78	--	88	110	131
Female fish filets, composite	9/9/2003	<340	90	84	--	102	126*	146**
Whole female fish (WS26)	5/12/2004	<1,100	89	88	100	101	--	94
Whole female fish (WS29)	5/12/2004	<1,100	90	84	97	97	--	87
Whole male fish (WS33)	5/12/2004	<1,100	90	90	97	96	--	89
Whole male fish (WS38.44 composite)	5/12/2004	<1,100	91	87	99	103	--	93
					Bed sediment			
Bed sediment	4/28/2003	**E 1,100**	54	53	56	54	58	46
Bed sediment	5/12/2004	**E 170**	53	54	55	50	56	53
					Quality-control samples			
Tissue method blank	4/28/2003	<330	88	76	89	84	82	88
Soil method blank	4/28/2003	<330	77	75	79	70	66	67
Tissue method blank	9/9/2003	<330	77	84	--	85	71	105
Soil method blank	5/12/2004	<330	81	81	83	74	67	74
Tissue method blank	5/12/2004	<330	65	76	70	74	--	64

* These surrogates were outside of control limits. The samples were reanalyzed at a higher dilution yielding generally similar results and better surrogate recoveries.

** This surrogate was outside of control limits. The sample was reanalyzed at a higher dilution yielding generally similar results but also still outside of control limits.

Appendix A2. Results of analyses for organochlorine pesticides in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.

[In 2003, filets from all fish collected were sorted by sex and then composited. In 2004, whole fish were collected. When individual fish were too small, multiple fish were composited into one sample and the sample numbers identify the individual fish analyzed for that sample (e.g. WS38.44 is a composite of fish WS38 and WS44). Quality-control data are included in this table; µg/kg, micrograms per kilogram; E, estimated result—compound was detected, but value was less than the reporting level; C, more than 40 percent relative percent deviation (RPD) between primary and confirmation column results; the lower of the two results is reported; NC, the recovery and RPD were not calculated due to dilution and the presence of interfering analytes; NA, not applicable; --, undetermined; values above the detection limits are reported in **BOLD**; <, less than; %, percent]

	Date	Percent lipids	Aldrin in µg/kg	gamma-BHC (Lindane) in µg/kg	alpha-Chlordane in µg/kg	gamma-Chlordane in µg/kg	4,4′-DDD in µg/kg	2,4′-DDD in µg/kg	4,4′-DDE in µg/kg	2,4′-DDE in µg/kg	4,4′-DDT in µg/kg	2,4′-DDT in µg/kg	Dieldrin in µg/kg	Endosulfan I in µg/kg
						Fish tissue								
Male fish filets, composite	4/28/2003	0.56	--	--	--	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	E 0.060	<6.0	<6.0	**C 8.4**	<6.0	**C 13**	<6.0	**26**	<6.0	**C 9.6**	**E 2.1**	**E,C 3.6**	<6.0
Male fish filets, composite	9/9/2003	1.2	<60	<60	**E,C 11**	<60	<60	<60	**E 15**	<60	<60	<60	<60	<60
Female fish filets, composite	9/9/2003	0.6	<60	<60	<60	<60	<60	<60	<60	<60	<60	<60	<60	<60
Whole female fish (WS26)	5/12/2004	3	**E 11**	<60	**E,C 35**	**E 17**	<60	<60	<60	<60	**E,C 24**	<60	**E 23**	<60
Whole female fish (WS29)	5/12/2004	2.4	<60	<60	<60	<60	<60	<60	<60	<60	<60	<60	<60	**E 10**
Whole male fish (WS33)	5/12/2004	4.6	**E 9.1**	<60	**E,C 32**	**E 15**	<60	<60	<60	<60	**E 15**	<60	**E 33**	C <60
Whole male fish (WS38.44 composite)	5/12/2004	2.1	<60	<60	**E,C 21**	**E 9.8**	<60	<60	<60	<60	**E,C 25**	<60	**E,C 11**	<60
						Bed sediment								
Bed sediment	4/28/2003	NA	<83	<83	**E,C 14**	<83	<83	<83	<83	<83	<83	<83	<83	<83
Bed sediment	5/12/2004	NA	**3**	<2.4	**C 5.5**	**C 3.0**	<2.4	**E,C 0.97**	**C 2.4**	<1.1	**4.7**	**C 1.3**	**E,C 1.4**	<2.4
						Quality-control samples								
Soil method blank	4/28/2003	NA	<1.7	<1.7	<1.7	<1.7	<1.7	<0.75	<1.7	<0.75	<1.7	<0.75	<1.7	<1.7
Tissue method blank	4/28/2003	<0.10	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
Tissue method blank	9/9/2003	<0.01	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
Soil method blank	5/12/2004	NA	<1.7	<1.7	<1.7	<1.7	<1.7	<0.75	<1.7	<0.75	<1.7	<0.75	<1.7	<1.7
Tissue method blank	5/12/2004	E 0.066	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0

Appendix A2. Results of analyses for organochlorine pesticides in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.—Continued

	Date	Endosulfan II in µg/kg	Endosulfan Sulfate in µg/kg	Endrin in µg/kg	Heptachlor in µg/kg	Heptachlor epoxide in µg/kg	Mirex in µg/kg	Toxaphene in µg/kg	Decachlorobi-phenyl, surrogate % recovery	Tetrachloro-m-xylene, surrogate % recovery
						Fish tissue				
Male fish filets, composite	4/28/2003	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	<6.0	<6.0	<6.0	<6.0	<22	<6.0	<60	95	97
Male fish filets, composite	9/9/2003	<60	<60	<60	<60	<220	<60	<600	NC	NC
Female fish filets, composite	9/9/2003	<60	<60	<60	<60	<220	<60	<600	NC	NC
Whole female fish (WS26)	5/12/2004	<60	<60	<60	<60	**E 14**	<60	<600	NC	NC
Whole female fish (WS29)	5/12/2004	<60	<60	<60	<60	**E,C 25**	<60	<600	NC	NC
Whole male fish (WS33)	5/12/2004	<60	<60	<60	<60	**E 27**	<60	<600	NC	NC
Whole male fish (WS38.44 composite)	5/12/2004	<60	<60	<60	<60	**E,C 7.9**	<60	<600	NC	NC
						Bed sediment				
Bed sediment	4/28/2003	<83	<83	<83	<83	<83	<83	<8300	NC	NC
Bed sediment	5/12/2004	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<240	104	71
						Quality-control samples				
Soil method blank	4/28/2003	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	<170	79	78
Tissue method blank	4/28/2003	<6.0	<6.0	<6.0	<6.0	<22	<6.0	<60	91	90
Tissue method blank	9/9/2003	<6.0	<6.0	<6.0	<6.0	<22	<6.0	<60	70	101
Soil method blank	5/12/2004	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	<170	105	114
Tissue method blank	5/12/2004	<6.0	<6.0	<6.0	<6.0	<22	<6.0	<60	84	81

Appendix A3. Results of analyses for aroclors in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.

[In 2003, filets from all fish collected were sorted by sex and then composited. In 2004, whole fish were collected. When individual fish were too small, multiple fish were composited into one sample and the sample numbers identify the individual fish analyzed for that sample (e.g. WS38.44 is a composite of fish WS38 and WS44). Quality-control data are included in this table; µg/kg, micrograms per kilogram; E, estimated result—compound was detected, but value was less than the reporting level; NA, not applicable; --, undetermined; values above the detection limits are reported in **BOLD**; <, less than; %, percent]

	Date	Percent lipids	Aroclor 1262 in µg/kg	Aroclor 1268 in µg/kg	Aroclor 1016 in µg/kg	Aroclor 1221 in µg/kg	Aroclor 1232 in µg/kg	Aroclor 1242 in µg/kg	Aroclor 1248 in µg/kg	Aroclor 1254 in µg/kg	Aroclor 1260 in µg/kg	Tetrachloro-m-xylene, surrogate % recovery	Decachlorobiphenyl, surrogate % recovery
							Fish tissue						
Male fish filets, composite	4/28/2003	0.56	--	--	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	E 0.060	<100	<100	<100	<100	<100	<100	<100	**E 94**	**110**	88	79
Male fish filets, composite	9/9/2003	1.2	<100	<100	<100	<100	<100	<100	<100	<100	<100	99	91
Female fish filets, composite	9/9/2003	0.6	<100	<100	<100	<100	<100	<100	<100	<100	<100	105	126
Whole female fish (WS26)	5/12/2004	3	<150	<150	<150	<150	<150	<150	<150	**E 74**	<150	85	103
Whole female fish (WS29)	5/12/2004	2.4	<150	<150	<150	<150	<150	<150	<150	**E 68**	<150	84	101
Whole male fish (WS33)	5/12/2004	4.6	<150	<150	<150	<150	<150	<150	<150	**270**	<150	81	97
Whole male fish (WS38.44 composite)	5/12/2004	2.1	<150	<150	<150	<150	<150	<150	<150	**E 84**	<150	89	103
							Bed sediment						
Bed sediment	4/28/2003	NA	<160	<160	<160	<160	<160	<160	<160	<160	<160	92	84
Bed sediment	5/12/2004	NA	<47	<47	<47	<47	<47	<47	<47	<47	<47	112	81
							Quality-control samples						
Soil method blank	4/28/2003	NA	<33	<33	<33	<33	<33	<33	<33	<33	<33	71	71
Tissue method blank	4/28/2003	<0.10	<100	<100	<100	<100	<100	<100	<100	<100	<100	75	93
Tissue method blank	9/9/2003	<0.01	<100	<100	<100	<100	<100	<100	<100	<100	<100	105	107
Soil method blank	5/12/2004	NA	<33	<33	<33	<33	<33	<33	<33	<33	<33	95	88
Tissue method blank	5/12/2004	E 0.066	<100	<150	<150	<150	<150	<150	<150	<150	<150	87	89

Appendix A4. Results of analyses for dioxin and furan compounds in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.

[In 2003, filets from all fish collected were sorted by sex and then composited. In 2004, whole fish were collected. When individual fish were too small, multiple fish were composited into one sample and the sample numbers identify the individual fish analyzed for that sample (e.g. WS32.36 is a composite of fish WS32 and WS36). Quality-control data are included in this table. TEQ, Toxic Equivalents for total dioxins and furans expressed as picograms per gram of 2,3,7,8-TCDD (Van den Berg and others, 1998); pg/g, picograms per gram; E, estimated result—compound was detected, but value was less than the reporting level; **JA**—the analyte was positively identified, but the quantitation is an estimate; NA, not applicable; --, undetermined; values above the detection limits are reported in **BOLD**; <, less than; %, percent]

	Date	Percent lipids	2,3,7,8-TCDD[1] pg/g	Total TCDD[1] pg/g	1,2,3,7,8-PeCDD[2] pg/g	Total PeCDD[2] pg/g	1,2,3,4,7,8-HxCDD[3] pg/g	1,2,3,6,7,8-HxCDD[3] pg/g	1,2,3,7,8,9-HxCDD[3] pg/g	Total HxCDD[3] pg/g	1,2,3,4,6,7,8-HpCDD[4] pg/g	Total HpCDD[4] pg/g	OCDD[5] pg/g
							Fish tissue						
Male fish filets, composite	4/28/2003	0.56	--	--	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	E 0.060	<0.081	<0.081	<0.16	<0.24	<0.24	<0.24	<0.22	<0.24	<0.51	<0.81	**E 7.0**
Male fish filets, composite	9/9/2003	1.2	<0.11	<0.11	<0.33	<0.33	<0.13	<0.17	<0.15	<0.18	<1.0	<1.0	**E 5.2**
Female fish filets, composite	9/9/2003	0.6	<0.11	<0.11	<0.31	<0.31	<0.14	<0.14	<0.13	**0.16**	<0.91	<0.91	<4.6
Whole female fish (WS27)	5/12/2004	3	<0.68	<0.68	<1.8	<5.5	<0.84	<0.77	<0.93	<0.93	**E 2.6**	**2.6**	**16**
Whole female fish (WS28)	5/12/2004	2.4	<0.78	<0.78	<1.6	<5.0	<1.0	<0.97	<1.2	<1.2	<1.4	<2.5	**23**
Whole male fish (WS30.31 composite)	5/12/2004	4.6	<0.88	<0.88	<1.9	<3.2	<0.86	<0.79	<0.95	<0.95	<1.7	<2.2	**36**
Whole male fish (WS32.36 composite)	5/12/2004	2.1	<0.97	<0.97	<2.0	<2.4	<1.1	<1.0	<1.2	<1.2	<1.6	<1.6	**21**
							Bed sediment						
Bed sediment	4/28/2003	NA	<0.68	**5.9**	<2.0	<2.9	<3.7	<7.9	<9.3	**45**	**220**	**480**	**5,600**
Bed sediment	5/12/2004	NA	<1.3	<1.3	<2.8	<2.9	<1.5	<1.4	<1.7	<3.3	**36**	**99**	**1000**
							Quality-control samples						
Soil method blank	4/28/2003	NA	<0.11	<0.11	<0.16	<0.16	<0.24	<0.24	<0.21	<0.24	<0.11	<0.11	<0.43
Tissue method blank	4/28/2003	<0.10	<0.23	<0.23	<0.85	<0.85	<0.47	<0.64	<0.96	<0.96	<0.89	<0.89	<2.5
Tissue method blank	9/9/2003	<0.01	<0.10	<0.10	<0.18	<0.18	<0.13	<0.12	<0.12	<0.13	<0.12	<0.15	<0.69
Soil method blank	5/12/2004	NA	<0.83	<0.83	<1.8	<1.8	<1.2	<1.1	<1.3	<1.3	<1.5	<1.5	<1.4
Tissue method blank	5/12/2004	E 0.066	<0.23	<0.23	<0.91	<0.91	<0.37	<0.32	<0.32	<0.37	<0.18	<0.18	<0.98

[1] TCDD - tetrachlorodibenzo-p-dioxin.

[2] PeCDD - pentachlorodibenzo-p-dioxin.

[3] HxCDD - hexachlorodibenzo-p-dioxin.

[4] HpCDD - heptachlorodibenzo-p-dioxin.

[5] OCDD - octachlorodibenzo-p-dioxin.

Appendix A4. Results of analyses for dioxin and furan compounds in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.—Continued

	Date	2,3,7,8-TCDF[6] pg/g	Total TCDF[6] pg/g	1,2,3,7,8-PeCDF[7] pg/g	2,3,4,7,8-PeCDF[7] pg/g	Total PeCDF[7] pg/g	1,2,3,4,7,8-HxCDF[8] pg/g	1,2,3,6,7,8-HxCDF[8] pg/g	2,3,4,6,7,8-HxCDF[8] pg/g	1,2,3,7,8,9-HxCDF[8] pg/g	Total HxCDF[8] pg/g	1,2,3,4,6,7,8-HpCDF[9] pg/g	1,2,3,4,7,8,9-HpCDF[9] pg/g
Fish tissue													
Male fish filets, composite	4/28/2003	--	--	--	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	**E 0.70**	**0.70**	<0.12	<0.11	<0.98	<0.087	<0.082	<0.094	<0.10	<0.41	<0.13	<0.15
Male fish filets, composite	9/9/2003	**E 0.83**	**0.83**	<0.19	<0.19	<0.21	<0.10	<0.11	<0.10	<0.10	<0.16	<0.14	<0.12
Female fish filets, composite	9/9/2003	**E 0.63**	**0.63**	<0.17	<0.17	<0.17	<0.085	<0.085	<0.095	<0.095	<0.095	<0.095	<0.10
Whole female fish (WS27)	5/12/2004	**1.2**	**3**	<0.91	<0.93	**5.7**	<0.73	<0.70	<0.79	<0.84	<2.1	<1.2	<1.4
Whole female fish (WS28)	5/12/2004	**E 0.64**	**0.73**	<0.92	<0.94	**2.6**	<0.77	<0.74	<0.83	<0.88	<1.6	<1.2	<1.2
Whole male fish (WS30.31 composite)	5/12/2004	**1.2**	**1.9**	<1.0	<1.0	<3.8	<0.70	<0.67	<0.75	<0.80	<2.0	<1.1	<1.4
Whole male fish (WS32.36 composite)	5/12/2004	**E 0.83**	**1.6**	<1.3	<1.3	**4.3**	<0.85	<0.81	<0.91	<0.97	<2.4	<1.7	<2.0
Bed sediment													
Bed sediment	4/28/2003	**E 2.6**	**29**	<1.2	<2.1	**<11**	<3.8	<3.4	<3.2	<0.83	**36**	**JA 41**	<2.9
Bed sediment	5/12/2004	<0.50	**3.5**	<1.3	<1.3	**3.6**	<1.2	<1.2	<1.3	<1.4	**4.5**	**E, JA 6.1**	<1.1
Quality-control samples													
Soil method blank	4/28/2003	<0.087	<0.087	<0.12	<0.12	<0.12	<0.11	<0.11	<0.12	<0.13	<0.13	<0.087	<0.11
Tissue method blank	4/28/2003	<0.27	<0.27	<0.90	<0.89	<0.90	<0.99	<0.81	<0.85	<0.94	<0.99	<0.87	<1.0
Tissue method blank	9/9/2003	<0.15	<0.15	<0.17	<0.17	<0.17	<0.13	0.15	<0.11	<0.11	<0.15	<0.19	<0.19
Soil method blank	5/12/2004	<0.65	<0.65	<1.0	<1.1	<1.4	<0.83	<0.80	<0.90	<0.96	<0.96	<0.67	<0.82
Tissue method blank	5/12/2004	<0.32	<0.32	<0.24	<0.23	<0.31	<0.23	<0.21	<0.23	<0.26	<0.26	<0.20	<0.24

[6] TCDF - tetrachlorodibenzofuran.

[7] PeCDF - pentachlorodibenzofuran.

[8] HxCDF - hexachlorodibenzofuran.

[9] HpCDF - heptachlorodibenzofuran.

[10] OCDF - octachlorodibenzofuran.

Appendix A4. Results of analyses for dioxin and furan compounds in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.—Continued

	Date	Total HpCDF[9] pg/g	OCDF[10] pg/g	Toxic equivalents (TEQ) pg/g as TCDD	^{13}C-2,3,7,8-TCDD[1], surrogate % recovery	^{13}C-1,2,3,7,8-PeCDD[2], surrogate % recovery	^{13}C-1,2,3,6,7,8-HxCDD[3], surrogate % recovery	^{13}C-1,2,3,4,6,7,8-HpCDD[4], surrogate % recovery	^{13}C-OCDD[5], surrogate % recovery	^{13}C-2,3,7,8-TCDF[6], surrogate % recovery	^{13}C-1,2,3,7,8-PeCDF[7], surrogate % recovery	^{13}C-1,2,3,4,7,8-HxCDF[8], surrogate % recovery	^{13}C-1,2,3,4,6,7,8-HpCDF[9], surrogate % recovery
						Fish tissue							
Male fish filets, composite	4/28/2003	--	--	--	--	--	--	--	--	--	--	--	--
Female fish filets, composite	4/28/2003	<0.15	<0.12	0.04	75	68	74	96	95	71	71	74	95
Male fish filets, composite	9/9/2003	<0.14	<0.17	0.04	57	53	60	64	67	48	49	54	59
Female fish filets, composite	9/9/2003	<0.10	<0.17	0.03	75	66	81	85	89	60	63	72	80
Whole female fish (WS27)	5/12/2004	<1.4	<2.0	0.4	95	98	101	91	97	93	103	77	89
Whole female fish (WS28)	5/12/2004	<1.4	<2.0	0.2	96	96	98	94	94	91	95	76	91
Whole male fish (WS30.31 composite)	5/12/2004	<1.4	<2.0	0.1	90	104	100	84	82	86	99	81	84
Whole male fish (WS32.36 composite)	5/12/2004	<2.0	<2.5	0.3	83	90	93	88	89	82	89	67	87
						Bed sediment							
Bed sediment	4/28/2003	**110**	**120**	13	94	86	87	105	108	93	96	86	97
Bed sediment	5/12/2004	**16**	**17**	1.0	96	95	91	89	93	94	102	75	92
						Quality-control samples							
Soil method blank	4/28/2003	<0.11	<0.28	--	106	109	120	125	128	97	99	94	107
Tissue method blank	4/28/2003	<1.0	<1.0	--	77	62	78	104	102	74	70	80	102
Tissue method blank	9/9/2003	<0.24	<0.15	--	73	67	80	86	88	63	63	69	79
Soil method blank	5/12/2004	<0.82	<2.2	--	92	98	88	83	82	90	101	70	86
Tissue method blank	5/12/2004	<0.24	<0.65	--	57	48	60	53	44	60	56	54	55

Appendix A5. Results of analyses for total metals and metaloids in bed sediment (dry weight) and fish tissue (wet weight) collected in 2003 and 2004 at U.S. Geological Survey station 01648016, Rock Creek at Peirce Mill, Washington, D.C.

[In 2003, filets from all fish collected were sorted by sex and then composited. In 2004, whole fish were collected. When individual fish were too small, multiple fish were composited into one sample and the sample numbers identify the individual fish analyzed for that sample (e.g. WS38.44 is a composite of fish WS38 and WS44). Quality-control data are included in this table; µg/kg, micrograms per kilogram; E, estimated result—compound was detected, but value was less than the reporting level; values above the detection limits are reported in **BOLD**; <, less than]

	Date	Mercury (µg/kg)	Arsenic (µg/kg)	Cadmium (µg/kg)	Chromium (µg/kg)	Cobalt (µg/kg)	Copper (µg/kg)	Lead (µg/kg)	Nickel (µg/kg)	Silver (µg/kg)	Zinc (µg/kg)
						Fish tissue					
Male fish filets, composite	4/28/2003	**E 57**	**E 61**	<100	**420**	**E 11**	**720**	**E 28**	**E 47**	<100	**5,300**
Female fish filets, composite	4/28/2003	**E 83**	**E 77**	<100	**420**	**E 10**	**870**	**E 23**	**E 61**	<100	**5,400**
Male fish filets, composite	9/9/2003	**E 57**	<500	<100	**370**	**E 19**	**460**	**E 29**	**E 85**	**E 29**	**10,000**
Female fish filets, composite	9/9/2003	**E 45**	<500	<100	**380**	**E 24**	**550**	**E 26**	**120**	<100	**9,300**
Whole female fish (WS26)	5/12/2004	**E 31**	<500	<100	**950**	**120**	**2,300**	**130**	**530**	<100	**16,000**
Whole female fish (WS29)	5/12/2004	**E 72**	<500	**E 21**	**710**	**110**	**1,900**	**110**	**400**	<100	**14,000**
Whole male fish (WS33)	5/12/2004	**E 27**	<500	<100	**600**	**E 65**	**1,100**	**E 79**	**440**	<100	**15,000**
Whole male fish (WS38.44 composite)	5/12/2004	**E 74**	<500	<100	**720**	**E 88**	**1,600**	**160**	**500**	<100	**25,000**
						Bed sediment					
Bed sediment	4/28/2003	**E 110**	**5,900**	**890**	**130,000**	**36,000**	**100,000**	**89,000**	**87,000**	**E 210**	**240,000**
Bed sediment	5/12/2004	**E 9.4**	**E 1,600**	**E 120**	**26,000**	**8,100**	**15,000**	**17,000**	**18,000**	**<710**	**56,000**
						Quality-control samples					
Soil method blank	4/28/2003	<33	<500	<100	**E 75**	<100	**E 59**	**E 8.5**	**E 24**	<100	**E 560**
Tissue method blank	4/28/2003	<100	<500	<100	**E 99**	<100	<200	<100	**E 17**	<100	**E 430**
Tissue method blank	9/9/2003	**E 9.2**	<500	<200	**E 59**	<100	<200	<100	<100	<100	<1,000
Tissue method blank	5/12/2004	<100	<500	<100	**E 98**	<100	**E 140**	**E 15**	<100	<100	<1,000
Soil method blank	5/12/2004	<33	<500	<100	<200	<100	**300**	**E 47**	<100	<100	<1,000

Appendix B1. Sediment-quality guidelines for the protection of aquatic life and human health.

[ISQG, Interim Sediment Quality Guideline; PEL, Probable Effect Level; TEL, Threshold Effect Level. The ISQG or TEL is the level of possible effects that may occur from chronic or long-term exposures. The PEL is the level at which effects are probable and more likely under short-term exposures (Canadian Council of Ministers of the Environment, 2003). TEQ, Toxic Equivalency units, based on World Health Organization, 1998 toxics equivalency factors for fish (Van den Berg and others, 1998); TOC, total organic carbon; ng, nanograms; kg, kilograms; %, percent]

	Canadian freshwater sediment guidelines	
	ISQG (µg/kg)	PEL (µg/kg)
Pesticides		
Chlordane	4.50	8.87
DDD	3.54	8.51
DDE	1.42	6.75
DDT	1.19	4.77
Dieldrin	2.85	6.67
Endrin	2.67	62.4
Heptachlor/Heptachlor Epoxide	0.60	2.74
Lindane (γ-BHC)	0.94	1.38
Total PCBs	34.1	277
Arochlor 1254 (provisional based on 1% TOC)	60	340
Dioxins/Furans	0.85 ng TEQ/kg	21.5 ng TEQ/kg
Polyaromatic hydrocarbons		
Acenaphthene	6.71	88.9
Acenaphthylene	5.87	128
Anthracene	46.9	245
Benzo(a)anthracene	31.7	385
Benzo(a)pyrene	31.9	782
Benzo(b)fluoranthene	31.9	782
Chrysene	57.1	862
Dibenz(a,h)anthracene	6.22	135
Fluoranthene	111	2,355
Fluorene	21.2	144
2-Methylnaphthalene	20.2	201
Naphthalene	34.6	391
Phenanthrene	41.9	515
Pyrene	53.0	875
bis(2-ethylhexyl)phthalate[1]	*182* (*TEL*)	*2,647* (*PEL*)
Trace elements		
Arsenic	5,900	17,000
Cadmium	600	3,500
Chromium	37,300	90,000
Copper	35,700	197,000
Lead	35,000	91,300
Mercury (total)	170	486
Zinc	123,000	315,000

[1] Guidelines for bis(2-ethylhexyl)phthalate are the TEL and PEL from MacDonald (1994).

Appendix B2. U.S. Food and Drug Administration action and guidance levels for chemical contaminants in seafood.

[mg/kg, milligrams per kilogram]

Chemical	Concentration in mg/kg[1]	Tissue group
Aldrin + Dieldrin	0.3	All fish
Total Chlordane	0.3	All fish
DDT, TDE, DDE	5.0	All fish
Arsenic	76–86	Shellfish
Cadmium	3–4	Shellfish
Chromium	12–13	Shellfish
Lead	1.5–1.7	Shellfish
Nickel	70–80	Shellfish
Methyl Mercury	1 ppm	All fish
Heptachlor/Heptachlor Epoxide	0.3 ppm	All fish
Polychlorinated Biphenyls (PCBs)	2.0 ppm	All fish

[1] Except where noted in parts per million, or ppm.

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Miller, C.V., Weyers, H.S., Blazer, V.S., Freeman, M.E.—**Chemical and Ecological Health of White Sucker (*Catostomus commersoni*) in Rock Creek Park, Washington, D.C., 2003–04**—USGS Scientific Investigations Report 2006–5140