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Ecological Characterization of Streams, and Fish-Tissue Analysis for Mercury and Lead at Selected Locations, Fort Gordon, Georgia, June 1999 to May 2000

Open-File Report 01-203

Prepared in cooperation with

U.S. Department of the Army
Environmental and Natural Resources Management
Office of the U.S. Army Signal Center *and*
Fort Gordon

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

Cover: Stream reach on McCoy Creek downstream of North Range Road, Fort Gordon, Georgia, June 1999.
Photograph by M. Brian Gregory, U.S. Geological Survey.

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By M. Brian Gregory, Timothy C. Stamey, and John B. Wellborn

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CONTENTS

ILLUSTRATION

TABLES

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVC of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United Sttaes and Canada, formerly called Sea Level Datum of 1929.

ECOLOGICAL CHARACTERIZATION OF STREAMS, AND FISH-TISSUE ANALYSIS FOR MERCURY AND LEAD AT SELECTED LOCATIONS, FORT GORDON, GEORGIA, June1999 to May 2000

By M. Brian Gregory[1/], Timothy C. Stamey[2/], and John B. Welborn[3/]

ABSTRACT

The U.S. Geological Survey, in cooperation with the Environmental and Natural Resources Management Office of the U.S. Army Signal Center and Fort Gordon, Ga., documented the ecological condition of selected water-bodies on the Fort Gordon military installation from June 1999 to May 2000. This study includes stream-habitat assessments, aquatic invertebrate and fish-community surveys in selected stream reaches, and analyses of mercury and lead concentrations in largemouth bass (*Micropterous salmoides*) muscle tissue from three impoundments.

Assessment surveys indicate lower habitat value scores in some streams draining the more developed areas on Fort Gordon. A small tributary to Butler Creek—which drains parking lots associated with military motor pools and other impervious surfaces—is characterized by moderate levels of bank erosion and excess sediment in the stream channel compared to reference sites. Four other stream reaches are more similar to reference streams in respect to habitat conditions. Invertebrate communities in streams draining these urbanized watersheds are inhabited by 13 to 16 taxa per reach; whereas, 23 and 33 taxa were collected from the two reference stream reaches. Measures of invertebrate abundance, taxa richness, Ephemeroptera, Plecoptera, and Tricoptera Index are lower in streams draining urbanized watersheds. Measures of community similarity also indicate differences between streams draining urbanized areas and reference streams. Streams draining developed areas on Fort Gordon are inhabited by 3 to 10 fish species and included more species regarded as tolerant of degraded water-quality conditions; whereas, the two reference stream reaches support 4 and 10 species, respectively, including one species considered intolerant of degraded water-quality conditions.

Mercury was detected in all largemouth bass collected from three impoundments on Fort Gordon. Wet-weight mercury concentrations in fish tissue analyzed from all sites range from 0.08 micrograms per gram to 1.33 micrograms per gram. Median mercury concentrations in fish tissue are 0.83 micrograms per gram at Soil Erosion Lake, 0.72 micrograms per gram at Lower Leitner Lake, and 0.22 micrograms per gram at Gordon Lake. Median mercury concentrations in fish tissue analyzed from Soil Erosion Lake and Lower Leitner Lake are more than two times higher than U.S. Environmental Protection Agency recommendation of 0.3 micrograms per gram for fish consumption. Lead concentrations are below the minimum reporting limit for all specimens analyzed from reservoirs sampled at Fort Gordon.

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INTRODUCTION

Stormwater runoff from urbanized areas is a significant source of contamination to aquatic ecosystems and can cause aquatic habitat degradation in streams and rivers draining such areas (Baer and Pringle, 2000). Contaminants in stormwater runoff are derived from various sources including atmospheric deposition; industrial emissions; wastewater overflows; leaking landfills; and urban activities in general—such as automobile exhaust and runoff from parking lots and streets. Contaminants from these sources are transported to streams in runoff during rainfall events and are commonly adsorbed to streambed sediments.

Urban development within a watershed also can alter the hydrologic regime. Large amount of impervious surfaces in an urbanized watershed results in faster runoff to streams and markedly reduces infiltration into the soil. This altered flow regime results in periods of above normal streamflow during storms and below normal baseflow during dry weather (Urbonas and Roesner, 1993). The result is geomorphic changes to stream channels because above normal high-flow conditions scours stream banks and beds, and can significantly degrade or destroy habitat for aquatic life. Moreover, decreased baseflow resulting from decreased infiltration may reduce available habitat for aquatic organisms during low-flow periods.

Previous stream surveys conducted at Fort Gordon identified certain stream reaches having elevated levels of trace metals and semi-volatile organic compounds (McConnell and others, 2000). Some of these streams receive significant amounts of nonpoint-source runoff associated with urbanized areas of the Fort, and point-source runoff from abandoned and leaking landfills. Mercury and lead were detected at elevated concentrations in stream-bed sediments on Fort Gordon, and could adversely affect aquatic organisms and pose health risks to humans. Mercury is a concern because under certain environmental conditions, mercury is transformed into methylmercury—a toxic form which accumulates in muscle tissue of fishes (Weatherly and others, 1980). The U.S. Environmental Protection Agency (USEPA) has recently proposed a new criterion of 0.3 micrograms per gram (µg/g) of methylmercury in fish tissue (wet weight) (Borum and others, 2001). Lead also poses health risks to humans, and media-specific criteria have been proposed by the USEPA for drinking water, soil, dust, and paint; however, no criteria for concentrations of lead in tissue of freshwater fish have been established.

In order to implement the requirements of the National Pollutant Discharge Elimination System (NPDES) Permit for Stormwater Discharges from Municipal Separate Storm Sewer Systems, the U.S. Department of the Army requires stormwater-quality data for the development of a stormwater-management program at Fort Gordon. The program will use ecological data collected during this study to identify streams that may be degraded by stormwater runoff and to identify reservoirs in which concentrations of mercury and lead in fish tissue may be elevated.

Purpose and Scope

This report presents results of an ongoing stormwater monitoring project conducted by the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of the Army, Environmental and Natural Resources Management Office and Fort Gordon. The monitoring project is intended to provide baseline data related to the physical and biological conditions of selected waterbodies that may be affected by stormwater runoff from urbanized areas at Fort Gordon, and is based on data collected from June 1999 to May 2000. Specifically, this report (1) reviews previous water-quality investigations conducted at Fort Gordon to aid in selecting stream reaches to be assessed; (2) describes physical habitat and fish and invertebrate communities in selected stream reaches; and (3) reports mercury and lead concentrations from muscle tissue of largemouth bass (*Micropterus salmoides*) collected from three small reservoirs.

Description of Study Area

Fort Gordon is located in east-central Georgia about 8 miles southwest of Augusta—in Columbia, McDuffie, Jefferson, and Richmond Counties (fig. 1). The Fort lies in the northern part of the Coastal Plain physiographic province just south of the Fall Line in the Fall Line Sand Hills physiographic region (Omernik, 1987). Topography is characterized by rolling hills ranging in altitude from about 540 feet above sea level along the northern boundary to about 250 feet above sea level along the southern boundary. Soils consist of highly erodable, unconsolidated sands in layers as much as 20-feet thick. Locally, lenses of silty to sandy clay ranging in thickness from 1 to 3 feet are present (Fort Gordon Environmental and Natural Management Resources Office, written commun., 1998).

Well-developed dendritic stream patterns characterize the surface-water drainage network at Fort Gordon. Although located in an area of transition between the Piedmont and Coastal Plain physiographic provinces, streams draining Fort Gordon are similar to Coastal Plain, black-water, creek-swamp systems described by Wharton (1978) and are typified by glides and pools, low gradients, sandy substrates, and water with low pH and low specific conductance. Aquatic vegetation in streams at Fort Gordon is sparse, consisting mostly of mosses and some inundated grasses (Hoover and Kilgore, 1997).

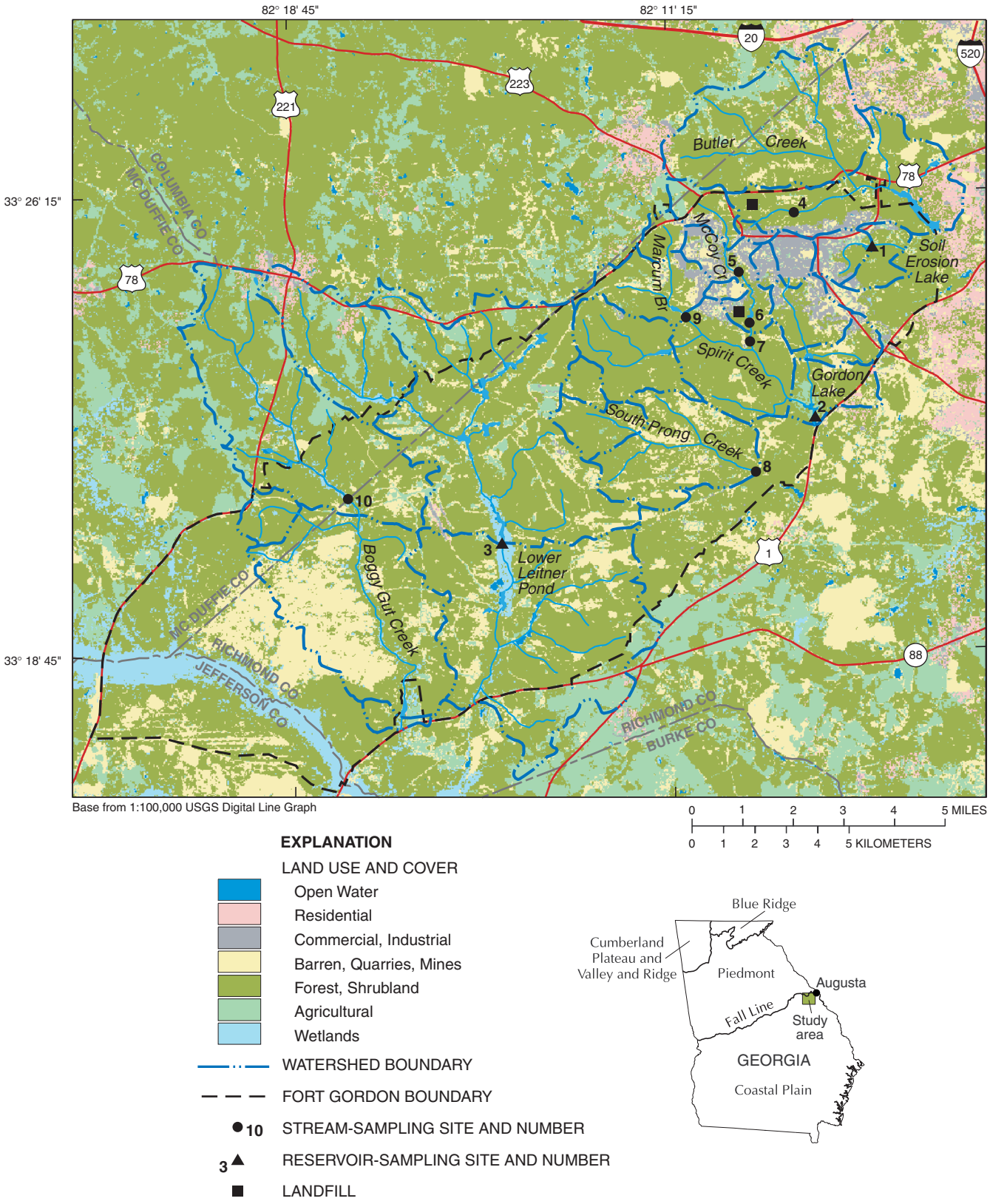

Figure 1. Fort Gordon, Georgia, study area, biological sampling sites, watershed boundaries, and land use.

Most development at Fort Gordon is restricted to the eastern part of the Fort, where land use is comprised of highly developed urban areas that consist of high-density residential, industrial, and military facilities (fig. 1; table 1). The largest areas of impervious surfaces at Fort Gordon are located in this area and comprise the headwaters of both Butler and Spirit Creeks. Upland forests and forested wetlands are the major types of land cover on the western part of the Fort. Major land-disturbing activities are associated with the use of small-arms-impact areas and artillery ranges. Large tracts of land on the western part of the Fort are being managed to restore the native long-leaf pine and wiregrass ecosystem and to enhance habitat for the Federally endangered red-cockaded woodpecker (*Picoides borealis*).

Table 1. Drainage areas and land-use and land-cover characteristics upstream of sampling sites, Fort Gordon, Georgia, June 1999 to May 2000

[site numbers in parenthesis refers to corresponding site where previous trace-element determinations in bed sediments were conducted by McConnell and others (2000); drainage area determined from U.G. Geological Survey 7.5 minute quadrangle maps—Augusta West (*photorevised* 1980), Avondale (1957), Blyth (*photorevised* 1971); Harlem (*photorevised* 1980); primary data source for land-use and land-cover coverages in Landsat Thematic Mapping data sets, acquired from 1989-93; NOTE: due to rounding, percentages may not sum to 100.0 percent]

Site number	Drainage area (square miles)	Forest (percent)	Commercial and industrial (percent)	Barren (percent)	Residential (percent)	Agricultural (percent)	Water (percent)	Wetland (percent)	Description of land use and land cover in drainage areas upstream of sampling site
1 (2)	0.9	53.1	26.3	12.4	0.0	7.6	0.4	0.1	base housing, military facility buildings and parking areas along western rim of divide; golf course along northeast rim of drainage area divide
2 (9)	17.5	66.1	13.5	14.1	0.4	5.3	0.3	0.4	mixed land use including roads and drainage, sewage treatment facility, abandoned land-fills, small arms impact area, motor pools, vehicle wash areas, residential housing; drainage area contains most of the military buildings that are located along the northern drainage area divide
3 (24)	19.7	69.0	10.1	0.8	2.0	14	1.1	3.0	mixed land use including mostly forested and open, natural areas; rural, small farm agriculture; town of Harlem headwaters; low-use military reservation area
4 (5)	7.5	69.1	0.6	12.0	5.7	11.6	0.2	0.7	mostly forested with some mixed land use including agriculture, industry, suburban residential, wetlands, roads and a small town; military facility buildings, parking, and motor pool service area; wash/grease racks along southern edge of drainage area divide
[1/]5 (17)	1.0	46.8	16.3	32.4	0.0	4.0	0.0	0.5	mostly forested areas with military facility buildings along southwestern part of drainage area divide; and an oil storage facility
[1/]6 (14)	3.2	35.2	20.8	32.2	0.0	11.5	0.0	0.5	mixed land use with wooded stream riparian areas; military buildings mostly along western part of drainage area; abandoned landfill; motor pool; vehicle wash area; and open, natural areas; part of streamflow consists of discharge from abandoned landfill
[1/]7 (14)	3.2	35.2	20.8	32.2	0.0	11.5	0.0	0.5	mixed land use; wooded stream riparian area; military buildings mostly along western part of drainage area; abandoned landfill; motor pool; vehicle wash area; and open, natural areas; part of streamflow consists of discharge from abandoned landfill
8 (6)	5.9	76.8	0.4	20.4	0.0	2.0	0.0	0.4	forested and open land; small-arms-impact area along western ridge of drainage divide
9 (18)	2.8	66.6	17.0	8.9	0.2	6.9	0.0	0.3	mostly forested with military facility buildings along eastern edge of drainage area divide; ammunition storage area
10 (29)	10.8	73.1	5.5	0.1	0.7	16.3	0.5	3.9	mostly forested with open areas along ridge tops

[1/]Approximate percentages of land use upstream of surveyed stream reaches.

Previous investigations

During 1978, a water-quality study was conducted by the U.S. Army at Fort Gordon (U.S. Department of the Army, Environmental Hygiene Agency, written commun.,1979). The primary focus of that study was to investigate the biological impact of point sources of contamination to Gordon Lake—an impoundment located on Spirit Creek. Data were collected from both Gordon Lake and the Richmond Factory Pond—reservoirs downstream from urban areas and wastewater treatment facilities on the military installation. The study documented nutrient concentrations, chlorophyll a levels, and phytoplankton biomass estimates during a dry period with low streamflows representing a "worst-case scenario" with respect to water-quality conditions. The study indicated that Gordon Lake served primarily as a "waste-stabilization pond" and was trophically enriched from phosphates in treated sewage effluent discharged into the stream and from fertilizers in runoff from the Gordon Lakes Golf Course. The study concluded that water-quality impacts on Spirit Creek from upstream sources of nutrients were minimal.

During 1992, the Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) conducted a water-quality investigation of Spirit Creek (Georgia Department of Natural Resources, 1992). The major focus of that study was to assess the quantity and quality of effluent flowing into Spirit Creek from three wastewater treatment plants. Data included water-quality characteristics collected from seven sites and biological data collected from six sites on Spirit Creek in September 1992. Standard field parameters were measured and augmented with measurements of biological oxygen demand, suspended solids, nutrients, total organic carbon, *Escherichia coli* bacteria, and total residual chlorine. Aquatic invertebrates were sampled at three of the six water-quality sampling sites. The study concluded that discharges from the three wastewater treatment plants were in compliance with NPDES permit limits and that water quality in Spirit Creek was within the range set by the State of Georgia for fishing water-use classification. Differences in macroinvertebrate communities were noted at the sampling sites, but were hypothesized to result from differences in habitat rather than from differences in water-quality conditions.

In 1995, water-quality conditions were evaluated at six sites in the Boggy Gut and Brier Creek drainages at Fort Gordon by the U.S. Department of Agriculture, Natural Resources Conservation Service; and the University of Georgia, Environmental and Agricultural Engineering Department (U.S. Department of Agriculture, 1995). These sites were selected because they receive runoff from urbanized areas of the Fort. The resulting data set was used to develop a comprehensive water-quality plan and to provide a limited inventory of 1995 water-quality conditions at Fort Gordon. Assessments were based on procedures recommended in the U.S. Department of Agriculture Water-Quality Indicators Guide (Terrell, 1989). Aquatic macroinvertebrate abundances were used to generate scores for the stream reaches under investigation. These scores indicated generally "good" water quality but recommended that future water-quality studies include a land-use component.

In 1997, the relation between stream-habitat characteristics and fish populations was investigated in Butler Creek, Spirit Creek, and Brier Creek—the three major drainages at Fort Gordon (Hoover and Kilgore, 1997). Although the study was not designed to assess direct impacts to streamwater quality, the relations among hydrologic, geomorphic, and physico-chemical measurements and fish populations at 19 sampling stations were investigated. Data collected during that study were used to developed species-specific regression models based on parameters describing the chemical and physical habitat. Results indicated that streams draining Fort Gordon contained 28 species of fishes whose diversity reflected a gradient of anthropogenic disturbance. Fish diversity was positively correlated with stream depth and negatively correlated with turbidity; and total fish abundance was positively correlated with stream width and negatively correlated with specific conductance. The study also concluded that fish populations were relatively low in the smaller headwater streams at Fort Gordon.

METHODS OF INVESTIGATION

Stream-Habitat Characterization

Stream habitat data were collected at 7 sites (fig. 1; table 2) from June 1999 to May 2000 using protocols developed for the USGS National Water-Quality Assessment Program (NAWQA) and the GaEPD Stream Habitat Assessment guide for glide/pool prevalent streams. NAWQA habitat assessment protocols (Meador and others, 1993b) include measurements of channel width, bank width, water depth, canopy angles, channel aspect, bank erosion, and types of in-stream habitat features. The GaEPD habitat assessment protocols (Georgia Environmental Protection Division, 1997) involved assigning scores to categories of habitats based on the amount of habitat present in a stream reach and included available cover, types of bottom substrate, pool variability, channel alterations, sediment deposition, channel sinuosity, channel flow status, bank vegetation, bank stability, and riparian zone width. The GaEPD habitat scores for each of these parameters were summed for a total score for each site and compared to average values derived

from reference stream reaches on Marcum Branch (site 9) and Boggy Gut Creek (site 10). South Prong Creek (site 8) initially was considered as an alternative reference stream due to its mostly forested condition and lack of urban areas within the watershed; however, due to the unknown effects of small-arms-impact areas located adjacent to South Prong Creek, the creek was not used as a reference stream during this study. All streams were classified as 2nd order (Strahler, 1964) at the sampling reaches—except for Boggy Gut Creek (site 10)—classified as a 3rd order stream. Reach lengths for sampling were to be at least 20 times the average channel width; however, due to the narrow widths of all sampled streams, 500-foot stream reaches were designated as a minumum reach length at all stream sites. Data from individual transects and photographs of sampled stream reaches are included in Appendix A. Temperature, dissolved oxygen, percent saturation of oxygen, specific conductance, and pH were measured at each site using a multiprobe water-quality meter calibrated daily prior to sampling.

Table 2. Site data and data-collection activities at selected sampling sites, Fort Gordon, Georgia, June 1999 to May 2000

[F-fish community characterization; I-invertebrate community characterization; H-habitat characterization; T- fish tissue analysis]

Site number (figure 1)	Station number	Site name	Latitude	Longitude	Type of data
		Impoundments			
1	02196842	Soil Erosion Lake	33°25′20″	82°07′13″	T
2	021970190	Gordon Lake	33°22′24″	82°08′23″	T
3	021975593	Lower Lietner Lake	33°20′33″	82°14′37″	T
		Stream reaches			
4	02196823	Butler Creek tributary	33°25′57″	82°08′56″	F, H, I
5	021970158	McCoy Creek at Lane Road and below Scout Lake	33°23′56″	82°09′37″	F, H
6	0219070150	McCoy Creek upstream of North Range Road	33°24′06″	82°09′39″	F, H
7	0219070158	McCoy Creek downstream of North Range Road	33°24′47″	82°09′43″	F, H, I
8	02197023	South Prong Creek at McDuffie Road	33°21′39″	82°09′34″	F, H, I
9	21970136	Marcum Branch below Maxwell dam	32°24′15″	82°10′59″	F, H, I
10	021975584	Boggy Gut Creek at Gibson Road	33°21′03″	82°17′27″	F, H, I

Stream-invertebrate Community Characterization

Invertebrate collections were made using a modified version of the USEPA Rapid Bioassessment Protocol III (Plafkin and others, 1989) suggested for use in Coastal Plain streams by the Georgia Bioassessment Protocol (Georgia Environmental Protection Division, 1997). Collections were made at 5 sites (fig. 1; table 2) using a d-frame net (210 µm mesh) to collect both a timed multihabitat-composite sample and a single-habitat sample targeted at undercut banks, exposed tree roots, and stable woody debris. Invertebrate collections were not made at sites 5 and 6 (fig. 1). Sampling effort consisted of 0.5 sampling person hours for each sample type at each stream reach. Large invertebrates were separated from the main body of samples while in the field and both portions of each sample were preserved separately on site and transported to the USGS Georgia District Office, Atlanta. The mainbody of each sample was sorted under low-power magnification using a timed procedure or until at least 100 individual specimens were removed from the sample. Voucher specimens were identified by a taxonomist at the USGS National Water-Quality Laboratory, Denver, Colo. Invertebrate counts from each type of sample collected at each stream were composited prior to use in metrics. Invertebrate abundance data from both sample types and from all sampled stream reaches are presented in Appendix B. Invertebrate metrics consisted of a suite recommended for use by the GaEPD (1997) for conducting stream bioassessments in Coastal Plain streams and included taxa abundance, taxa richness, Ephemeroptera, Plecoptera, and Tricoptera (EPT) taxa richness, percent contribution of dominant taxa and percentage of collector-filterers. These metrics were compared to mean values calculated for the two reference sites sampled during this study and expressed as a percentage of the mean reference value (MRV).

Stream-Fish Community Characterization

Fishes were collected from seven stream reaches using backpack electrofishing gear and standard sampling procedures (Meador and others, 1993a). Due to the low riparian canopy, extensive woody debris, and root mats along some stream banks, multiple collection passes were conducted at each stream reach and standard collection techniques were augmented by seine hauling and block netting where appropriate conditions existed. Common species were identified in the field and released. Fishes not identified in the field were preserved in 10 percent formalin and sent to a regional taxonomic expert at the University of Georgia for identification. Specimens retained during the study are housed at The University of Georgia, Museum of Natural History, Athens, Ga. Because a multimetric index that measures the biotic integrity of Coastal Plain fish

communities is not yet available, fish communities were compared using catch-per-unit effort (CPUE), abundance and species diversity.

Reservoir-Fish Tissue Analysis

Reservoir sampling sites were chosen based on elevated levels of mercury and lead in a bed-sediment survey (McConnell and others, 2000). Twenty-five largemouth bass (*Micropterus salmoides*) specimens were collected on September 30, 1999, from Soil Erosion Lake, Gordon Lake, and Lower Leitner Pond (fig. 1; table 2). Individual fish were collected by the Fort Gordon Environmental and Natural Resource Management Office staff using boat-mounted electrofishing gear and processed onsite. Specimens were weighed and measured, and one scaled fillet with skin attached was removed from each individual. Fillets were wrapped in foil, placed in individually labeled plastic bags, and shipped on dry ice to the USGS National Water-Quality Laboratory, Denver, Colo. Lead and mercury levels were determined using analysis methods described by Hoffman (1996). Because the objective of this sampling was to determine the potential effect of fish consumption on human health, only muscle tissue was analyzed.

RESULTS

Stream Habitats

Field water-quality characteristics in sampled stream reaches indicate low specific conductance and acidic to circumneutral conditions in all sampled streams. Specific conductances range from 8.3 microsiemens per centimeter (μS/cm) to 53.1 μS/cm and are highest at McCoy Creek upstream of North Range Road (site 6) and McCoy Creek downstream of North Range Road (site 7). The pH in surveyed stream reaches ranged from 4.7 to 6.2, with the lowest pH values occurring in the references sites—Marcum Branch (site 9) and Boggy Gut Creek (site 10). Dissolved-oxygen concentration range from 5.7 milligrams per liter (mg/L) at the Butler Creek tributary (site 4) to 14.2 mg/L at Marcum Branch (site 9).

The habitat-reach survey in the tributary to Butler Creek (site 4) indicate the lowest Georgia Habitat Assessment (GHA) score of any site in the study. This reach shows signs of bank erosion and has few pools, woody snags, or root mats. The bed material in this reach is dominated by coarse sand. Further investigations within the watershed and upstream of the surveyed reach reveal an area of highly eroded gullies about 20- to 30-feet deep located adjacent to the stream. Although these gullies do not appear to be actively eroding; during formation, the gullies may have contributed a large portion of the sand that currently dominates the channel bed. Runoff collected from a large area of impervious surface within the watershed also contributes to streamflow in this reach.

Three stream reaches surveyed on McCoy Creek (sites 5, 6, 7) has GHA scores 1.5 to 2 times greater than the score for Butler Creek (site 4; table 3). Moderate bank erosion was noted at 2 transects at site 5; whereas, bank erosion was not noted at site 6, and only slight bank erosion was noted along the surveyed transects at site 7 (table 3; Appendix A). The dominant substrate in these reaches is coarse sand and clay with patches of small gravel co-dominant. Mean percentage of root mats and woody debris range from 13 percent at site 5, to 28 percent at site 6 (table 3).

Stream habitat in South Prong Creek (site 8) is similar to habitat in reference stream reaches (sites 9 and 10), especially in respect to dominant substrate which is composed of coarse sand with fine sands co-dominant. Mean percentage of root mats and woody debris was higher in South Prong Creek than all other non-reference sites as well as site 10, one of the reference sites (table 3).

Marcum Branch (site 9) and Boggy Gut Creek (site 10) were selected to represent near-reference conditions. The watersheds of these streams is mostly forested with little or no urban development (table 1). The dominant substrate in the channels of these streams was coarse sand; however, the substrate at several transects in Boggy Gut Creek (site 10) consisted of coarse sand with cobble and cobble-sized brick, probably from historic dams or bridges. Mean percentage of woody debris range from 29 percent in Boggy Gut (site 10) to 48 percent in Marcum Branch (site 9; table 3).

Georgia stream-habitat assessment scores for all sites range from 69 to 156 (table 3). Reaches with the lowest scores drain watersheds containing relatively large urban areas or areas of impervious surfaces in close proximity to the stream; whereas, stream reaches without large urban areas within the watershed generally score the highest. South Prong Creek (site 8)—a stream with minimal urbanization in its watershed—scores higher than at Marcum Branch (site 9)—a reference stream reach.

Stream-Invertebrate Communities

Stream-invertebrate communities at Fort Gordon consist of 50 taxa of aquatic invertebrates. Seven taxa including *Dineutus* sp., Chironomidae sp., Procambarus sp., Araneae sp., Hydropsychidae sp., *Rhagovelia obesa*, *Boyeria vinosa*, and *Calopteryx* sp. are the most commonly collected aquatic invertebrates and are present at all of the surveyed stream reaches. An additional 26 taxa of aquatic invertebrates, including most taxa of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies) (EPT) are present only at the two reference sites (table 4).

Table 3. Summary of habitat characteristics and biological condition scores for selected streams, Fort Gordon, Georgia, June 1999 to May 2000

Characteristic		Butler Creek tributary	McCoy Creek downstream of Lane Road	McCoy Creek upstream of North Range Road	McCoy Creek downstream of North Range Road	South Prong Creek	Marcum Branch[1/]	Boggy Gut Creek[1/]
		Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Stream bed								
Mean channel width (feet)		14.4	9.2	7.8	9.4	9.4	6.4	15.1
Mean water depth (feet)		0.2	1.5	0.8	0.7	1.2	1.4	1.1
Dominant substrate		coarse sand	coarse sand	coarse sand	coarse sand	coarse sand	coarse sand	cobble-coarse sand
Subdominate substrate		fine sand	clay	small gravel	small gravel	fine sand	small gravel	small gravel-coarse sand
Mean percent root mats/ woody debris		20	13	28	19	38	48	29
Stream bank								
Mean bank height (feet)	left bank	2.8	4.7	2.5	2.90	2.4	1.70	2.6
	right bank	1.9	4.9	2.6	3.2	1.8	1.8	2.5
Bank Shape	left bank	linear	linear	linear-concave	linear	linear	linear	linear
	right bank	linear	linear	linear	linear-concave	linear	linear	linear
Mean bank angle (degrees)	left bank	46	49	39	59	65	69	69
	right bank	23	65	53	76	58	68	54
Bank erosion	left bank	moderate	slight	none	none-slight	none	none	none
	right bank	moderate	slight-moderate	none	slight	none	none	none
Georgia Habitat Assessment Score		69	103	141	132	154	146	156

[1/]Reference stream reach.

Ecological stresses—such as habitat alteration, changes in hydrologic regime, and degradation of water quality—have been shown to cause a decline in absolute numbers (abundance) of organisms (Resh and Grodhaus, 1983). Abundances are lower in Butler Creek (site 4) and South Prong Creek (site 8) than in the reference sites. In contrast, the abundances in McCoy Creek downstream of North Range Road (site 7) are within the range of abundances observed in the reference stream reaches (table 4). Abundance as a percentage of the mean reference value (MRV) range from 22 to 77 percent in streams draining urbanized watersheds (table 4).

The number of aquatic invertebrate taxa present in a stream generally reflects the health of a community. Taxa richness generally increases with better water quality and with greater habitat suitability and habitat diversity (Resh and Grodhaus, 1983). Taxa richness in streams surveyed for this study ranges from 13 to 33 taxa. Taxa richness is highest in the reference streams, with 33 at Boggy Gut (site 10) and 23 at Marcum Branch (site 9), respectively (table 4). The lowest taxa richness was observed in the unnamed tributary to Butler Creek (site 4), and in the McCoy Creek reach downstream of North Range Road (site 7) (table 4).Taxa richness generally is highest in the reference streams and lowest in the stream draining urbanized watersheds. Taxa richness as a percentage of the MRV range from 46 to 57 percent in streams draining urbanized watersheds (table 4).

Taxa in the orders Ephemeroptera, Plecoptera, and Tricoptera (EPT) generally are thought to be more sensitive to contaminants and usually are present in higher numbers in streams with better water quality and habitat conditions (Lenat, 1988). Numbers of EPT taxa range from 2 to 7 taxa per stream and are highest in the two reference streams and South Prong Creek (site 8), and are lowest in the Butler Creek (site 4) and McCoy Creek downstream of North Range Road (site 7). EPT index scores (abundance) range from 2 to 42 in all sampled streams. EPT index scores as a percentage of the MRV ranged from 5 to 94 percent in streams draining watersheds in urbanized areas, indicating a wide range of abundances of these taxa in Fort Gordon streams draining urbanized areas (table 4).

Table 4. Invertebrate metric values for selected streams, Fort Gordon, Georgia, June 1999 to May 2000
[NA, not applicable; % MRV, metric expressed as a percentage of the mean metric value for reference stream reaches = (metric value/mean metric value from reference reaches) x 100]

Metric values	Butler Creek	McCoy Creek downstream of North Range Road	South Prong Creek	Marcum Branch[1/]	Boggy Gut Creek[1/]
	Site 4	Site 7	Site 8	Site 9	Site 10
Abundance[2/]	28	99	62	78	175
Abundance % MRV	22	77	49	NA	NA
Taxa Richness[3/]	13	14	16	23	33
Taxa Richness as % MRV	46	50	57	NA	NA
EPT Index[4/]	2	13	36	34	42
EPT Index as % MRV	5	34	94	NA	NA
% contribution of dominant taxon[5/]	25	38	23	15	21
% collector-filterers[6/]	7	12	2	15	15
Coefficient of community loss[7/]	1.67	1.00	1.10	NA	NA

[1/]Reference stream reach.

[2/]Absolute number of organisms. Certain stress such as declining habitat and water-quality conditions can reduce numbers of organisms

[3/]Number of unique organisms; and generally decreases with decreasing water-quality and habitat conditions.

[4/]Number of organisms in the order Ephemeroptera, Plecoptera, and Trichoptera.; and are generally more sensitive to environmental perturbations and numbers will decrease with decreasing water-quality and habitat conditions.

[5/]Ratio of the number of organisms in the numerically dominant taxa to the total number of organisms. A community dominated by relatively few taxa is indicative of environmental stress.

[6/]Number of organisms which feed by filtering particles out of the water column; and these organisms are often sensitive to pollutants bound to fine particles in the water column and stresses communities generally have a lower percentage of collector filterers, especially in Coastal Plan streams.

[7/]Similarity index calculated as the number of taxa at reference minus the number of taxa at the degraded site divided by number of taxa at both sites. Stressed communities will become more dissimilar and have higher community loss coefficients. Based on numbers of taxa collected from the Marcum Branch reference stream reach (site 9), a community loss coefficient ranging from 0.05 to 0.1 would indicate highly similar invertebrate communities; whereas, number outside this range indicate a portion of the reference community is missing.

The percent contribution of the dominant taxa is calculated as the ratio of abundance in the numerically dominant taxa to the total number of organisms collected and expressed as a percentage. This metric is a measurement of community balance and is based on the observation that stressed communities generally are dominated by relatively few taxa (Plafkin and others, 1989). Taxa dominance generally is lower in the reference stream reaches—ranging from 15 to 21 percent. Percent contribution of the dominant taxa in stream reaches draining watersheds with significantly urbanized areas range from 23 to 38 percent, with McCoy Creek downstream of North Range Road (site 7) having the highest percent contribution of the dominant taxa (table 4).

Coastal Plain streams having a healthy community of invertebrates usually contain a high percentage of organisms that belong to the collector-filterer feeding guild (Barbour and others, 1996). These organisms feed by collecting small particles of organic matter from the water column, usually by some means of filtering the water with specialized body parts or behavioral adaptations such as larval blackfly cephalic fans or nets constructed by caddisflies. The percentage of collector-filterers in macroinvertebrate communities has been shown to decline in stressed Coastal Plain streams (Barbour and others, 1996). In Fort Gordon streams draining urbanized watersheds, macroinvertebrate communities consist of only 2 to 12 percent collector-filterers; whereas, reference stream reaches have macroinvertebrate communities that are composed of 15 percent collector-filterers (table 4).

The coefficient of community loss (Courtemanch and Davies, 1987) is a community-similarity index that provides a measure of the degree of similarity between two streams. This coefficient is based on the total number of taxa present in nearby reference streams and the number of taxa in common between the reference stream and the stream under investigation. Higher coefficients of community loss describe communities that are increasingly different from a particular reference stream. Based on numbers of taxa collected from the Marcum Branch reference stream reach (site 9), a coefficient of community loss ranging from 0.05 to 0.1 would indicate highly similar invertebrate communities in both reference and comparison stream. The selected streams reaches that drain urbanized areas at Fort Gordon have community loss coefficients ranging from 1.00 to 1.67. These values are outside the range that indicates similar communities—suggesting that a significant portion of the invertebrate community was not present in the non-reference streams.

Stream-Fish Communities

Twenty-one species of fishes were collected from 7 sites in the study area (table 5). Fish abundances generally are low in all streams surveyed at Fort Gordon, with numbers collected per stream reach ranging from 6 to 23 individuals. McCoy Creek downstream from Range Road (site 7) contain 10 species and represents the most diverse assemblage of fishes collected at a site during this study. The reference stream reaches located on Marcum Branch (site 9) and Boggy Gut Creek (site 10) contain 4 and 9 species of fishes, respectively. Eight species of fishes were collected in Butler Creek tributary (site 4), despite having the lowest habitat scores. Four species were collected from McCoy Creek downstream of Lane Road (site 5), and 6 species were collected from McCoy Creek upstream of North Range Road (site 6). South Prong Creek (site 8) has the lowest fish species diversity with only three species collected. Four species of fishes including iron color shiners (*Notropis chalybaeus*), northern hog suckers (*Hypentelium nigricans*), speckled madtoms (*Noturus leptacanthus*), and pumpkinseeds (*Lepomis gibbosus*) were collected only from the Boggy Gut Creek reference site (site 10). Site 7 on McCoy Creek had higher fish diversity than both reference streams. However, the close proximity of this reach to the confluence with Spirit Creek—a stream larger than those sampled in this study—might have a significant influence on fish diversity and abundance in this reach.

Table 5. Fish number(s), by species, collected in selected streams, Fort Gordon, Georgia, June 1999 to May 2000

[—, none collected; catch-per-unit effort (CPEU) is calculated by dividing the number individuals collected in a reach by the sampling time, in seconds]

Scientific name	Common name	Butler Creek	McCoy Creek at Lane Road	McCoy Creek upstream of Range Road	McCoy Creek downstream of Range Road	South Prong Creek[1/]	Marcum Branch[1/]	Boggy Gut Creek
		Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Aphredoderus sayanus	pirate perch	1	—	—	2	—	—	1
Esox americanus	grass pickerel	5	—	2	1	—	—	—
Notropis chalybaeus	ironcolor shiner	—	—	—	—	—	—	8
Notropis cummingsae	dusky shiner	—	—	1	2	—	—	—
Notropis hypsilepis	highscale shiner	—	—	1	—	3	—	—
Notemigonus crysoleucas	golden shiner	1	—	—	—	—	—	—
Erimyzon sucetta	lake chubsucker	—	—	—	1	—	—	—
Hypentelium nigricans	northern hog sucker	—	—	—	—		—	2
Ameiurus natalis	yellow bullhead	2	—	—	1	2	3	—
Noturus leptacanthus	speckled madtom	—	—	—	—	—	—	1
Gambusia affinis	mosquitofish	—	—	—	1	—	—	—
Elassoma zonatum	banded pygmy sunfish	1	—	—	—	—	—	—
Acantharchus pomotis	mud sunfish	3	—	—	1	—	—	1
Micropterus salmoides	largemouth bass	—	1	1	1	—	—	—
Lepomis auritus	redbreast sunfish	5	2	6	11	—	3	
Lepomis gibbosus	pumpkinseed	—	—	—	—	—	—	1
Lepomis gulosus	warmouth	—	1	—	—	—	—	—
Lepomis macrochirus	bluegill sunfish	—	3	—	—	—	—	—
Lepomis marginatus	dollar sunfish	2	—	1	2	—	1	1
Etheostoma fricksium	Savannah darter	—	—	—	—	1	—	5
Percina nigrofasciata	blackbanded darter	—	—	—	—	—	3	3
Total number of species		**8**	**4**	**6**	**10**	**3**	**4**	**9**
Abundance per reach		**20**	**7**	**12**	**23**	**6**	**10**	**23**
CPEU (individuals/second)		**0.03**	**0.01**	**0.04**	**0.03**	**0.01**	**0.02**	**0.04**

[1/]Reference stream reach.

Species of fishes known to be tolerant of declining water-quality conditions (Georgia Environmental Protection Division, 2000) commonly were found at sites draining urban areas. The only species of fish collected and listed as intolerant to poor water-quality conditions is the northern hog sucker (*Hypentelium nigricans)*, and was collected from Boggy Gut Creek (site 10)—a reference stream. Catch-per-unit effort was low at all sites and range from 0.01 individuals per second at McCoy Creek at Lane Road (site 5) to 0.04 individuals per second at both Boggy Gut Creek (site 10) and McCoy Creek upstream of Range Road (site 6).

Reservoir-Fish Tissue

Twenty-five largemouth bass (*Micropterous salmoides*) specimens were collected and analyzed for mercury and lead contamination. Standard lengths of specimens range from 195 millimeters (mm) to 370 mm and are within the ranges of largemouth bass commonly kept for consumption by anglers at Fort Gordon (Fort Gordon Environmental and Natural Resources Management Office, oral commun., 1999). Wet-weight mercury concentrations in largemouth bass sampled range from 0.59 micrograms per gram (µg/g) to 1.3 µg/g at Soil Erosion Lake, 0.08 µg/g to 0.53 µg/g at Gordon Lake, and 0.54 µg/g to 0.95 µg/g at Lower Leitner Lake (table 6). Median mercury concentrations were 0.22 µg/g at Gordon Lake, 0.83 µg/g at Soil Erosion Lake, and 0.72 µg/g at Lower Leitner Lake. Generally, larger specimens collected contain higher concentrations of mercury than smaller specimens and is indicative of bio-acummulation procesess. Median wet-weight concentrations of mercury in fish tissue collected at both Soil Erosion Lake and Gordon Lake are higher than the 0.3 µg/g (wet-weight) criterion for fish consumption (Borum and others, 2001). Although median concentrations of mercury are lower than the USEPA (Borum and others, 2001) recommended level of 0.3 µg/g—in Gordon Lake—the two largest specimens contain concentrations in muscle tissue that are higher than this value. Lead levels in all largemouth bass collected during this study are below the minimum reporting limit.

Table 6. Results of mercury and lead analyses on muscle tissue of largemouth bass (*Micropterus salmoides*) collected in Soil Erosion Lake, Gordon Lake, and Lower Leitner Lake, Fort Gordon, Georgia, September 30, 1999
[<, less than detection limit; NA, not applicable]

Specimen number	Specimen length (milimeter)	Sample wet weight (grams)	Lead (micrograms per gram)		Mercury (micrograms per gram)	
			Dry weight	Wet weight	Dry weight	Wet weight
Site 1. Soil Erosion Lake						
1	230	22.41	<0.2	NA	3.4	0.65
2	235	19.69	<.2	NA	3.2	.66
3	210	21.73	<.2	NA	2.9	.59
4	330	22.61	<.2	NA	4.7	1.10
5	360	21.41	<.2	NA	3.9	.83
6	325	22.83	<.2	NA	3.9	.93
7	335	22.72	<.2	NA	5.9	1.33
Site 2. Gordon Lake						
1	195	20.79	<.2	NA	0.6	.13
2	205	21.61	<.2	NA	0.5	.10
3	215	22.68	<.2	NA	0.4	.08
4	310	22.61	<.2	NA	0.8	.20
5	370	20.75	<.3	NA	2.3	.53
6	275	21.51	<.2	NA	1.1	.27
7	325	20.48	<.2	NA	1.5	.32
8	285	22.28	<.2	NA	1.1	.24
Site 3. Lower Leitner Lake						
1	285	23.32	<.2	NA	2.6	.59
2	200	22.97	<.2	NA	2.9	.61
3	305	22.65	<.2	NA	4.2	.87
4	285	25.22	<.2	NA	4.3	.88
5	250	21.57	<.3	NA	2.7	.54
6	330	21.49	<.3	NA	3.6	.68
7	290	19.73	<.3	NA	3.7	.71
8	275	21.75	<.2	NA	3.4	.72
9	290	21.78	<.2	NA	4.6	.95
10	295	20.51	<.3	NA	4.1	.83

SUMMARY

A study was conducted by the U.S. Geological Survey, in cooperation with the Environmental and Natural Resources Management Office of the U.S. Army Signal Center and Fort Gordon, to document the ecological condition of streams draining significantly developed areas of the fort. As part of this study, additional work was conducted to determine if fish communities in selected reservoirs at Fort Gordon contain elevated levels of mercury and lead. Stream-habitat characterizations were conducted at 7 stream reaches using methods developed by the National Water Quality Assessment Program and Georgia Environmental Protection Division. Stream fish communities were sampled at these same stream reaches and the invertebrate communities were sampled at 5 of these sites. Mercury and lead concentrations in largemouth bass were determined from 17 specimens collected from 2 small reservoirs where previous studies indicated the potential for metal contamination. Mercury and lead concentrations were compared to concentrations in 8 largemouth specimens collected from a third reservoir chosen to represent background concentrations of mercury and lead.

Results from these studies indicate that stream reaches downstream from developed areas and large areas of impervious surfaces at Fort Gordon are more likely to have eroded banks, shallower mean water depth, less root mat area, less woody debris in the stream channel, and lower habitat condition scores. Five invertebrate community metrics indicated differences between streams that drain urbanized watersheds and reference stream reaches. Fish diversity is relatively low in all surveyed reaches; however, species of fishes known to be tolerant of degraded water-quality condition are more commonly found at the sites draining urban areas or large areas of impervious surfaces.

Mercury was detected in all largemouth bass specimens collected from the three reservoirs investigated during this study. Mercury levels were higher in the two reservoirs downstream from locations where previous studies had indicated elevated levels of mercury in sediments than in the reservoir chosen to represent background mercury levels. Median wet-weight mercury concentrations in fish tissue from all sampled reservoirs are higher than the minimum concentration recommended by the U.S. Environmental Protection Agency for unlimited consumption of fish; however, the median mercury concentration from Gordon Lake are below the U.S. Environmental Protection Agency water-quality criterion for methylmercury. Concentrations of lead are below the minimum reporting limit in all specimens collected from all reservoirs sampled.

REFERENCES CITED

Barbour, M.T., Gerritsen, J., Griffith, G.E., Frydenborg, R., McCarron, E., White, J.S., and Bastian, M.L., 1996, A framework for biological criteria for Florida streams using benthic macroinvertebrates: Journal of the North American Benthological Society, v. 15, no. 2, p. 386-391.

Baer, K.E., and Pringle, C.M., 2000, Special problems of urban river conservation—the encroaching megalopolis, *in* Boon, P.J., Davies, B.R., and Petts, G.E., *eds*., Global Perspectives on River Conservation: New York, N.Y., John Wiley & Sons Ltd., Science, Policy and Practice, p. 385-402.

Borum, Denis, Manibusan, M.K., Schoeny, R., and Winchester, E.L., 2001, Water-quality criterion for the protection of human health—methylmercury: Washington, D.C., U.S. Environmental Protection Agency, Office of Science and Technology, EPA-823-R-01-001, variously paged.

Courtemanch, D.L. and Davies, S.P., 1987, A coefficient of community loss to assess detrimental change in aquatic communities: Water Research, v. 21, no. 2, p. 217-222.

Georgia Department of Natural Resources, 1992, A water-quality investigation of Spirit Creek, Richmond County, Georgia: unpublished report on file at Fort Gordon, U.S. Department of the Navy, Environmental and Natural Resources Management Office, 26 p.

____2000, Draft standard operating procedures for conducting biomonitoring on fish communities in the Piedmont Ecoregion of Georgia: Atlanta, Ga., Georgia Department of Natural Resources, Wildlife Resources Division, Fisheries Section, 89 p.

Georgia Environmental Protection Division, 1997, Standard operating procedures—freshwater macroinvertebrate biological assessment: Atlanta,Ga.,Georgia Department of Natural Resources, Water Protection Branch, 139 p.

Hoffman, G.L., 1996, Methods of analysis by the U.S. Geological Survey, National Water-Quality Laboratory preparation procedure for aquatic biological material determined for trace metals: U.S. Geological Survey Open-File Report 96-362, 42 p.

Hoover, J.J. and Kilgore, K.J., 1997, Fish-habitat relationships in the stream of Fort Gordon, Georgia: Vicksburg, Miss., U.S. Department of the Army, Waterways Experiment Station, U.S. Army Corps of Engineers, unpublished report on file at Fort Gordon, Ga., U.S. Department of the Navy, Environmental and Natural Resources Management Office, 24 p.

Lenat, D.R., 1988, Water-quality assessments of streams using a qualitative collection method for benthic invertebrate: Journal of the North American Benthological Society, v. 7, no. 1, p. 22-33.

McConnell, J.B., Stamey, T.C., Persinger, H,H., Jr., and McFadden, K.W., 2000, Trace elements and semi-volatile organic compounds in bed sediments from streams and impoundments at Fort Gordon, Georgia: U.S. Geological Survey Open-File Report 00-87, 39 p.

Meador, M,R., Cuffney, T..F., and Gurtz, M.E., 1993a, Methods for sampling fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-104, 40 p.

Meador, M.R., Hupp, C.R., Cuffney, T.F., and Gurtz, M.E., 1993b, Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-408, 48 p.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, p. 118-125.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish: Washington, D.C., U.S. Environmental Protection Agency, Office of Water Regulations and Standards, EPA/444/4-89/001,variously paged.

Resh, V.H., and Grodhaus, G., 1983, Aquatic insects in urban environments, *in* Frankie, G.W. and Koehler, C.S., *eds.*, Urban Entomology: New York, Praeger Publications, Interdisiplinary Perspectives, p. 247-76.

Strahler, A.N., 1964, Quantitative geomorphology of drainage basins and channel networks, *in* Chow, Ven te, *ed*., Handbook of Applied Hydrology: New York, N.Y., McGraw Hill, section 4-2, variously paged.

Terrell, C.R., 1989, Water-quality indicators guide—surface waters: U.S. Department of Agriculture, Soil Conservation Service, v. 161, 208 p.

Urbonas, B.R. and Roesner, L.A., 1993, Hydrologic design for urban drainage and flood control, in Maidment, David R. ed., Handbook of Hydrology: New York, N.Y., McGraw Hill, section 28, p. 28.1-28.51.

U.S. Department of Agriculture, 1995, Water-quality evaluation results and recommendations: Fort Gordon, Ga., Natural Resources Conservation Service and the University of Georgia, Environmental and Agricultural Engineering Department, unpublished report on file at Fort Gordon Environmental and Natural Resources Management Office, variously paged.

Weatherly, A.H., Lakes, P.S., and Rogers, S.C, 1980, Zinc pollution and the ecology of the freshwater environment, *in* Nriagu, J.O., *ed*., Zinc in the Environment, Part I, Ecological Cycling: New York, N.Y., Wiley-Interscience, p. 337- 418.

Wharton, C.H., 1978, The natural environments of Georgia: Atlanta, Ga., Georgia Department of Natural Resources, 227 p.

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000
[%, percent; do., ditto]

Site 4. Butler Creek

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	5.1	53	linear	moderate	30.5	0.2	coarse sand	fine sand	10% woody debris/root mats; 5 % overhanging vegetation
Right	1	25	do.	do.					
Transect 2									
Left	4.1	40	do.	severe	11.5	0.1	do.	do.	50% woody debris/root mats; 25% overhanging vegetation
Right	2.2	10	do.	moderate					
Transect 3									
Left	0.5	40	do.	slight	7.5	0.2	do.	do.	10% woody debris/root mats;
Right	1.2	45	do.	moderate					10% overhanging vegetation
Transect 4									
Left	1.4	50	do.	do.	8.2	0.1	do.	do.	10% woody debris/root mats;
Right	3.2	10	do.	do.					5% overhanging vegetation

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 5. McCoy Creek downstream of Lane Road and Scout Lake

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	4.8	60	linear	moderate	10	1.6	coarse sand	small gravel	10% woody debris/root mats
Right	5.2	65	do.	do.					
Transect 2									
Left	4.1	45	do.	do.	7.5	1.8	small gravel	clay	sand bar
Right	5.2	85	do.	do.					20% woody debris/root mats
Transect 3									
Left	5.8	65	do.	slight	8.1	1.6	coarse sand	clay	15% woody debris/root mats undercut bank
Right	4.7	55	do.	do.					
Transect 4									
Left	3.9	25	do.	none	11.1	1.1	coarse sand	clay	10% woody debris/root mats
Right	4.3	55	do.	slight					

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 6. McCoy Creek upstream of Range Road

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	3.1	50	linear	none	8.5	1.1	coarst sand	small gravel	40% woody debris/root mats; undercut bank
Right	2.5	45	do.	do.					
Transect 2									
Left	2.2	20	concave	do.	6.0	0.9	do.	do.	25% woody debris/root mats; undercut back
Right	2.5	80	linear	do.					
Transect 3									
Left	2.4	45	do.	do.	6.5	0.7	do.	do.	30% woody debris/root mats; undercut bank
Right	2.2	35	do.	do.					
Transect 4									
Left	2.2	40	do.	do.	10.2	0.3	do.	do.	15% woody debris/root mats; undercut bank
Right	3.2	50	do.	do.					

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 7. McCoy Creek downstream of North Range Road

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	4.3	70	linear	sllight	10.6	0.6	coarse sand	small gravel	50% woody debris/root mats; 50% overhanging vegetation; undrcut bank
Right	2.8	65	do.	none					
Transect 2									
Left	1.6	72	do.	do.	11.8	0.8	do.	do.	10% woody debris/root mats; 20% overhanging vegetation; undercut bank
Right	3.6	85	do.	slight					
Transect 3									
Left	3.1	65	do.	none	9.1	0.5	do.	do.	5% woody debris/root mats; 20% overhanging vegetation; undercut bank
Right	4.3	70	concave	slight					
Transect 4									
Left	2.4	30	linear	none	6.2	0.9	do.	do.	10% woody debris/root mats; 10% overhanging vegetation; sand bar
Right	2.9	82	concave	slight					

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 8. South Prong Creek

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	2.8	74	linear	none	7.5	1.2	coarse sand	fine sand	50% woody debris/root mats; 10% overhanging vegetation; undercut bank
Right	1.8	70	do.	do.					
Transect 2									
Left	1.7	77	do.	do.	9.0	1.1	coarse gravel	do.	50% woody debris/root mats; 10% overhanging vegetation; undercut bank; sand bar
Right	2.8	71	do.	do.					
Transect 3									
Left	2.9	45	do.	do.	12.3	1.6	coarse sand	do.	50% woody debris/root mats; 10% overhanging vegetation
Right	1.3	39	do.	do.					
Transect 4									
Left	2.3	64	do.	do.	8.8	1.0	do.	fine gravel	10% overhanging vegetation; undercut bank
Right	1.6	51	do.	do.					

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 9. Marcum Branch

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate: Dominant	Substrate: Sub-dominant	Habitat features
Transect 1									
Left	2.2	70	linear	none	6.2	1.2	coarse sand	small gravel	50% woody debris/root mats; 20% overhanging vegetation; undercut bank
Right	1.6	60	do.	do.					
Transect 2									
Left	1.5	50	do.	do.	7.2	1.2	do.	do.	50% woody debris/root mats; 20% overhanging vegetation; undercut bank
Right	1.8	65	do.	do.					
Transect 3									
Left	1.3	70	do.	do.	5.4	2.3	do.	do.	60% woody debris/root mats; 80% overhanging vegetation
Right	1.8	80	do.	do.					
Transect 4									
Left	1.8	85	do.	do.	6.8	1.0	do.	do.	30% overhanging vegetation; undercut bank
Right	2.0	65	do.	do.					

Appendix A. National Water-Quality Assessment Program habitat characterization data and photographs of sampled stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued
[%, percent; do., ditto]

Site 10. Boggy Gut Creek

Stream bank					Stream bed				
Streambank	Height (feet)	Angle (degrees)	Shape	Erosion	Channel width (feet)	Average water depth (feet)	Substrate		Habitat features
							Dominant	Sub-dominant	
Transect 1									
Left	1.6	65	linear	none	14.1	0.6	cobble - sized bricks	sandl	25% woody debris/root mats; 80% cobble-sized brick; undercut bank
Right	1.9	30	do.	do.					
Transect 2									
Left	3.3	60	do.	do.	17.5	1.4	coarse sand.	gravel	35% woody debris/root mats;
Right	3.4	40	do.	do.					
Transect 3									
Left	2.9	70	do.	do.	15.5	0.8	do.	small gravel.	40% woody debris/root mats;
Right	2.2	80	do.	do.					
Transect 4									
Left	2.5	80	do.	do.	13.2	1.7	do.	do.	15% woody debris/root mats
Right	2.6	65	do.	do.					

Appendix B. Aquatic invertebrate abundance in targeted and multiple habitat samples in surveyed stream reaches, Fort Gordon, Georgia, June 1999 to May 2000

[TH, target habitat sample—semi-qualitative samples collected from snags, woody debris, and submerged riparian vegetation; MH, multi-habitat sample—semi-qualitative samples collected from all available habitat types within the stream except target-habitat sample (TH); —, none collected]

Taxon	Butler Creek tributary		McCoy Creek, downstream of Lane Road		South Prong Creek		Marcum Branch[1/]		Boggy Gut Creek[1/]	
ORDER	Site 4		Site 7		Site 8		Site 9		Site 10	
Family *Genus species*	TH	MH	TH	MH	TH	MH	TH	MH	TH	MH
TUBIFICIDA										
Undetermined										
undetermined	—	—	—	6	—	—	—	2	—	—
AMPHIPODA										
Talitridae										
*Hyalella azteca (*Saussure*)*	—	—	—	—	—	—	—	—	1	—
Hyalella sp.	—	—	—	—	—	—	—	5	—	—
DECAPODA										
Astacidae										
Procambarus sp.	1	—	4	—	—	—	—	2	2	—
ARANEA										
Undetermined										
undetermined	1	—	—	1	1	—	1	—	—	—
EPHEMEROPTERA										
Baetidae										
Pseudocloen propiguum (Walsh)	—	—		1	—	—	—	—	—	—
Pseudocloen sp.	—	—	—	—	—	—	—	12	4	2
Pseudocloeon ephippiatum (Traver)	—	—	—	—	3	—	—	—	—	—
Ephemerellidae										
Eurylophella aestiva (McDunnough)	—	—	—	—	—	—	—	—	—	12
Eurylophella sp.	—	—	—	—	—	—	1	—	6	7
Heptageniidae										
Stenonema sp.	—	—	—	—	9	—	2	—	1	1
Leptophlebiidae										
Paraleptophlebia sp.	—	—	—	—	13	—	—	—	—	—
PLECOPTERA										
Leuctridae										
Leuctra sp.	—	—	—	—	—	—	5	1	—	—
Perlidae										
Perlesta sp.	—	—	—	—	1	—	1	—	1	—
TRICHOPTERA										
Brachycentridae										
Brachycentrus chelatis (Ross)	—	—	—	—	—	—	5	1	—	—
Hydropsychidae										
Hydropsyche depravata Group	1	—	—	—	—	—	—	—	—	—
Hydropsyche elissoma Ross	—	—	—	—	—	—	5	1	—	—
Hydropsychidae sp.	—	1	3	9	—	1	—	—	1	5
Polycentropodidae										
Neureclipsis sp.	—	—	—	—	—	—	—	—	—	1
Psychomyiidae										
Psychomyiidae sp.	—	—	—	—	9	—	—	—	—	—
Rhyacophilidae										
Rhyacophila carolina Banks	—	—	—	—	—	—	—	—	1	—
HEMIPTERA										
Belostomatidae										
Belostoma testaceum (Leidy)	1	—	—	—	—	—	—	—	—	—
Corixidae										
Palmocorixa sp.	—	—	—	—	—	—	—	—	1	—
Trichocorixa calva (Say)	—	—	—	—	—	—	—	—	1	—

Appendix B. Aquatic invertebrate abundance in targeted and multiple habitat samples in surveyed stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued

[TH, target habitat sample—semi-qualitative samples collected from snags, woody debris, and submerged riparian vegetation; MH, multi-habitat sample—semi-qualitative samples collected from all available habitat types within the stream except target-habitat sample (TH); —, none collected]

Taxon	Butler Creek tributary		McCoy Creek, downstream of Lane Road		South Prong Creek		Marcum Branch[1/]		Boggy Gut Creek[1/]	
ORDER	Site 4		Site 7		Site 8		Site 9		Site 10	
Family *Genus species*	TH	MH	TH	MH	TH	MH	TH	MH	TH	MH
HEMIPTERA—CONTINUED										
Gerridae										
Aquarius conformis (Uhler)	—	—	—	1	—	—	1	—	2	—
Gerridae sp.	—	—	—	—	—	—	—	—	—	1
Rheumatobates sp.	—	—	—	—	—	—	—	—	1	—
Trepobates sp.	—	2	—	—	—	—	—	—	—	—
Notonectidae										
Notonecta irrorata Uhler	—	1	—	—	—	—	—	—	—	—
Veliidae										
Microvelia sp.	—	—	—	—	—	—	—	—	1	—
Rhagovelia obesaa	—	4	5	14	—	—	7	—	7	13
MEGALOPTERA										
Corydalidae										
Corydalus cornutus (Linnaeus)	—	—	—	—	1	—	—	—	—	1
ODONATA										
Aeshnidae										
Boyeria vinosa (Say)	1	1	28	10	1	1	1	—	—	—
Calopterygidae										
Calopteryx sp.	—	1	—	3	—	1	—	—	1	11
Coenagrionidae										
Argia fumipennis (Bermeister)	—	—	—	—	—	—	—	—	1	—
Argia sp.	—	—	—	—	—	—	—	—	7	—
Enallagma divagans Selys	—	—	—	—	—	—	—	—	4	—
Enallagma sp.	—	—	—	—	—	—	—	—	1	—
Corduliidae										
Corduliidae sp.	—	—	—	—	—	—	—	—	—	1
Neurocordulia sp.	—	—	—	—	1	—	—	—	—	—
Gomphus sp.	—	—	—	—	1	—	1	—	—	1
Progomphus obscurus (Rambur)	—	—	—	—	—	—	1	—	—	—
Progomphus sp.	—	—	—	—	—	—	1	—	—	—
Libellulidae										
Libellulidae sp.	—	—	—	1	—	1	—	—	—	—
Macromiidae										
Macromiidae sp.	—	—	—	1	—	—	1	1	1	1
COLEOPTERA										
Elmidae										
Ancyronyx variegata (Germar)	—	—	—	—	—	—	—	—	5	3
Stenelmis sp.	—	—	—	—	1	—	3	—	—	—
Gyrinidae										
Dineutus discolor Aube	—	—	—	—	—	—	—	—	—	1
Dineutus sp.	—	5	2	5	2	1	4	1	5	1
Hydrophilidae										
Berosus sp.	—	—	—	—	—	—	—	—	—	2
Sperchopsis tessellata (Ziegler)	—	—	2	1	—	—	—	—	—	—

Appendix B. Aquatic invertebrate abundance in targeted and multiple habitat samples in surveyed stream reaches, Fort Gordon, Georgia, June 1999 to May 2000—Continued

[TH, target habitat sample—semi-qualitative samples collected from snags, woody debris, and submerged riparian vegetation; MH, multi-habitat sample—semi-qualitative samples collected from all available habitat types within the stream except target-habitat sample (TH); —, none collected]

Taxon	Butler Creek tributary		McCoy Creek, downstream of Lane Road		South Prong Creek		Marcum Branch[1/]		Boggy Gut Creek[1/]	
ORDER	Site 4		Site 7		Site 8		Site 9		Site 10	
Family *Genus species*	TH	MH	TH	MH	TH	MH	TH	MH	TH	MH
DIPTERA										
Chironomidae										
Chironomidae sp.	4	3	—	2	14	—	—	10	24	12
Simulidae										
Simulidae sp.	—	—	—	—	—	—	—	—	18	1
Tabanidae										
Chlorotabanus crepuscularis (Bequaert)	—	—	—	—	—	—	—	—	—	1
Tabanus sp.	—	—	—	—	—	—	—	1	—	—
Tipulidae										
Hexatoma sp.	—	—	—	—	—	—	1	—	—	—
Tipula sp.	—	1	—	—	—	—	—	—	—	—

[1/]Denotes streams chosen to represent near-reference conditions.