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Water and Streambed Sediment Quality, and Ecotoxicology of a Stream along the Blue Ridge Parkway, Adjacent to a Closed Landfill, near Roanoke, Virginia: 1999

Water-Resources Investigations Report 03-4116

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

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By Donna Belval Ebner[1], Donald S. Cherry[2], and Rebecca J. Currie[2]

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Prepared in cooperation with
National Park Service

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
Volume		
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)

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

°F = (1.8 x °C) + 32

Horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27). Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).

Abbreviated water-quality units: Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Specific electrical conductance of water is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Water and Streambed Sediment Quality, and Ecotoxicology of a Stream along the Blue Ridge Parkway, Adjacent to a Closed Landfill, near Roanoke, Virginia: 1999

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Abstract

A study was done of the effects of a closed landfill on the quality of water and streambed sediment and the benthic macroinvertebrate community of an unnamed stream and its tributary that flow through Blue Ridge Parkway lands in west-central Virginia. The primary water source for the tributary is a 4-inch polyvinyl chloride (PVC) pipe that protrudes from the slope at the base of the embankment bordering the landfill. An unusual expanse of precipitate was observed in the stream near the PVC pipe. Stream discharge was measured and water and streambed sediment samples were collected at a nearby reference site and at three sites downstream of the landfill in April and September 1999. Water samples were analyzed for major ions, nitrate, total and dissolved metals, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds, including organochlorine pesticides and polychlorinated biphenyls (PCBs). Streambed sediment samples were analyzed for total metals, total organic carbon, percent moisture, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs.

The benthic macroinvertebrate community within the stream channel also was sampled at the four chemical sampling sites and at one additional site in April and September. Each of the five sites was assessed for physical habitat quality. Water collected periodically at the PVC pipe discharge between November 1998 and November 1999 was used to conduct 48-hour acute and 7-day chronic toxicity tests using selected laboratory test organisms. Two 10-day chronic toxicity tests of streambed sediments collected near the discharge pipe also were conducted.

Analyses showed that organic and inorganic constituents in water from beneath the landfill were discharged into the sampled tributary. In April, 79 percent of inorganic constituents detected in water had their highest concentrations at the site closest to the landfill; at the same site, 59 percent of inorganic constituents detected in streambed sediments were at their lowest concentration. The low dissolved-oxygen concentration and relatively low pH in ground water from beneath the landfill probably had a direct effect on the solubility of metals and other constituents, resulting in the high concentration of inorganic constituents in water, low concentration in sediment, and the development of the precipitate. Most constituents in water in April were progressively lower in concentration from the landfill site downstream. The highest concentrations for 59 percent of constituents detected in sediment were at the farthest downstream site, suggesting that the inorganic constituents came out of solution as the stream water was exposed to the atmosphere. In September, 52 percent of inorganic constituents detected in water were at their highest concentrations at the site nearest the landfill. Of inorganic constituents detected in streambed sediments in September, 60 percent were at their highest concentrations near the landfill. A storm that occurred a few days prior to the September sampling probably affected the preceding steady-state conditions and the distribution of constituents in sediment along the stream. Concentrations of many inorganic constituents in water remained elevated at the farthest downstream site in comparison to the reference site in April and Sep-

tember, indicating that concentrations did not return to background concentrations. In April and September, most of the 17 organic compounds detected in water, including volatile organic and semivolatile organic compounds, were collected in samples near the landfill, and most concentrations were below their respective reporting limits. Probably because of their volatility, few organic compounds were detected at sites downstream of that site. A total of 17 discrete organic compounds were detected in sediment samples in either April or September, including trichloroethene and tetrachloroethene along with their degradation products, 1, 1-dichloroethane and 1,2-dichloroethene; and 4, 4' DDT.

All benthic macroinvertebrate community metrics indicated significantly better conditions at the reference site in comparison to the site nearest the landfill. At the reference site and at three other sites, the taxa collected included several macroinvertebrates that would normally be found under good stream-quality conditions; those collected at the site near the landfill comprised primarily very tolerant macroinvertebrates, including snails, oligochaetes, and a pollution-tolerant dipteran.

The reaction of test organisms to samples of the water discharged from the PVC pipe showed acute toxicity in 10 out of 11 independent tests from November 1998 to November 1999. Organism mortality was observed in every acute test at 100-percent sample strength, and a 48-hr LC_{50} (the lethal concentration that causes 50-percent mortality of the test organisms after a defined period of exposure) was exceeded 89 percent of the time. Chronic toxicological impairment was reported for C*eriodaphnia dubia* with survival and reproduction impaired at 50- and 25-percent concentration of the sample water, respectively. No impairment occurred at 12.5-percent concentration. Overall, the three most notable factors indicating stressed and (or) impacted conditions in the stream near the landfill consisted of (1) the layer of fine metal oxide precipitate in the streambed at and below the site nearest the landfill; (2) the significantly depressed numbers of benthic macroinvertebrate fauna, particularly of sensitive or pollution-intolerant groups; and (3) the consistent acute toxicity of water to C*eriodaphnia dubia*.

Introduction

After obtaining its operating permit in 1974, the Roanoke Regional Sanitary Landfill served as the primary landfill for Roanoke City and County, Va., for nearly 20 years, and received a variety of solid wastes, including household and business waste, construction and wood products, and asbestos-contaminated materials. The approximately 100-acre landfill was capped and closed in 1995.

The closed landfill and the Blue Ridge Parkway, a roadway and park administered by the National Park Service (NPS), share a common boundary near the base of a steep, approximately 40-ft-high embankment at the western edge of the landfill. Near this boundary, a small first-order stream ("the sampled tributary") originates at the base of the embankment and flows west through Parkway lands and beneath the Parkway road before merging into the mainstem of an unnamed stream.

The primary source of water to the sampled tributary is a 4-in. polyvinyl chloride (PVC) pipe that protrudes from beneath the landfill at the base of the embankment. Water flows steadily from this pipe into a small pool that is the farthest upstream point of the sampled tributary. The mainstem of the unnamed stream parallels the Parkway road along its western side, partly within NPS lands, and ultimately discharges into the Roanoke River.

In 1995, during routine observations along the Parkway, NPS personnel noted unusual conditions in the sampled tributary relative to similar streams in the area. "Yellowboy," an orange-yellow metal-oxide precipitate, was observed in the pool and streambed for a number of yards rather than the 1 to 3 ft observed in most local streams; also noted were unusual colors of algae, bacteria, and (or) flocculent and, at times, a pungent odor. Researchers from the Virginia Polytechnic Institute and State University (VPI) made preliminary field observations and measurements, and collected water samples from the tributary downstream of the landfill to conduct toxicological tests. Preliminary results of these tests, along with the steady flow of water from the PVC pipe and the unusual appearance of the stream, suggested that leachate from the landfill could be discharging with the ground water into the stream.

The chemical composition of the materials in many landfills is not well known. In Virginia, documentation of waste that was delivered to individual landfills, including chemicals and containers, was not required and enforced until the institution of Solid Waste Management regulations in December 1988 (A. Farahmand, Virginia Department of Environmental Quality, written commun., July

2001). It is possible that landfill leachate is transported with ground water, discharging, and affecting the stream system. This possibility has resulted in a concern for the health of the sampled tributary and the unnamed stream, particularly in lands owned by the NPS and open to the public. There also is concern for the potential effects of the contents of the landfill downstream of the landfill and on the Roanoke River.

In January 1999, NPS and the U.S. Geological Survey (USGS), along with researchers from VPI, entered into a cooperative agreement to investigate the effects of the closed landfill on the water, streambed sediment, and benthic macroinvertebrate community in the first-order tributary where the unusual conditions had been observed.

Purpose and Scope

This report presents the results of a study of the effects of a closed landfill along the Blue Ridge Parkway on the water chemistry, the streambed sediment chemistry, and the benthic macroinvertebrate community of a first-order tributary that originates from beneath the landfill and the unnamed stream into which it flows. Water and streambed sediment samples were collected at four sites on the unnamed stream and the sampled tributary in April and September 1999. Water samples were analyzed for major ions, nitrate, total and dissolved metals, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds, including organochlorine pesticides and polychlorinated biphenyls (PCBs). Streambed sediment samples were analyzed for total metals, total organic carbon, percent moisture, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs.

Field ecotoxicological measurements were made at the four sites sampled for water and streambed sediment and at another site on the unnamed stream downstream of its confluence with the sampled tributary. At each of these five sites, habitat quality was assessed and benthic macroinvertebrates were collected and assessed using the Rapid Bioassessment Protocols (RBPs) of the U.S. Environmental Protection Agency (USEPA) (Plafkin and others, 1989; Barbour and others, 1999). Water samples collected from the 4-in. PVC pipe draining the landfill and sediment samples collected downstream from the pipe from November 1998 to November 1999 were used to test acute and chronic toxicity to laboratory test organisms.

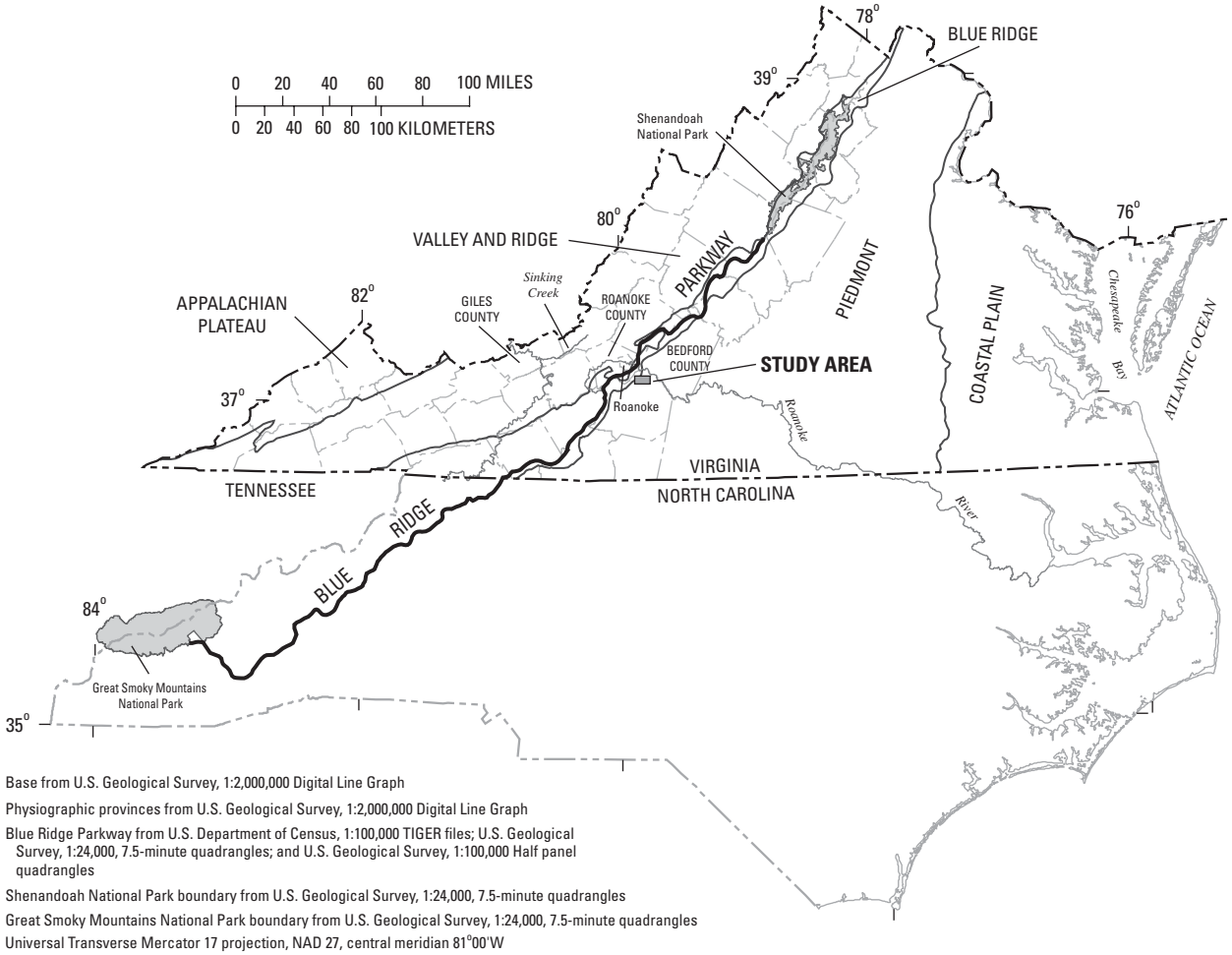
Description of the Study Area

The study area is within the boundaries of the Blue Ridge Parkway, in Roanoke County, near Roanoke, Va. (fig. 1). The Parkway is a 469-mi roadway and park administered by the NPS, extending from Shenandoah National Park in Virginia to Great Smoky Mountains National Park in North Carolina along the ridgeline of the Blue Ridge Mountains. Throughout most of its length, the Parkway boundary extends about 500 yards on either side of the road surface. Some areas, however, are wider to accommodate public rest areas, historical sites, and overlooks.

The study area is in the Blue Ridge Physiographic Province of southwestern Virginia, which has been described as a "rugged region with steep slopes, narrow ridges, broad mountains, and high relief" (Bailey, 1999). The study area is underlain by rocks of Middle Proterozoic age and is near the western edge of the Blue Ridge Thrust Sheet. The underlying geologic units include layered gneiss and granulite. Soils in the area are naturally iron-rich; within a few miles of the closed landfill are units of metasandstone and sandstone that have been mined extensively for iron (Henika, 1997).

Geologic structure, topography, and lithology control the occurrence and flow of ground water in the Blue Ridge Physiographic Province. The rocks underlying the thin soil layer are relatively impermeable except where fractured or weathered. Contact zones between different rock types, however, may accumulate water in some areas. Openings that provide ground-water storage in these rocks usually occur within a few hundred feet of the surface, although a thin layer of saprolite, or weathered rock, also may provide near-surface ground-water storage (State Water Control Board, 1988; David Nelms, U.S. Geological Survey, written commun., 2000). Small streams in this area tend to have stone substrates edged with boulder and rock, resulting in rocky riffle and cascade areas. The cascade areas are interspersed with pools where silt and sand collect.

Ground-water storage is limited in the Blue Ridge, and ground-water recharge and resultant discharge occur at a relatively fast rate. Age-dating studies of ground water in the Blue Ridge Physiographic Province north of the study site have shown that water discharging from springs near the crest of the Blue Ridge Mountains is of nearly modern age, from 0 to 2 years old, under wet and dry conditions. Samples collected from springs at Shenandoah National Park during a drought were only slightly older than those collected during years with nor



Base from U.S. Geological Survey, 1:2,000,000 Digital Line Graph

Physiographic provinces from U.S. Geological Survey, 1:2,000,000 Digital Line Graph

Blue Ridge Parkway from U.S. Department of Census, 1:100,000 TIGER files; U.S. Geological Survey, 1:24,000, 7.5-minute quadrangles; and U.S. Geological Survey, 1:100,000 Half panel quadrangles

Shenandoah National Park boundary from U.S. Geological Survey, 1:24,000, 7.5-minute quadrangles

Great Smoky Mountains National Park boundary from U.S. Geological Survey, 1:24,000, 7.5-minute quadrangles

Universal Transverse Mercator 17 projection, NAD 27, central meridian 81°00'W

Figure 1. Location of study area, the Blue Ridge Parkway, and physiographic provinces of Virginia.

mal rainfall (Nelms and others, 1999; Plummer and others, 1999).

The topography of the closed Roanoke Regional Sanitary Landfill closely resembles that of the naturally broad, flat hills in this area. Near the landfill, the altitude ranges from more than 800 ft along the Roanoke River to near 1,200 ft at the highest point of the landfill. The closed landfill and the Blue Ridge Parkway share a common boundary (fig. 2), near the base of an approximately 40-ft-high embankment at the west edge of the landfill.

The landfill and the basin of the unnamed stream sampled in this study are shown on the Roanoke, Stewartsville, Garden City, and Hardy, Va., USGS 7.5-minute topographic maps. Neither the unnamed stream nor its tributaries are shown on the topographic maps as either perennial or intermittent streams. However, all of these streams were flowing during state-wide drought conditions during the study period and during previous years and were therefore judged to be perennial.

Sampling was conducted downstream of the landfill in a first-order stream that originates at the base of the embankment at the western boundary of the landfill and flows approximately 0.2 mi west on Parkway land and through a culvert beneath the Parkway road. West of the Parkway road, the first-order tributary discharges into the mainstem of an unnamed stream, which flows north another 0.2 mi prior to discharging to the Roanoke River about 0.1 mi upstream (west) of the Blue Ridge Parkway Bridge. Sampling was also conducted on the unnamed stream. The length of the sampled tributary from the landfill boundary through NPS lands to where the unnamed stream discharges to the Roanoke River is approximately 0.4 mi. A reference site was chosen on the unnamed stream upstream of the confluence with the sampled tributary; another reference site, from which water and sediment samples were collected, was on Sinking Creek in Giles County, Va. There are no other tributaries to the unnamed stream downstream of its confluence with the sampled tributary.

The principal source of water to the sampled tributary is a 4-in. polyvinyl chloride (PVC) pipe at the western boundary of the landfill that protrudes from beneath the landfill at the base of the embankment (fig. 3). The water from the 4-in. pipe flows directly into a small pool from which the sampled tributary originates. When asked about the pipe in 2000, landfill personnel recalled that a series of "spring boxes" had been produced at the periphery of the landfill when it was first constructed to provide outlets for known springs in the area (Katherine Glass, Virginia Department of Environmental Quality, personal commun., 2000). This 4-in. PVC pipe is one of several outlets subsequently found by Virginia Department of Environmental Quality (DEQ) personnel along the perimeter of the landfill. Other sources of water to the sampled tributary include intermittent ground-water seeps along the western boundary of the landfill embankment and ground water discharging from stream banks. In addition, in periods of high precipitation, excess water from a sedimentation pond near the western boundary of the landfill is channeled over the embankment via an overflow pipe to an approximately 1-ft-diameter galvanized tin pipe from which the water flows into the pool and the channel of the sampled tributary.

Background Information

Wastes in landfills undergo physical changes such as compaction and fragmentation, and chemical changes such as microbially mediated degradation. The rate of degradation of landfill waste is controlled by its composition, degree of compaction, and water content, and by the conditions within the landfill, such as availability of oxygen, internal temperature, and inhibitory substances such as bactericidal chemicals. In sanitary landfills, where wastes are compacted and covered with soil, chemical oxidation and the action of aerobic microbes quickly deplete oxygen. As oxygen availability decreases and the environment within the landfill becomes anaerobic, the rate of waste degradation also decreases.

By-products of the early stage of anaerobic degradation in a landfill include carbon dioxide and organic acids, substances that decrease pH and thereby promote dissolution of many inorganic materials. At this stage, landfill conditions are characterized by low pH (4.0 to 5.0 units) and high specific conductance, high metals content, and high chemical-oxygen demand. In the later stage of anaerobic degradation, methanogenic bacteria produce methane by utilizing carbon dioxide and hydrogen ions, resulting in an increased pH (7.0 to 8.0 units). At this stage, chemical-oxygen demand and specific conductance are moderate (Ferrell and Smith, 1995). At any one time, wastes in various parts of a landfill can be in different stages of decomposition.

Leachate, the liquid produced by solid waste in landfills, is generated by percolation of water through the contents of the landfill, and its chemical characteristics parallel the stage of decomposition of the landfill. Leachate formed in the early anaerobic stage is characterized by a low pH, high specific conductance, and high concentrations of organic compounds and dissolved metals; the later anaerobic stage also has a low pH, high

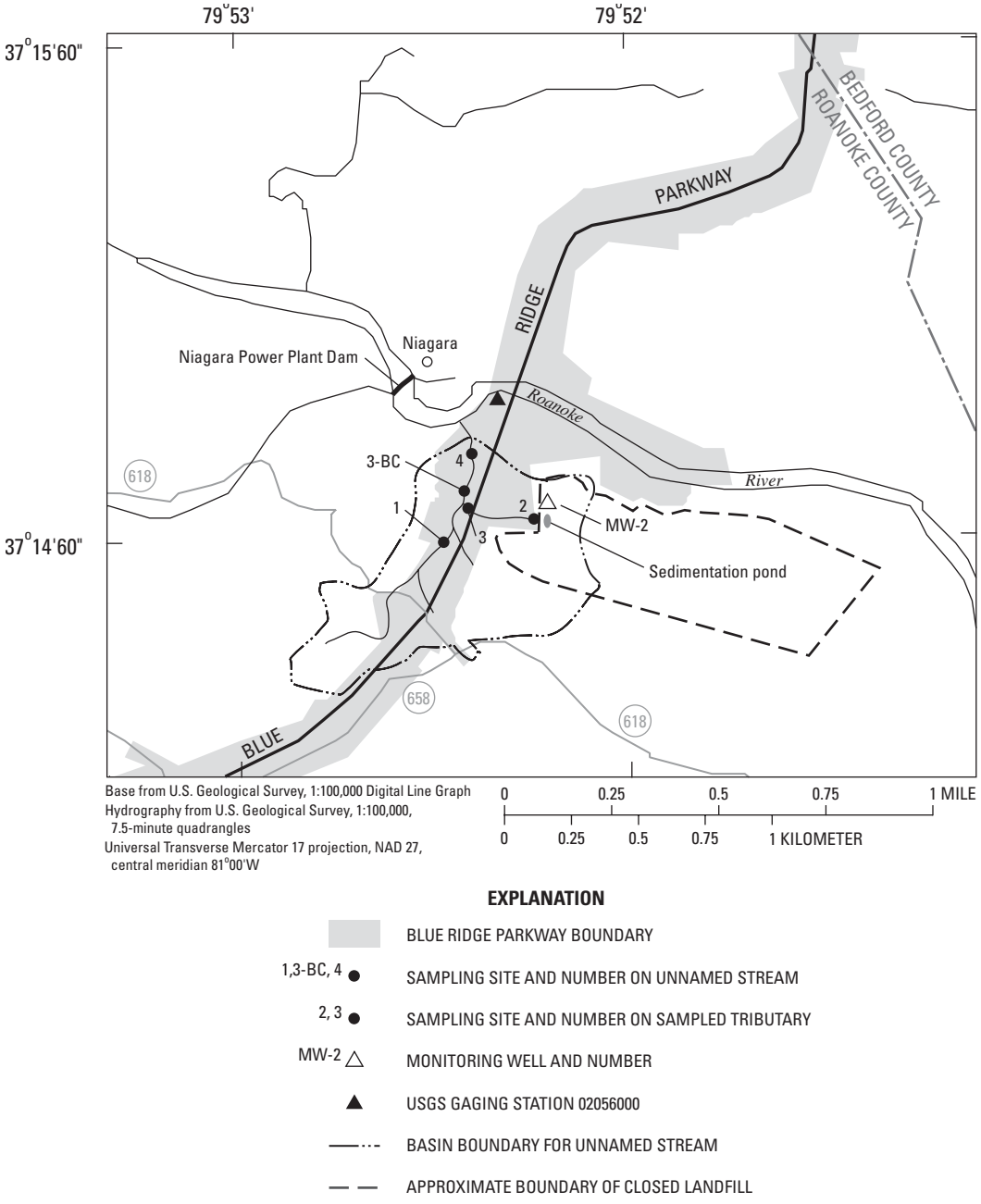


Figure 2. Sampling sites near Blue Ridge Parkway and a closed landfill, Roanoke County, Virginia.

Figure 3. Pool at base of closed landfill, at origin of sampled tributary (site 2), showing 4-inch polyvinyl chloride (PVC) pipe and overflow pipe (A), and the sampled tributary, looking downstream from site 2, facing west (B), near Roanoke, Virginia.

organic acid concentration, and high specific conductance, but has lower concentrations of metals (Ferrell and Smith, 1995).

In this area of the Blue Ridge, soils are naturally iron-rich. When iron-rich, low-oxygen ground water comes into contact with oxygen at land surface, iron and other metal constituents oxidize and precipitate out into a receiving stream, producing yellowboy. Yellowboy is a general term that may include not only the metal oxide precipitate (ferric hydroxide, for example), but also bacteria, algae, and (or) other organic matter, which combine to create the yellowish-red flocculent in the stream.

Yellowboy is found in many areas of the United States where low-oxygen, metal-rich ground water is discharged to land surface, and commonly occurs in this area of the Blue Ridge. Beginning in 1995, however, yellowboy was observed frequently in the pool and streambed near the landfill for a number of yards rather than the 1 to 3 ft observed in most local streams. Unusual colors and forms of sheathed bacteria were observed in the pool, including a genus of bacteria (*Sphaerotilis*) associated with waters of high organic content. These bacteria commonly create problems at wastewater treatment plants by impeding water flow in discharge canals.

Previous Investigations

Waste was no longer accepted at the landfill beginning May 1994, and capping and closure were completed in January 1995. In accordance with requirements of the DEQ Department of Waste Management, air vents and ground-water monitoring wells were installed at the landfill to monitor air and water quality. Currently (2003), an environmental contractor samples the monitoring wells once every six months, and air quality is monitored more frequently. Previous investigators analyzed gas emissions from the landfill (Marshall Miller and Associates, 1995, 1996) and assessed potential hazards associated with soils and facilities areas at the landfill (Professional Service Industries, Inc., 1991).

Results of ground-water monitoring showed inorganic and organic constituents in downgradient wells, including MW-2, the monitoring well nearest to the sampled tributary (Virginia Department of Environmental Quality, unpub. data, 2000) (fig. 2). Constituents frequently detected in samples collected from MW-2 between May 1996 through May 2000 include the metals cadmium, chromium, mercury, and zinc; and organic compounds benzene, delta-BHC, chloroethane, 2,4-dichlorophenoxyacetic acid, *p*-dichlorobenzene, 1,1-dichloroethane, *cis*-1,2-dichloroethene, methyl chloride, methylene chloride, tetrachloroethene, trichloroethene, vinyl chloride, and *o*-xylene. Of these constituents, the laboratory and industrial compounds methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride were detected at concentrations exceeding the USEPA maximum contaminant level for drinking water in all samples collected. Benzene concentrations exceeded the USEPA maximum contaminant level for drinking water in all but the May 2000 sample.

The potential effects of the landfill on the water resources of Blue Ridge Parkway lands were not investigated until 1996, when a preliminary study was completed for the NPS by VPI researchers (Cherry and Currie, 1996). As part of this reconnaissance investigation, general water chemistry and trace-element concentrations were evaluated, and possible toxicity of the water from the unnamed stream was investigated. Results included a 45-percent mortality of a water flea (*Ceriodaphnia dubia*) exposed to water samples collected from the stream and significant chronic reproductive impairment to the water flea *Daphnia magna,* which was exposed to streambed sediment samples from the same area. Concentrations of zinc in bed sediments of the unnamed stream were elevated relative to those in sediments from a background site. Findings from this study indicated the need for further investigation of the potential effects of the closed landfill on the water resources of Blue Ridge Parkway lands and adjoining lands (Cherry and Currie, 1996).

Numerous studies have described the chemical characteristics of landfill leachates, including nutrient content, organic and inorganic composition, and microbiology, but relatively few studies have characterized leachate toxicity (Cameron and Koch, 1980; Plotkin and Ram, 1984). Cameron and Koch (1980) reviewed landfill toxicity data obtained from bioassays utilizing rainbow trout (*Salmo gairdneri,* or *Oncorhynchus mykiss*) and concluded that landfill leachates usually are highly toxic to this species. A specific conclusion was that leachates are highly toxic within the confines of landfills and usually remain so at the point of discharge from the landfill despite dilution that might occur prior to that point from surface runoff and ground water. Plotkin and Ram (1984) tested the toxicity of a sanitary landfill leachate and found the leachate to be highly toxic to *Photobacterium phosphorium*, moderately toxic to *Daphnia magna*, and slightly toxic to *Pimephales promelas* (fathead minnow). *Selenastrum capricornutum* (a freshwater alga) growth was inhibited at exposure to a solution of 10-percent leachate, but cells recovered after centrifuga-

tion and reinoculation into algal nutrient medium (Plotkin and Ram, 1984).

Acknowledgments

In this effort, technical assistance was provided by Tom Davis and Bambi Teague, NPS. The authors also acknowledge Richard J. Ahlin and John M. Gearheart, USGS, for their experienced and focused sampling efforts. Mitchell Harris, Terrence Messinger, and Marty Gurtz are thanked for their technical reviews of this report.

Study Design and Methods

This study was divided into two components: the first component consisted of analysis of water and streambed sediment samples and measurements of stream discharge at each of four sites on the sampled tributary and the unnamed stream (sites 1, 2, 3, and 4). Water samples were analyzed for major ions, nitrate, total and dissolved metals, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds, including organochlorine pesticides and polychlorinated biphenyls (PCBs). Streambed sediment samples were analyzed for total metals, total organic carbon, percent moisture, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs. Ground-water-quality data that had been provided to the DEQ Waste Management Division, and which showed the presence of inorganic and organic constituents in monitoring wells near the western boundary of the landfill, were used to determine potential groups of compounds for analysis.

Laboratory analyses for both water and streambed sediment samples were performed by Quanterra Environmental Services, Denver, Co. All containers for shipping sediment or water samples to the laboratory were washed, rinsed, and quality-assured by the contract laboratory, and preservatives were added prior to being sent to the USGS Virginia district office in Richmond, Va. The prepared containers were delivered to the USGS office within guidelines of chain-of-custody procedures.

Analytical results were provided to the investigators in a hard-copy report, which included a discussion of any anomalies observed during the analysis, a tabulation of analyses, a summary of all quality-control samples associated with the field samples, and a raw data set suitable for independent validation.

The second component of the study consisted of biological and toxicological analyses at each of the four sites sampled for water and streambed sediment, and benthic macroinvertebrate sampling at these four sites and one additional site on the unnamed stream. These analyses included (1) an assessment of stream habitat and measurements of the composition of the benthic macroinvertebrate community using the Rapid Bioassessment Protocols (RBPs) of the USEPA (Plafkin and others, 1989; Barbour and others, 1999) and (2) tests of acute and chronic toxicity. Toxicity tests quantitatively measure the survival or reproductive rate of test organisms in a particular environmental medium. Sediment toxicity testing was performed on samples collected at sites 1, 2, 3, and 4. In addition, water column toxicity testing was performed from samples collected from the PVC pipe draining the landfill at site 2. Both 48-hr acute and 7-day chronic toxicity tests of water collected from the PVC pipe were performed using selected laboratory test organisms, as were the two 10-day chronic toxicity tests of streambed sediments.

Sampling had been planned for two seasons, during what were anticipated to be periods of high base-flow (February, March or April) and low base-flow (July, August, or September) conditions. Prior to all but one sampling event, no substantial rainfall had occurred for several weeks. In September 1999, a storm occurred two days prior to sampling; however, near-base-flow conditions were re-established prior to sample collection on September 8. Water, streambed sediment, and benthic macroinvertebrate samples collected in April and September 1999 thus were considered to be under steady-state flow conditions.

Site Selection

Sampling sites for chemical and biological analyses were selected on the basis of their location within the watershed with respect to water sources to the unnamed stream, and by the appropriateness of the site for either water-and-sediment chemistry or biological sampling (fig. 2, table 1). The four sites that were selected included a reference site along the mainstem of the unnamed stream (site 1); two sites along a first-order tributary to the unnamed stream (the "sampled tributary"), one directly downstream of the landfill (site 2) and the other downstream of the Blue Ridge Parkway (site 3); and a site downstream of the confluence of the unnamed stream and the sampled tributary, the site closest to the Roanoke River (site 4). Benthic macroinvertebrate samples were collected at these four sites and at another site (site 3-BC, "below confluence") that was chosen to provide ecological information downstream

Table 1. Sites sampled for the study of an unnamed stream and its tributary near the Blue Ridge Parkway, Roanoke County, Virginia

[See fig, 2 for site locations; n.a., not applicable]

Site	Station name and location	USGS station number	Site description	Sample type collected		
				Water	Streambed sediment	Benthic macro-invertebrates
Site 1	Roanoke River tributary 1 below Rt. 618 at Niagara, Va.	0205599710	Reference site on unnamed stream, upstream of confluence with sampled tributary	X	X	X
Site 2	Roanoke River tributary 1 to tributary 1 above Parkway at Niagara, Va.	0205599730	Sampled tributary, at outflow pipe from closed landfill	X	X	X
Site 3	Roanoke River tributary 1 to tributary 1 at Niagara, Va.	0205599740	Sampled tributary, west of Blue Ridge Parkway and upstream of confluence with unnamed stream	X	X	X
Site 3-BC	Roanoke River tributary 1 below confluence with tributary 1 below Rt 618 at Niagara, Va.	n.a.	Unnamed stream, downstream of confluence with sampled tributary	n.a.	n.a.	X
Site 4	Roanoke River tributary 1 at mouth at Niagara, Va.	0205599760	Unnamed stream at farthest downstream point, approaching Roanoke River	X	X	X
Sinking Creek	Sinking Creek reference site	n.a.	Reference site, adjacent to Route 42 near Route 460, near Newport, Va.	X	X	X

from the confluence of the unnamed stream and the sampled tributary. The unnamed stream is a second-order stream throughout its sampled length, from the reference site (site 1) to where it discharges into the Roanoke River.

All samples for a sampling event were collected on the same day. Samples were collected beginning at the site farthest downstream (site 4) and working upstream (3 or 1, then 2) to prevent streambed disturbance or contamination from upstream. At each site, water samples were collected first, while field measurements were made and discharge was measured; then streambed sediment samples were collected; benthic macroinvertebrates were collected last.

A site on Sinking Creek was used as an independent reference site for the purpose of comparing the growth and toxicity of benthic macroinvertebrates from this study with other benthic macroinvertebrate data sets. Sinking Creek is in the rural area of Giles County, Va. (fig. 1), and has been used for the past 10 years by the ecotoxicology laboratory at VPI to provide water and streambed sediments for benthic macroinvertebrate studies. Water and streambed sediment samples obtained there have produced little or no deleterious effects on benthic macroinvertebrates in toxicity tests. In addition, Sinking Creek water was used as a second water source for the cultivation of test organisms and as an additional reference site for all toxicity tests in this study.

Water Chemistry

Samples were collected by USGS personnel using preparation, sampling, processing, and shipping methods as documented in Wilde and others (1997, 1998, 1999). All streams from which water samples were collected were small enough to assume that they were well mixed so that depth- and width-integrated samples were unnecessary. Water samples were analyzed for major ions, total and dissolved metals, nitrate, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs.

Because the water in a stream moves rapidly relative to movement of sediment and the biota, the stream sample provides a single, instantaneous view of the conditions and chemical composition of the stream at the time

of sampling. The instantaneous data have limited applicability, however, because stream chemistry can be affected by many variables, including the prevailing weather, seasonal changes, ambient temperature, any effects of recent precipitation, the preceding and current streamflow conditions, the geology of the immediate area, and chemical and biologic processes in the stream. Repeated field and laboratory analyses may be able to account for changes in conditions affecting stream chemistry over time. Because this study was limited to two sampling events, however, any changes noted in seasonal and temporal data may not constitute a trend.

Stream discharge was measured near the four water-chemistry sites to determine the amount and relative location of ground-water discharge and surface water inflow to the stream. Discharge was measured using a Price pygmy flow meter. Established streamflow measurement procedures for small, rocky streams were used (Rantz and others, 1982). Discharge was measured within 20 ft of each sampling site. Air and water temperature, dissolved oxygen, pH, and specific conductance were measured in the center-of-flow of the stream at each site. A Yellow Springs Instruments (YSI) multiparameter meter was used to make field measurements.

Water samples analyzed for major ions, total metals, nitrate, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds were collected directly into laboratory-prepared sample bottles. Samples analyzed for total organic carbon were collected into baked amber glass bottles and preserved with sulfuric acid to a pH less than 2. Samples for semivolatile organic compounds, including pesticides and PCBs, were collected into baked amber glass bottles. Samples for volatile organic compounds (VOCs) were collected in sets of three 40-mL vials and preserved with hydrochloric acid.

Samples analyzed for total metals were collected into acid-rinsed polyethylene bottles. Water from which "dissolved" (filtered) metals were to be analyzed was collected from the stream into an acid-rinsed Teflon holding bottle and filtered from the holding bottle into acid-rinsed polyethylene bottles. A single-use 0.45-µm-pore-size capsule filter was used to filter the sample. Both total and dissolved metals were preserved with nitric acid to a pH less than 2.

Filtration into sample bottles was completed as soon as possible after sample collection, usually within 15 minutes. All filled sample bottles were chilled to 4°C immediately upon completion of processing. Prior to overnight shipment to the laboratory, samples were repacked in fresh ice and sealed.

Streambed Sediment Chemistry

Sediment is fragmental material derived primarily from the disintegration of rocks from the earth's crust and can range widely in terms of particle size, shape, specific gravity, and mineral composition (Edwards and Glysson, 1999). Within a stream, sediment is a major repository for the more persistent chemicals, including some pesticides and PCBs, which may be introduced into surface waters (Ingersoll and others, 1995). Streambed samples were collected from a range of depositional areas at each site, including pools, along stream margins, and in riffle areas. Areas where fine-grained streambed sediment was deposited were preferentially sampled over areas of coarse sediment; constituents adsorbed onto sediments tend to be concentrated in the finer sediment because of the larger surface area. Care was taken to disturb the stream as little as possible to minimize effects on stream chemistry and biological conditions immediately downstream. Because the streams were relatively free of leaves and other organic matter, sieving of the sediment was not necessary.

Although fine-grained areas were targeted, the streambed sediment at sites 1, 3, and 4 was limited to silt and sand collected from small pools in the sampling area, and some larger grained sediments also were included in the samples. In contrast, at site 2, the streambed sediment was several inches of a silt/mud/precipitate mixture, which was easily suspended in water. As samples were collected, the sediment/precipitate was allowed to settle as much as possible before the water was decanted and the sediment sample collected. The final sample resembled a silty slurry.

Streambed sediment samples were collected at each stream site using Teflon scoops. Samples were composited in a large, clean glass bowl, homogenized, and distributed into clean wide-mouthed containers for analysis by the laboratory, and into clean plastic bags for toxicity testing by VPI. Samples analyzed for total organic carbon were preserved with sodium bisulfite. All streambed sediment samples were chilled to 4°C. Samples were analyzed for total metals, total organic carbon, percent moisture, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs. VPI researchers used subsamples of the streambed sediments to analyze toxicity of the sediment to laboratory organisms.

Ecological Sampling and Toxicity Testing

Field and laboratory ecotoxicological measurements, including routine water chemistry and field measurements, a volumetric estimate of flow, an assessment of habitat quality, and collections of benthic macroinvertebrates were done at sites within the sampled tributary and unnamed stream. Several 48-hr acute tests, one 7-day chronic test of the leachate to *Ceriodaphnia dubia* (a water flea), and two 10-day chronic sediment toxicity tests were conducted with *Chironomus tentans* (a midge) and *Daphnia magna* (a water flea). Water samples for ecotoxicological analyses were collected periodically from the PVC pipe at site 2 between November 1998 and November 1999 (table 2). These samples provided background field measurements and were used to determine if toxicity from the water occurred intermittently or consistently.

Benthic Macroinvertebrates

The use of benthic macroinvertebrates as biological indicators is the cornerstone of many water-quality assessments. The importance of invertebrates in biological monitoring is demonstrated by the development of the USEPA RBPs by Plafkin and others (1989), and Barbour and others (1999), and by the Ohio Environmental Protection Agency's (OEPA) development of the Invertebrate Community Index (Ohio Environmental Protection Agency, 1988, 1989).

VPI researchers collected benthic macroinvertebrates in April and September 1999 at sites 1, 2, 3, 4, and 3-BC, using a combination of the methods described in the USEPA RBPs (Plafkin and others, 1989; Barbour and others, 1999) and OEPA (1988, 1989) guidelines, with some modifications. Organisms were collected from the natural substrate using D-frame nets with 800-µm mesh and forceps to remove organisms from the net. Benthic macroinvertebrates were collected for a minimum of 20 minutes per sample, and collection continued until no new taxa were observed in gross examination. Sampling effort is assumed to be consistent among sites and between sampling teams. Four replicates were collected at each site; each replicate sample was a composite that included, whenever possible, a pool, riffle, margin, and run area. An attempt was made to sample similar habitats at each site. Macroinvertebrates on rocks and pebbles as well as in sand, silt, and leaf packs were collected. Samples were preserved initially with 70-percent ethanol in the field and transported to the laboratory at VPI for sort

Table 2. Schedule of field measurements made at all sites, and benthic macroinvertebrate, water, and streambed samples collected for ecotoxicological assessment at site 2, near the Blue Ridge Parkway, Roanoke, Virginia

[–, not collected or measured; *, indicates collection date of water and sediment samples]

Date	Field measurements	Benthic macro-invertebrates	Water		Streambed sediment
			48-hour acute toxicity	7-day chronic toxicity (survival and reproduction)	10-day chronic toxicity
11/29/98	X	–	X	–	–
12/9/98	X	–	–	–	–
1/26/99	–	–	X	–	–
2/18/99	X	–	X	–	–
2/19/99	X	–	–	–	–
3/12/99	X	–	X	–	–
*4/26/99	X	X	–	–	X
6/18/99	X	–	X	–	–
7/24/99	X	–	X	–	–
7/30/99	X	–	X	–	–
7/31/99	–	–	–	X	–
8/2/99	X	–	–	–	–
8/26/99	X	–	X	–	–
9/6/99	X	–	X	–	–
*9/8/99	–	X	–	–	X
10/14/99	X	–	X	–	–
11/28/99	X	–	X	–	–

ing and identification. In the laboratory, samples were washed with water and stored in 70-percent ethanol. Prior to identification and enumeration, samples were sieved through a 500-µm mesh and rinsed. Macroinvertebrates were identified to the lowest practical taxonomic level following taxonomic keys by Pennak (1989), Merritt and Cummins (1996), and Wiggins (1996). No subsampling was necessary due to the small number of organisms obtained.

On the basis of the organisms identified, nine benthic macroinvertebrate community metrics were evaluated statistically, with four replicates taken per station. The metrics evaluated were total abundance, taxa richness, caddisfly abundance, stonefly abundance, mayfly abundance, percent mayfly abundance, Ephemeroptera/Plecoptera/Trichoptera (EPT) abundance, percent EPT abundance, and EPT richness.

Statistical analysis of the summary metrics for benthic macroinvertebrates was performed using the Statistical Analysis System (SAS) developed by the Statistical Analysis System Institute, Inc. (1996). Data were analyzed for normality using the Shapiro-Wilk Test for normality (α=0.05). Data that were distributed significantly differently than normal were transformed to meet assumptions of normality. The data were square-root transformed with percentages using an arcsine square root transformation. A parametric analysis of variance (ANOVA, α=0.05) was conducted on normally distributed data, while a nonparametric ANOVA (NPAR1Way (Kruskal-Wallis), α=0.05) was used to analyze data that did not meet the assumption of normality either before or after data transformation (U.S. Environmental Protection Agency, 1993; Hollander and Wolfe, 1973). A Least Squares Difference (LSD) multiple comparison (α=0.05) was conducted on ranked data to determine whether there were statistically significant differences among the four stations. Raw benthic macroinvertebrate identification data are found in Appendixes 5 and 6.

Habitat Assessment

The USEPA's RBPs were used to conduct habitat assessments at the five sites sampled for benthic macroinvertebrates and also at Sinking Creek, the reference site, prior to field data collection. Habitat is a major determinant of aquatic community potential, with both the quality and quantity of available habitat affecting the structure and composition of resident biological communities (Plafkin and others, 1989). The RBPs assess differences in habitat quality that are attributed to bank erosion and channel sedimentation, processes that indirectly influence water quality.

Habitat is assessed by means of nine metrics within three categories–substrate and instream cover, channel morphology, and riparian and bank structure (table 3). The habitat metrics, which are evaluated on the basis of habitat use by aquatic life, are used to identify potential sources of limitation to the aquatic biota. Sites are rated from Excellent to Poor, depending upon the scores for each metric (Plafkin and others, 1989).

Table 3. Habitat assessment metrics and possible rating for each metric (Plafkin and others, 1989; Barbour and others, 1999)

Habitat Metric	Rating			
	Poor	Fair	Good	Excellent
Primary-Substrate and Instream Cover				
1. Bottom substrate and available cover	0-5	6-10	11-15	16-20
2. Embeddedness	0-5	6-11	11-15	16-20
3. Flow/velocity	0-5	6-12	11-16	16-20
Secondary-Channel Morphology				
4. Channel alteration	0-3	4-7	8-11	12-15
5. Bottom scouring and deposition	0-3	4-7	8-11	12-15
6. Pool/riffle, run/bend ratio	0-3	4-7	8-11	12-15
Tertiary-Riparian and Bank Structure				
7. Bank stability	0-2	3-5	6-8	9-10
8. Bank vegetation	0-2	3-5	6-8	9-10
9. Streamside cover	0-2	3-5	6-8	9-10
Minimum to Maximum Possible Score	0-30	39-66	75-102	111-135

Field Measurements

Field measurements were made under different flow conditions at site 2 between November 1998 and November 1999 during trips to collect water for use in acute and chronic toxicity testing. Field measurements also were made prior to each biological sampling event. Those measurements included temperature, specific conductance, DO, pH, and alkalinity. DO was measured using a YSI Model 55 oxygen meter; specific conductance and temperature were measured using an Orion Model 122 specific conductance meter. A Fisher Scientific Accumet 1001 with a combination electrode was used to measure pH. The three meters were calibrated and used following standard operating procedures provided by the manufacturer. Alkalinity was determined at the laboratory with a standard titration method to pH 4.5, using bromocresol green as the indicator.

Toxicity Testing

Laboratory toxicity testing consisted of acute and chronic water column and chronic sediment toxicity tests. Laboratory toxicity testing has been used extensively for the past 50 years, and specific guidelines and protocols have been developed to provide reliable and accurate data (U.S. Environmental Protection Agency, 1993, 1994; American Society for Testing and Materials, 1995).

Water Column Acute and Chronic

The objective of acute toxicity testing is to determine the concentration of a test material (for example, a chemical or effluent) or the value of a chemical measurement (for example, temperature or pH) that produces a deleterious effect on test organisms during a short-term exposure under laboratory conditions (Parrish, 1985). Acute toxicity test results are reported in terms of $LC_{50,}$ the concentration at which 50 percent of the test organisms die during a defined exposure period. Acute toxicity tests with *C. dubia* were analyzed by the Connecticut Department of Environmental Protection's CT-TOX program to determine LC_{50} values using the Spearman-Karber method (Connecticut Department of Environmental Protection, 1990).

Acute water column testing was conducted with *C. dubia,* less than 24 hrs old, following USEPA (1993) protocols. Five ceriodaphnids were used per replicate with four replicates per concentration. Testing was done with a control of moderately hard synthetic water (EPA^{100}) and five concentrations based on a 0.5 serial dilution starting at 100 percent. Survivorship was the endpoint value determined after 48 hours. Water samples for use in toxicity testing were collected in November and December 1998 and in January, February, March, April, June, July, August, September, October, and November 1999. All samples were collected from the PVC pipe draining the landfill at site 2.

Chronic toxicity tests are used to determine whether impairment of test organism growth and reproduction occurs in waters or sediments that do not cause acute toxicity. Such impairment would indicate disruption of ecological integrity and the subsequent loss of invertebrate community populations from impacted fresh waters (Nebeker and others, 1984). In this report, chronic toxicity endpoint values for water samples are survival, expressed as percent survival of test organisms, and reproduction, expressed as mean number of young (neonates) produced.

Chronic water column testing also used *C. dubia*, less than 24 hrs old, following USEPA (1994) protocols. Moderately hard synthetic water (EPA^{100}) was used as test diluent. Testing consisted of a control with five concentrations of leachate based on a 0.5 serial dilution starting at 100 percent. Chronic toxicity tests were conducted for 7 days or until 60 percent of the control organisms had their third brood of offspring.

Sediment

Nebeker and others (1984) first described general methods for conducting toxicity tests with sediments using invertebrates. The water flea *Daphnia magna* and the midge *Chironomus tentans* are the most frequently used test organisms to evaluate toxicity of freshwater sediments (Doi, 1998). *Daphnia* generally have been shown to be the most sensitive organisms used for sediment tests, especially to metals, while midges maintain intimate contact with and burrow into the sediment and may be sensitive to toxic organic chemicals (Nebeker and others, 1984). Standard methods for conducting toxicity tests using both *D. magna* and *C. tentans* have been developed (American Society of Testing and Materials, 1995; Environmental Protection Agency, 1994).

Streambed sediment samples were collected from depositional areas at each site; approximately 500 g of sediment from each site were placed into a sterile plastic bag that was returned to the VPI laboratory on ice, and then refrigerated at 4°C for up to two weeks before testing. Sediment toxicity tests using whole organisms were conducted with *D. magna* and *C. tentans*, with survival,

growth, and reproduction as endpoints. Testing protocols followed those described by the American Society of Testing and Materials (1995) and USEPA (1994).

Testing with *D. magna* consisted of the placement of one daphnid, 5 days old, into a 50-ml beaker with approximately 10 ml (by volume) of sediment and 30 ml of site water. Site water was used in the sediment toxicity tests instead of reference water to simulate environmental conditions and to prevent dilution of sediment toxicity by the reference water. The overlaying water was renewed each day by siphoning and refilling. *Daphnia* were fed, observed, and checked for survival and reproduction daily. Eight replicates were used per site, and an additional control was added with Sinking Creek water and sediments.

Chironomus testing was conducted by placing ten 8-day old midge larvae into a 600-ml glass beaker with 100 g (by weight) of sediment and 400 ml of overlaying site water, with five replicates per site. Overlaying water in the beakers was renewed each day. Midges were also fed and observed over 10 days for survival and growth. All sediment tests required aeration due to the anaerobic conditions of some of the sediments.

Sediment toxicity test endpoint values included survival, reproduction, and growth, expressed as mean weight. Sediment toxicity test results were analyzed using recommended USEPA guidelines (1994). All survival, reproduction, and growth data were tested for normality (Shapiro-Wilk test for normality, α=0.05) and then analyzed using the appropriate parametric or nonparametric statistical tests (one-way parametric ANOVA or NPAR1Way ANOVA, α=0.05).

Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) measures were implemented to ensure that data were obtained using appropriate methods and were of known precision, accuracy, and completeness. QA measures included using established procedures for the preparation of field equipment and collection and preservation of samples; adhering to consistent individual sampling responsibilities; using procedures that minimize cross-contamination of samples; and collecting QC samples for testing field and laboratory methodologies. These QA methods were determined based on guidelines provided in Averett and Schroeder (1994) and Shampine and others (1992).

For water and sediment chemistry sampling, equipment blanks were used to document any systematic contamination from cleaning and preparation of the equipment, as well as from processing of the samples in the field. Similarly, a method blank run by the laboratory for each analytical method used documented any systematic contamination of the laboratory equipment.

QC samples collected along with water (environmental) samples included an equipment blank prepared at the beginning of each day, a trip blank, a replicate sample, and a matrix spike and matrix spike duplicate. Replicate samples were collected to ensure analytical and field reproducibility. The trip blank was used to document any volatile organic compounds that may have contaminated similarly prepared bottles or permeated the sample bottles along the sequence of sample shipment. The matrix spike and spike duplicate samples were collected as a second and third sample at one site and injected with a known solution to determine recovery to qualify the performance of the analytical equipment for these individual samples and to measure any potential interference by the sample water (the matrix) on the sample.

QC samples collected along with streambed sediment samples included a replicate sample at one station and two replicate samples collected at a different station: one used as a matrix spike and the other used as a matrix spike duplicate. The laboratory ran a method blank for each analytical method used. Chain-of-custody procedures were followed throughout the study for sample collection, sample shipping and receiving, analysis, and delivery of final data. Results of analyses of QA samples are in Appendixes 1-4.

Standard benthic macroinvertebrate QA/QC procedures were followed (American Society of Testing and Materials, 1995; American Public Health Asssociation, the American Water Works Association, and the Water Environment Federation, 1998; USEPA, 1994). All samples were labeled and preserved in 70-percent ethanol and returned to the laboratory at VPI for sorting and identification by an analyst using a dissection microscope (Zeiss, Stemi SV11) and the appropriate taxonomic keys. Sample check-in sheets and sample chain-of-custody records are on file at VPI. Ten percent of the sorted samples were re-examined by laboratory personnel. Any additional organisms found were enumerated, identified, and added to the original sample vial. If the difference from the original sample was fewer than 10 percent in samples with more than 100 organisms, or fewer than 10 organisms in smaller samples, the sample was accepted (Barbour and others, 1999). Raw benthic macroinvertebrate identification data are in Appendixes 5 and 6.

Standard QA/QC procedures were followed with regard to handling sediment samples, organism cultur-

ing, and testing of the effects of sediment on laboratory organisms. In order to ensure organism health throughout the period of toxicity testing, acute and chronic reference tests were conducted monthly and quarterly; data were reported to DEQ on a quarterly basis and kept on file in the VPI laboratory. Chain-of-custody records, laboratory check-in records and test data records, including all end-point data and water chemistry, are on file at VPI.

Water and Streambed Sediment Quality

Although sampling for this study was planned for periods of high and low base-flow conditions, 1998 and 1999 were extremely dry years, with little of the higher seasonal precipitation expected for winter months. Sampling in both April and September 1999, accordingly, was conducted during low base-flow conditions. Record low streamflows had been recorded in most parts of Virginia throughout the winter of 1998 and into the spring and summer of 1999, and little significant rainfall occurred until September 1999 (White and others, 2000).

Water

Even under low streamflow conditions, water was observed to flow from the 4-in. PVC pipe at the base of the landfill, and in the sampled tributary and the unnamed stream throughout the study period. On September 5 and 6, 1999, between 3 and 4 in. of rain fell in the area (National Climatic Data Center, 1999). Because of the dry antecedent conditions, however, base-flow conditions were re-established by the time sampling was conducted on September 8.

Field Measurements

Because of the pre-existing dry conditions, all of the discharge measured in April in the unnamed stream and its tributaries can be attributed to ground-water discharge. As the result of the storm two days prior to September sampling, the discharge in September cannot solely be attributed to ground water; however, the discharge measured at each site in September was less than that measured in April (table 4). The increase in discharge from site 2 downstream to site 4 in both April and September shows that these are gaining streams, resulting from the discharge of ground water to the stream throughout the stream length.

At sites 1, 2, 3, and 4, water temperature ranged from 12.0ºC to 13.7ºC in April and from 17.5ºC to 19.0ºC in September. The smallest seasonal temperature change was observed at site 2, nearest the landfill, with the highest temperature in April and the lowest in September. The water being discharged from the PVC pipe is ground water that has been isolated from the atmosphere, in contrast to the water at sites 1, 3, and 4. Due to the insulating qualities of the Earth, ground-water temperatures tend to remain relatively constant, unlike surface waters that are affected by wide-ranging air temperature (Todd, 1980).

In both April and September, specific conductance was lower at site 1, the reference site, than at the other

Table 4. Field measurements of water quality and discharge of an unnamed stream and its tributary near the Blue Ridge Parkway, April and September, 1999, and usual ranges for selected water-quality field measurements at the Sinking Creek reference site

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; ft^3/s, cubic feet per second; –, not known]

Name	Site 1		Site 2		Site 3		Site 4		Sinking Creek reference site[a]
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept	
Water temperature, in °C	12.6	19	13.7	17.5	12.4	18.4	12.0	18.6	–
Specific conductance, in µS/cm	100	118	426	912	327	501	156	232	220-230
Dissolved oxygen, in mg/L	8.8	7.8	4.4	4.1	8.7	7.9	9.6	8.4	7.2-10.0
pH, in standard units	7.6	6.7	6.6	5.9	7.3	7.1	7.5	7.3	–
Instantaneous stream discharge, in ft^3/s	0.047	0.017	0.010	0.008	0.030	0.021	0.171	0.096	–
Alkalinity, in mg/L	–	–	–	–	–	–	–	–	120-130

[a]Usual range during historical collection period 1990-2000

sites. The high conductance at site 2 affected all sites downstream, such that conductance at both sites 3 and 4 did not recover to the value measured at site 1. The progressively lower conductance values at sites 3 and 4 as compared to site 2 probably resulted from one or more factors: dilution by ground-water inflow along the stream banks; dilution of the sampled tributary by the unnamed stream; and (or) removal of conductive constituents that were in solution at site 2 by precipitation. Researchers from VPI periodically measured the specific conductance at site 2 from November 1998 to November 1999, at values ranging from 510 to 850 µS/cm. There are no State or Federal water-quality standards for specific conductance, and the water is not considered toxic at a measurement lower than 3,000 µS/cm. Specific conductance also is not considered to be a limiting factor to the biological community structure (Latimer, 1999).

The dissolved-oxygen (DO) concentration at site 2 was much lower than that at other sites, at a concentration of 4.4 mg/L in April and 4.1 mg/L in September. At sites 1, 3, and 4, DO concentrations ranged from 8.7 to 9.6 mg/L in April and from 7.8 to 8.4 mg/L in September. DO concentrations measured at site 2 in April and September were lower than the Virginia Surface Water Quality Criteria of 5.0 mg/L (daily average minimum concentration) and at or slightly higher than the Surface Water Quality Minimum of 4.0 mg/L (State Water Control Board, 1997). DO concentrations at other sites were higher than the standards. Similar DO concentrations were measured at this site by VPI between November 1998 and November 1999; concentrations ranged from a low of 3.6 mg/L to 6.0 mg/L, with most values lower than 5.0 mg/L. Low DO conditions cannot be tolerated by sensitive fish and insect groups (for example, mayflies).

Although the pH also was lower at site 2 than at the other sites during both sampling events, the pH values measured in April and September were between 5.9 and 7.6 at all stations. These values are within the acceptable range for surface waters, according to Virginia water-quality criteria, and are consistent with the values obtained from periodic sampling by VPI.

The lower DO concentration, higher specific conductance, and lower pH at site 2 relative to the other sites are indicative of reducing conditions normally found in landfills where anaerobic degradation is taking place. Downstream of site 2, aeration of the water as it flowed toward the Roanoke River resulted in progressively higher DO concentrations at sites 3 and 4, exceeding the concentration at the reference site, site 1. Oxygenation of the water downstream of site 2 also probably contributed to the increase in pH downstream of site 2, as metals in solution formed metal oxides and were precipitated. The unusual extent of precipitate along the streambed, therefore, was a result of the low pH and low DO (reducing) conditions in the interior of the landfill and the high concentration of constituents in solution, particularly metals, as would be expected in landfill leachate.

Inorganic Constituents and Total Organic Carbon

Of 55 inorganic constituents sampled for, 20 were not detected in either the April or September samples (table 5). Virginia water-quality criteria exist for 10 of the 35 constituents that were detected in April or September (table 6). Some constituents were detected at concentrations less than their respective reporting limits, and these concentrations are considered estimated values. Constituents that were not detected or that had estimated concentrations on both sampling dates were not used in the comparisons among sites; these constituents include total fluoride, dissolved aluminum, dissolved antimony, dissolved and total arsenic, total copper, dissolved lead, total mercury, dissolved and total vanadium, and dissolved and total zinc. If the constituent was at a concentration greater than its reporting limit at least once, it was considered in these comparisons. Constituents that were detected at equal concentrations at two different sites were not included in the subtotals used in the site comparisons that follow.

Site 1, the reference site, had the lowest concentrations for 13 of the 33 inorganic constituents detected at the four sites in April. Present at other sites, total nitrate and total aluminum were not detected at site 2; the lowest concentrations of dissolved and total iron were at site 3; and the lowest concentrations of total organic carbon and dissolved and total barium were at site 4. Dissolved and total vanadium were not detected at any sites in April. In September, the lowest concentrations again were most often at site 1 (20 of 31 constituents detected). At site 2, total nitrate and total sulfate were detected at concentrations lower than their respective reporting limits; total aluminum and total lead were not detected. No constituents were at their lowest concentration at site 3; total iron was at its lowest concentration at site 4. Dissolved aluminum, dissolved antimony, total copper, and total mercury were not detected at any sites in September.

Table 5. Inorganic constituents analyzed for but not detected in water samples at Blue Ridge Parkway sampling stations, April and September 1999

[µg/L, micrograms per liter]

Constituent	Analytical method number	Reporting limit, in µg/L
Non-metals		
Phosphate as P, ortho	300.0A	500
Metals		
Antimony, total	6020	2
Beryllium, dissolved	6010B	2
Beryllium, total	6010B	2
Cadmium, dissolved	6010B	5
Cadmium, total	6010B	5
Copper, dissolved	6010B	20
Chromium, dissolved	6010B	10
Chromium, total	6010B	10
Mercury, dissolved	7470A	0.2
Molybdenum, dissolved	6010B	20
Molybdenum, total	6010B	20
Nickel, dissolved	6010B	40
Nickel, total	6010B	40
Selenium, dissolved	6010B	5
Selenium, total	6010B	5
Silver, dissolved	6010B	10
Silver, total	6010B	10
Thallium, dissolved	6010B	7.4
Thallium, total	6010B	7.4

The larger number of lowest concentrations of inorganic constituents detected at site 1 confirms that it is an appropriate reference site. Although some constituents were detected at lower concentrations at other sites, these lower concentrations may have resulted from conditions at those sites that caused the removal of that constituent from the water. For example, in April and September, both total aluminum and total nitrate either were not detected or were at their lowest concentrations at site 2. In September, total sulfate also was lowest at site 2. These low concentrations probably resulted from reducing conditions within the landfill. The oxidized species nitrate and sulfate were likely not present in waters coming from the anoxic environment of the landfill because nitrogen within a landfill is converted to ammonia or nitrogen gas, and sulfur is converted to hydrogen sulfide, also a gas. Aluminum normally is detected in very small concentrations in natural water and tends to be incorporated into metal or organic complexes when the pH of the water is near 7 (neutral), and therefore may have been precipitated from the water at site 2. Aluminum concentrations increased progressively downstream of site 2 to values that are similar to those at the reference site. In April, the concentration of total organic carbon was lowest at site 4 and showed a progressive decrease from site 2, and also may have been incorporated into organic complexes in the water. The low concentrations of dissolved and total barium at site 4 were comparable to those at site 1 in both April and September samples.

The highest concentrations for 26 of the 33 inorganic constituents detected in April (79 percent) were at site 2, closest to the landfill. The only exceptions were total lead (0.64 µg/L) and total copper (2.9 µg/L) at site 1, both at concentrations less than their respective reporting limit; nitrate (820 µg/L) and total mercury (0.084 µg/L, less than the reporting limit), which were highest at site 3; and total aluminum, highest at site 4 (360 µg/L). In September, highest concentrations were distributed primarily between sites 2 and 3. Of 31 constituents detected in September, 16 (52 percent) were at highest concentrations at site 2, and 13 of 31 constituents detected (42 percent) were highest at site 3. The only exception was total lead (1.1 µg/L), which was highest at site 1.

Constituent concentrations that were highest at site 2 in both April and September included total dissolved solids, and total and dissolved forms of barium, calcium, cobalt, iron, magnesium, and manganese. Concentrations that were highest at site 2 in April and at site 3 in September included total chloride, total organic carbon, total sulfate, total and dissolved potassium, and total and dissolved sodium. Total nitrate was highest at site 3 in both April and September. In September, only total lead was highest at site 1; no constituent was highest at site 4.

In April, most constituent concentrations were progressively lower at sites 3 and 4 compared to those at site 2. The exceptions were total nitrate, highest at site 3, and total aluminum, highest at site 4. On the other hand, several constituents were higher at site 3 than at site 2 in September. The different distribution may be a result of changed conditions near the landfill as a result of the storm two days prior to the September sampling.

The concentrations of total and dissolved iron and of manganese decreased in samples from sites downstream of site 2 in both April and September. Like aluminum, iron and manganese are readily dissolved in acidic water. Both constituents were at relatively high concentrations near site 2 and at nearly equal concentrations in water discharged from beneath the landfill (dissolved/total ratio of 103 percent for iron and 100 percent for manganese). By the time the water reached site 3, most of the iron and manganese had precipitated out, resulting in a dissolved/

Table 6. Inorganic constituents and total organic carbon detected in water samples, and associated Virginia Surface Water Quality Criteria at Blue Ridge Parkway sampling stations, April and September, 1999

[Virginia Surface Water Quality Criteria are maximum contaminant levels for aquatic life and human health as defined by the State Water Control Board (1997); µg/L, micrograms per liter; ND, not detected; –, no criterion]

Constituent	Analytical method number	Reporting limit, in µg/L	Concentration, in µg/L								Virginia Surface Water Quality Criteria, in µg/L			
			April				September				Aquatic Life		Human Health	
			Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Acute	Chronic	Public water supplies	All other surface waters
Nonmetals														
Chloride, total	300.0A	3,000	4,600	48,200[a]	23,200	6,300	4,100	24,800	54,100[b]	12,600	860,000	230,000	250,000	–
Dissolved solids, total	160.1	10,000	93,000	487,000	230,000	120,000	105,000	402,000	329,000	186,000	–	–	500,000	–
Fluoride, total	300.0A	1,000	230[c]	230[c]	240[c]	250[c]	270[c]	230[c]	310[c]	300[c]	–	–	–	–
Nitrate, total	300.0A	500	700	ND	820	530	550	210[c]	1,700	640	–	–	10,000	–
Organic carbon, total	9060	1,000	1,300	5,600	2,600	960[c]	1,500	4,900	6,600	2,600	–	–	–	–
Sulfate, total	300.0A	5,000	2,700[c]	3,900[c]	3,100[c]	3,300[c]	3,700[c]	2,600[c]	9,800	5,400	–	–	–	–
Metals														
Aluminum, dissolved	6010B	100	43[c]	35[c]	41[c]	36[c]	ND	ND	ND	ND	–	–	–	–
Aluminum, total	6010B	100	340	ND	110	360	440	ND	440	240	–	–	–	–
Antimony, dissolved	6020	2	ND	0.38[c]	ND	ND	ND	ND	ND	ND	–	–	14	4,300
Arsenic, dissolved	6020	5	ND	1.1[c]	0.27[c]	ND	ND	1.2[c]	0.75[c]	0.39[c]	–	–	50,000	–
Arsenic, total	6020	5	ND	1.1[c]	0.47[c]	ND	0.24[c]	0.89[c]	1.1[c]	0.61[c]	–	–	–	–
Barium, dissolved	6010B	10	42	540	77	40	48	550	120	54	–	–	2,000	–
Barium, total	6010B	10	44	540	77	42	54	560	130	58	–	–	–	–
Calcium, dissolved	6010B	200	7,900	69,900	27,600	13,500	9,600	65,400	39,000	19,600	–	–	–	–
Calcium, total	6010B	200	7,900	68,600	27,400	13,200	9,600	65,300	39,300	19,500	–	–	–	–
Cobalt, dissolved	6010B	10	ND	20	ND	ND	ND	26	ND	ND	–	–	–	–
Cobalt, total	6010B	10	ND	19	ND	ND	ND	25	ND	ND	–	–	–	–
Copper, total	6010B	20	2.9[c]	ND	ND	ND	ND	ND	ND	ND	–	–	–	–
Iron, dissolved	6010B	100	11.1[c]	9,100	ND	13.5	38[c]	11,800	47[c]	52[c]	–	–	300	–
Iron, total	6010B	100	390	8,800	140	530	810	11,900	990	600	–	–	–	–

Table 6. Inorganic constituents and total organic carbon detected in water samples, and associated Virginia Surface Water Quality Criteria at Blue Ridge Parkway sampling stations, April and September, 1999—Continued

[Virginia Surface Water Quality Criteria are maximum contaminant levels for aquatic life and human health as defined by the State Water Control Board (1997); µg/L, micrograms per liter; ND, not detected; –, no criterion]

Constituent	Analytical method number	Reporting limit, in µg/L	Concentration, in µg/L								Virginia Surface Water Quality Criteria, in µg/L			
			April				September				Aquatic Life		Human Health	
			Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Acute	Chronic	Public water supplies	All other surface waters
Lead, dissolved	6020	1	ND	0.079[c]	ND	ND	ND	0.091[c]	0.094[c]	0.14[c]	120	14	15	–
Lead, total	6021	1	0.64[c]	0.087[c]	ND	0.20[c]	1.1	ND	0.44[c]	0.77[c]	–	–	–	–
Magnesium, dissolved	6010B	200	4,200	37,000	15,200	7,100	4,700	32,100	21,400	10,000	–	–	–	–
Magnesium, total	6010B	200	4,100	36,100	15,100	7,000	4,700	32,100	21,600	9,900	–	–	–	–
Manganese, dissolved	6010B	10	1.9[c]	3,200	2.2[c]	9[c]	14	3,300	23	27	–	–	50	–
Manganese, total	6010B	10	9.8[c]	3,200	27	32	31	3,300	100	44	–	–	–	–
Mercury, total	7470A	0.2	ND	ND	0.084[c]	ND	ND	ND	ND	ND	–	–	–	–
Potassium, dissolved	6010B	5,000	1,600[c]	5,200	4,200[c]	1,800[c]	1,900[c]	4,800[c]	7,000	2,800[c]	–	–	–	–
Potassium, total	6010B	5,000	1,600[c]	5,100	4,100[c]	2,200[c]	1,600[c]	4,600[c]	7,300	2,900[c]	–	–	–	–
Sodium, dissolved	6010B	5,000	6,300	35,500	17,500	7,500	6,600	23,800	33,100	10,100	–	–	–	–
Sodium, total	6010B	5,000	6,900	34,800	17,100	7,600	6,600	23,500	33,400	10,800	–	–	–	–
Vanadium, dissolved	6010B	10	ND	ND	ND	ND	ND	1.6[c]	ND	ND	–	–	–	–
Vanadium, total	6010B	10	ND	ND	ND	ND	1.7[c]	ND	2.2[c]	ND	–	–	–	–
Zinc, dissolved	6010B	20	ND	3.0[c]	ND	ND	3.4[c]	5.4[c]	3.7[c]	3.7[c]	120	110	5,000	–
Zinc, total	6010B	20	3.5[c]	3.8[c]	ND	ND	6.1[c]	6.3[c]	13[c]	3.9[c]	–	–	–	–

[a]Elevated reporting limit due to matrix interference
[b]Elevated reporting limit due to high analyte levels
[c]Estimated value–value is less than reporting limit

total ratio of zero percent iron and 8 percent manganese at site 3, and 2 percent iron and 30 percent manganese at site 4, showing the downstream changes in solution. Iron, which ranged in concentration at site 2 from 8,800 to 11,900 µg/L and manganese, at concentrations from 3,200 to 3,300 µg/L, were the only inorganic constituents at concentrations greater than their Virginia Water Quality Criteria (300 µg/L and 50 µg/L, respectively) in April and September. Both of these standards, however, are standards for taste and odor in drinking water, a standard that is not currently applicable for this stream.

A comparison between site 4 and site 1, the reference site, indicates whether concentrations in the unnamed stream recovered to background conditions downstream of the confluence with the sampled tributary. Generally, a downstream decrease in constituent concentrations may be a result of (1) dilution of the constituents in the stream by inflow from tributaries, (2) dilution of constituents by ground-water discharge, (3) precipitation of constituents, (4) adsorption and concentration of constituents onto sediment particles, or (5) other in-stream processes.

Although concentrations of some constituents decreased downstream from site 2, concentrations for the majority of constituents at site 4 did not recover to the concentrations at the reference site, site 1. Concentrations for 17 of 24 constituents detected at both sites in April (71 percent) and 23 of 28 detected at both sites in September (82 percent) were greater at site 4 than at site 1. In April, concentrations of total organic carbon, total nitrate, and total and dissolved barium were less at site 4 than at site 1. In September, total aluminum, total iron, and total lead had concentrations lower at site 4 than those at site 1.

To determine whether there were seasonal or other time-related differences in water chemistry among the four sites, relative percent differences in constituent concentrations between the two sampling periods were calculated for each constituent by subtracting the concentration in April from the concentration in September, dividing that difference by the concentration in April, and multiplying the result by 100. This served to normalize the data around a value of zero. Constituents were divided into nonmetals, dissolved metals, and total metals, and then concentrations were plotted to determine whether there was an observable pattern in relative percent difference within and between groups having similar chemical structure and (or) reactivity (fig. 4). It is important to note that when values are low, as at site 1, a small difference in concentration can result in a large relative percent difference.

The boxplots for sites 1 and 2 show small ranges in percent difference in total nonmetals. Although there are wider ranges for dissolved metals and total metals at site 1 relative to site 2, the medians for both sites are near zero, indicating that constituent concentrations in the stream were consistent (at these streamflows) for these two sample-collection dates. Larger percent differences in concentrations at sites 3 and 4 are seen in the wider ranges and the higher median values of the boxplots. The highest medians for each group of constituents are at site 3, showing the greatest change in constituent concentrations from the April sample to the September sample.

Several hypotheses may explain the differences in concentrations between April and September samples. For example, prior to the April sampling, conditions were dry; water discharged from the PVC pipe at site 2 and throughout the basin of the unnamed stream would have been representative of steady-state conditions. In contrast, the brief but significant storm in September two days prior to sampling after a prolonged dry period would have flushed the water in the stream as well as the sediment in the streambed. Although flow conditions were similar to conditions in April, the storm would have effectively redistributed any precipitate or constituents associated with sediment throughout the basin. These different sampling conditions probably affected the concentrations and the distribution of sediment and associated constituents in the basin. Another possible explanation for the differences in concentrations between the two sampling dates is seasonal changes in air and water temperatures, which affect conductance, pH, and DO concentration. These field conditions can change the potential for chemical precipitation and other in-stream processes. Also, ground water being discharged along the banks of streams may contain elevated concentrations of inorganic constituents as a result of contamination from the landfill and subsequent subsurface flow through saprolite or cracks and fissures in the rock. Because ground-water storage time along the crest of the Blue Ridge Physiographic Province can be relatively short (on the order of 0-2 years for springs) (Plummer and others, 1999), recharge from the September storm may have resulted in increased discharge from ground-water storage.

Organic Compounds

Of 121 organic compounds analyzed for, 104 were not detected in either water or bottom-sediment samples (table 7). Of the 17 discrete compounds that were detected in water in either April or September, most

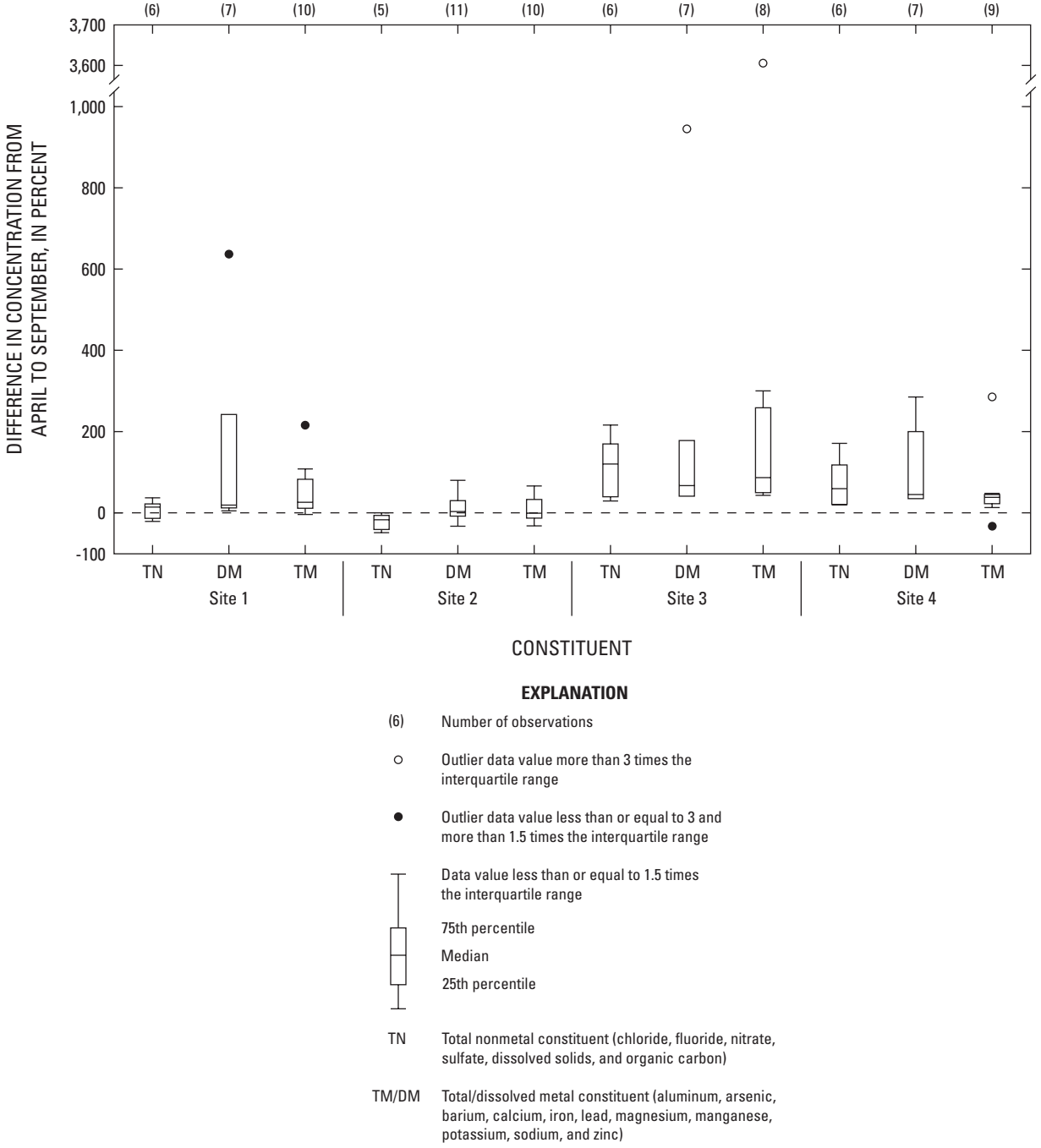


Figure 4. Ranges in percent difference in concentrations of inorganic constituents and organic carbon between April 1999 sampling and September 1999 sampling, at sites near the Blue Ridge Parkway, Virginia.

Table 7. Organic compounds analyzed for but not detected in water and streambed sediment samples at Blue Ridge Parkway sampling stations

[µg/L, micrograms per liter, µg/kg, micrograms per kilogram, GC/MS, gas chromatography/mass spectrometry; PCBs, polychlorinated biphenyl compounds]

	Reporting limit, in µg/kg	
Constituent	**Water**	**Sediment**
Method 8260B–Volatile organic compounds analyzed by GC/MS		
1,1,1-Trichloroethane	1.0	5.0
1,1,2,2-Tetrachloroethane	1.0	5.0
1,1,2-Trichloroethane	1.0	5.0
1,1-Dichloroethene	1.0	5.0
2-Hexanone	5.0	20
4-Methyl-2-pentanone	5.0	20
Bromodichloromethane	1.0	5.0
Bromoform	1.0	5.0
Bromomethane	2.0	10
Carbon disulfide	1.0	5.0
Carbon tetrachloride	1.0	5.0
Chlorodibromomethane	1.0	5.0
Chloromethane	2.0	10
cis-1,3-Dichloropropene	1.0	5.0
Styrene	1.0	5.0
trans-1,3-Dichloropropene	1.0	5.0
Method 8270C–Semivolatile organic compounds analyzed by GC/MS		
1,2,4-Trichlorobenzene	10	330
1,2-Dichlorobenzene	10	330
1,3-Dichlorobenzene	10	330
2,2'-oxybis(1-Chloropropane)	10	330
2,4,5-Trichlorophenol	10	330
2,4,6-Trichlorophenol	10	330
2,4-Dichlorophenol	10	330
2,4-Dimethylphenol	10	330
2,4-Dinitrophenol	50	1,600
2,4-Dinitrotoluene	10	330
2,6-Dinitrotoluene	10	330
2-Chloronapthalene	10	330
2-Chlorophenol	10	330
2-Methylnapthalene	10	330
2-Methylphenol	10	330
2-Nitroaniline	50	1,600
2-Nitrophenol	10	330
3,3-Dichlorobenzidene	50	1,600
3-Methylphenol	10	330
3-Nitroaniline	50	1,600

Table 7. Organic compounds analyzed for but not detected in water and streambed sediment samples at Blue Ridge Parkway sampling stations—Continued

[µg/L, micrograms per liter, µg/kg, micrograms per kilogram, GC/MS, gas chromatography/mass spectrometry; PCBs, polychlorinated biphenyl compounds]

	Reporting limit, in µg/kg	
Constituent	**Water**	**Sediment**
4,6-Dinitro-2-methylphenol	50	1,600
4-Bromophenyl phenyl ether	10	330
4-Chloro-3-methylphenol	10	330
4-Chloroaniline	10	330
4-Chlorophenyl phenyl ether	10	330
4-Methylphenol	10	330
4-Nitroaniline	50	1,600
4-Nitrophenol	50	1,600
Acenapthene	10	330
Acenapthylene	10	330
Anthracene	10	330
Benzo(a)anthracene	10	330
Benzo(a)pyrene	10	330
Benzo(b)fluoranthene	10	330
Benzo(g,h,i)perylene	10	330
Benzo(k)fluoranthene	10	330
bis(2-Chloroethoxy)methane	10	330
bis(2-Chloroethyl)ether	10	330
bis(2-Ethylhexyl)phthalate	10	330
Butylbenzyl phthalate	10	330
Chrysene	10	330
Dibenzo(a,h)anthracene	10	330
Dibenzofuran	10	330
Dibutylphthalate	10	330
Diethyl phthalate	10	330
Dimethyl phthalate	10	330
Di-n-octyl phthalate	10	330
Fluoranthene	10	330
Fluorene	10	330
Hexachlorobenzene	10	330
Hexachlorobutadiene	10	330
Hexachlorocyclopentadiene	50	1,600
Hexachloroethane	10	330
Indeno (1,2,3-c,d) pyrene	10	330
Isophorone	10	330
Napthalene	10	330
Nitrobenzene	10	330
N-Nitroso di-n-propylamine	10	330

Table 7. Organic compounds analyzed for but not detected in water and streambed sediment samples at Blue Ridge Parkway sampling stations—Continued

[µg/L, micrograms per liter, µg/kg, micrograms per kilogram, GC/MS, gas chromatography/mass spectrometry; PCBs, polychlorinated biphenyl compounds]

	Reporting limit, in µg/kg	
Constituent	**Water**	**Sediment**
N-Nitrosodimethylamine	10	330
Pentachlorophenol	50	1,600
Phenanthrene	10	330
Phenol	10	330
Pyrene	10	330
Method 8081–Semivolatile organic compounds analyzed by GC (PCBs)		
Arochlor 1016	1.0	33
Arochlor 1221	1.0	33
Arochlor 1232	1.0	33
Arochlor 1242	1.0	33
Arochlor 1248	1.0	33
Arochlor 1254	1.0	33
Arochlor 1260	1.0	33
Method 8081A–Semivolatile organic compounds analyzed by GC (Organochlorine pesticides)		
4,4'-DDE	0.05	1.7
a-BHC	0.05	1.7
a-Chlordane	0.05	1.7
Aldrin	0.05	1.7
Chlorobenzilate	0.05	1.7
d-BHC	0.05	1.7
Dieldrin	0.1	1.7
Endosulfan I	0.05	1.7
Endosulfan II	0.05	1.7
Endosulfan sulfate	0.05	1.7
Endrin	0.05	1.7
Endrin ketone	0.05	1.7
g-BHC A37(Lindane)	0.05	1.7
g-Chlordane	0.05	1.7
Heptachlor	0.05	1.7
Heptachlor epoxide	0.05	1.7
Methoxychlor	0.5	3.3
Toxaphene	5	67

organic compounds were detected only at site 2 (table 8). The only exceptions are methylene chloride, a common laboratory solvent, which was detected at least once at each of the four sites, and 2-butanone, or methyl ethyl ketone, which was detected at site 2 and at a concentration less than its reporting limit at site 3 in September. Although organic compounds detected in water at site 2 included both volatile and semivolatile organic compounds, no organochlorine pesticides or PCBs were detected in any water samples. Volatile or semivolatile compounds are quickly converted to a gaseous state (volatilized) when exposed to the atmosphere. This volatility probably explains their presence in water sampled from site 2, closest to the landfill, and their absence from samples collected at sites 3 and 4. Constituents that were not detected or had estimated concentrations on either sampling date were not used in the comparisons among sites. A compound is included in the following discussion if it was detected at a concentration greater than its reporting limit in at least one sample.

Constituents detected were primarily industrial and (or) manufacturing solvents (table 9), some of which tend to persist in the environment and have a high potential for bioconcentration (the accumulation of persistent contaminants in plants and animals). Although several of these compounds detected have water-quality criteria related to human health, no compounds detected in either April or September were present at concentrations greater than the Virginia Water Quality Criteria (State Water Control Board, 1997) (table 6). Several of the organic compounds found in April or September also were detected in ground-water samples collected and reported to DEQ during periodic monitoring from 1996-2000. These include benzene, chloroethane, dichlorobenzene, 1,1-dichloroethane, *cis*-1,2-dichloroethene, methylene chloride, tetrachloroethene, trichloroethene, vinyl chloride and *o*-xylene (Virginia Department of Environmental Quality, unpub. data, 2000).

Quality Control Samples

The results of analyses of QC samples associated with water samples collected are in Appendixes 1 and 2. Duplicate analyses showed good reproducibility for all constituents analyzed in both April and September.

In April, total and dissolved aluminum, dissolved antimony, total iron, total magnesium, and total and dissolved sodium were detected in laboratory method blanks. Dissolved aluminum, magnesium, and sodium in the equipment blank that was collected prior to the environmental samples reflect detections in the laboratory method blank. This indicates that any contamination from these constituents probably was due to laboratory practices. Concentrations of all constituents in blanks were less than their reporting limits, however, so that no qualification of the environmental data is needed for April.

In September, total dissolved solids, total organic carbon, total chloride, dissolved iron, dissolved sodium, and total zinc were detected in laboratory method blanks, all at concentrations lower than their reporting limits. The equipment blank reflects the detection of dissolved iron, sodium, and zinc in the laboratory method blank. All constituents in blanks are at concentrations less than the reporting limit, so that no qualification of the environmental data is needed for September.

A duplicate sample collected for organic constituents at site 2 in April showed very good reproducibility. No organic compounds analyzed for were detected in equipment blanks that were collected prior to collection of environmental samples in either April or September. The trip blank in September showed the detection of methylene chloride, a solvent commonly used in laboratory analysis of organic compounds and often found in low concentrations as a laboratory contaminant. Based on these QA results, no qualification of the results of organic compounds is necessary for either April or September samples.

Streambed Sediment

Sediment moves along a streambed at a relatively slow rate, making it useful in evaluating any long-term effects of the water quality of the stream. Hydrophobic organic compounds and metal ions tend to bind or adhere to sediment particles; therefore, chemical analysis of any material on the surface of streambed sediment that has been exposed to consistent concentrations of constituents in stream water over a period of time may display a "record" of the constituents.

The movement rate of sediment is largely determined by grain size, because water moves lighter particles such as clays and silts faster than heavier particles. As water slows and flow rates drop (for example, after a storm), particles will tend to be sorted by size, with the heavier (larger) grains on the bottom and finer (smaller) grains on top. Finer particles also are deposited along stream margins, where flow rate may be reduced by friction or reduction in water depth.

A mass of fine-grained sediments has a larger surface area than an equal mass of larger particles such as sand, rocks, or boulders. Therefore, organic or inorganic com-

Table 8. Organic compounds detected in water samples, and associated Virginia Surface Water Quality Criteria at Blue Ridge Parkway sampling stations, April and September, 1999

[µg/L, micrograms per liter; GC/MS, gas chromatography/mass spectrometry; ND, not detected; –, no criterion]

Constituent	Reporting limit, in µg/L	Concentration, in µg/L								Virginia Surface Water Quality Criteria, in µg/L			
		April				September				Aquatic Life		Human Health	
		Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Acute	Chronic	Public water supplies	All other surface waters
Method 8260B–Volatile organic compounds analyzed by GC/MS													
1,1-Dichloroethane	2.0	ND	28	ND	ND	ND	27	ND	ND	–	–	–	–
1,2-Dichloroethane	2.0	ND	2.3	ND	ND	ND	2.6	ND	ND	–	–	4	990
cis-1,2-Dichloroethene	2.0	ND	57	ND	ND	ND	71	ND	ND	–	–	–	–
trans-1,2-Dichloroethene	1.0	ND	1.3	ND	ND	ND	1.2	ND	ND	–	–	–	–
1,2-Dichloroethene (total)	2.0	ND	59	ND	ND	ND	73[a]	ND	ND	–	–	–	–
1,2-Dichloropropane	2.0	ND	2.5	ND	ND	ND	2.7	ND	ND	–	–	–	–
Benzene	2.0	ND	9.5	ND	ND	ND	10	ND	ND	–	–	12	710
2-Butanone (methyl ethyl ketone)	5.0	ND	ND	ND	ND	ND	ND	2.4[b]	ND	–	–	–	–
2-Butanone (methyl ethyl ketone)	10.0	ND	ND	ND	ND	ND	44	ND	ND	–	–	–	–
Chlorobenzene	2.0	ND	0.74[b]	ND	ND	ND	0.87[b]	ND	ND	–	–	–	–
Chloroethane	4.0	ND	5.4	ND	ND	ND	3.5[b]	ND	ND	–	–	–	–
Ethylbenzene	2.0	ND	8.3	ND	ND	ND	13	ND	ND	–	–	3,100	29,000
Methylene chloride	2.0	ND	4.5	0.24[b]	ND	0.23[b,c]	5.1[c]	ND	0.21[b,c]	–	–	–	–
Tetrachloroethene	2.0	ND	8.1	ND	ND	ND	5.9	ND	ND	–	–	320	3,500
Toluene	2.0	ND	18	ND	ND	ND	30	ND	ND	–	–	6,800	200,000
Trichloroethene	2.0	ND	16	ND	ND	ND	12	ND	ND	–	–	27	810
Vinyl chloride	4.0	ND	6.7	ND	ND	ND	7.1	ND	ND	–	–	20	5,300
Xylenes (total)	2.0	ND	55	ND	ND	ND	74	ND	ND	–	–	–	–
Method 8270C–Semivolatile organic compounds analyzed by GC/MS													
1,4-Dichlorobenzene	10.0	ND	10	ND	ND	ND	11	ND	ND	–	–	400	2,600

[a] Elevated reporting limit due to high analyte levels

[b] Estimated value–value is less than reporting limit

[c] Associated method blank contains the target analyte at a reportable level

Table 9. Organic compounds detected in water or streambed sediment at Blue Ridge Parkway sampling stations, April and September, 1999, their use, environmental fate, and potential for bioconcentration (Spectrum Laboratories, Inc., 2001; U.S. Environmental Protection Agency, 1998)

Analyte	Use	Environmental fate	Potential for bioconcentration in aquatic organisms
Method 8260B–Volatile organics compounds analyzed by GC/MS			
1,1-Dichloroethane	Solvent for plastics, oils, and fats; cleaning agent; degreaser; fumigant and insecticide spray; formerly used as an anesthetic.	Volatilizes rapidly if released on land, although it may leach into ground water, where fate is unknown. Half-life of 62 days in the atmosphere, 2 to 9 days from surface water.	Low
1,2-Dichloroethane	Manufacturing, fumigant, solvent for fats, oils, waxes, gum resins, and particularly rubber, cleaning agent.	Evaporates rapidly. Half-life in atmosphere approximately 1 month, up to 10 days from water.	Low
cis-1,2-Dichloroethene	Solvent for perfumes, dyes, and lacquers, thermolastics, fats, and phenols. Agent in retarding fermentation. Very flammable.	Under anaerobic conditions, may likely be found as breakdown products of reductive dehalogenation of trichloroethylene and tetrachloroethylene. Will evaporate on soil, or leach into ground water where slow biodegradation will occur. In water, will volatilize (half-life 3 hours).	Data not available
trans-1,2-Dichloroethene	Solvent for waxes and resins, extraction of rubber, as refrigerant, in manufacturing, extraction of oils from fish and meat.Very flammable.	Priority pollutant. In anaerobic conditions that may exist in landfills or sediments, can be formed as a breakdown product from reductive halogenation of trichloroelthylene, tetrachloroethylene, and 1,1,2,2,-tetrachloroethane. Evaporates on soil or leaches into ground water, where slow bidegradation should occur. Half-life in water, 3 hours. Half-life in atmosphere 3.6 days.	Data not available
1,2-Dichloropropane	Insecticide mixture for stored grain for livestock, solvent in plastics, resins, and metals industries, rubber processing, degreasing, oil and fat solvent, fumigant, insecticide for nematodes, dry cleaning fluids.	Evaporates on soil. Detected in ground water where fate is unknown. Half-life in water 6 hours to 10 days. Half-life in atmosphere greater than 23 days.	Low
Benzene	Manufacturing for medicinal chemicals, dyes, organic compounds, artifical leather, linoleum, varnishes, lacquer, printing, paints, degreaser.	In soil, will rapidly evaporate, and that which does not will be highly mobile in soil, and may leach to ground water. Subject to biodegradation on shallow, anaerobic ground waters, but probably not under anaerobic conditions. Half-life in water, 3 hours. Half-life in atmosphere 17 days.	Low
2-Butanone (methyl ethyl ketone)	Solvent, surface coating industry, lacquer and varnish industry, pharmaceuticals and cosmetics, synthetic rubber manufacturing, cements and adhesives.	On ground, partially evaporates, partly leaches into ground. Degradation in soil is unknown. In water, volatilizes (half-life 3-12 days) or is slowly biodegraded. In atmosphere, half-life 2.3 days or less.	Low
Chloroethane	Chemical intermediate, refrigerant, solvent, alkylating agent, manufacturing, solvent, insecticides.	Evaporates rapidly in soils where release is possible, but hydrolyzes rapidly in water, and is susceptible to leaching. Half-life in atmosphere ~40 days. Half-life in water 1-6 days. In moist soil systems or in ground water, hydrolysis may be the most important mechanism, estimated to be 38 days at 25°C.	Low
Ethylbenzene	Intermediate for styrene monomer production, solvent.	Volatilizes. Moderate adsorption in soil, may biodegrade. Half-life in atmosphere is 0.5 to 2 days. Half-life in water several days to 2 weeks.	Data not available
Methylene chloride	Paint strippers, aerosols, chemical processing, foam blowing agent, metal degreasing, electronics.	Volatilizes. Probably will leach through subsoil into ground water. Degradation in ground water is unknown. In water, volatilizes (half-life is hours). Biodegradation will be slow compared to evaporation. In soil, may biodegrade. Half-life in atmosphere is several months.	Low

Table 9. Organic compounds detected in water or streambed sediment at Blue Ridge Parkway sampling stations, April and September, 1999, their use, environmental fate, and potential for bioconcentration (Spectrum Laboratories, Inc., 2001; U.S. Environmental Protection Agency, 1998)—Continued

Analyte	Use	Environmental fate	Potential for bioconcentration in aquatic organisms
Tetrachloroethene	Solvent in drycleaning, degreasing solvent, chemical intermediate for fluorocarbons, agent in textile manufacture.	If released to soil, subject to evaporation into the atmosphere and to leaching into the ground water. Biodegradation may be important in anaerobic soils. In water, subject to rapid volatilization (half-life 3 hours to 14 days). In atmosphere, half-life of up to 2 months.	Low
Toluene	Chemical intermediate for benzene and other chemicals, solvent, gasoline blending.	At soil surface, lost by evaporation, although it is relatively mobile in soil and may reach ground water and remain there. In water, lost by volatilization and biodegradation (half-life days to several weeks) In atmosphere, half-life is 3 hours to less than 2 days.	Low
Trichloroethene	Degreasing of metals, chemical intermediate, solvent, refrigerant and heat exchange liquid.	May be transported through soil; low potential to adsorb to sediments. Rapid evaporation from water (half-life several minutes to hours)	Moderate
Vinyl chloride	In plastic industry to produce PVC, as refrigerant, chemical intermediate.	In soil, subject to rapid volatilization. Any which does not evaporate will be expected to be highly mobile in soil and may leach to the groundwater. Subject to degradation under anaerobic conditions, but some data suggest that it is resistant to biodegradation in aerobic systems. Half-life in water less than 1 hour, half-life in atmosphere of 1.5 days.	Data not available
Xylenes (total)	Used in gasoline, solvents, chemical intermediates, manufacturing, pharmaceutical synthesis, insecticides.	In soil, volatilizes and leaches into ground. In water, volatilization, half-life 1-6 days. Can persist in ground water. In atmosphere, half-life of 1.7 to 18 hours. Some adsorption to sediment.	Data not available
Method 8270C–Semivolatile organic compounds analyzed by GC/MS			
1,4-Dichlorobenzene	Insecticidal fumigant, dye intermediate and insecticide manufacture.	In soil, moderately to tightly adsorbed. Leaching to ground water can occur. Volatilization or slow biodegradation may occur. Volatile from water with half-life of 4.3 hours. Half-life in atmosphere is estimated at 31 days. Adsorption to sediments is a major environmental fate process. Not expected to biodegrade under anaerobic conditions.	Data not available
Method 8081A–Semivolatile organic compounds analyzed by GC			
4,4'DDT	Pesticide	Banned from general use in the United States since 1972. Very persistent in the environment. Significant evidence that it significantly bioconcentrates in fish, and adsorbs strongly to sediment.	High

pounds that adhere to the surface of sediment particles tend to be concentrated in areas where fine-grained materials are located. This sorting and concentrating also result in a streambed sediment chemistry that may be more highly variable than the water chemistry of the stream.

Inorganic Constituents and Total Organic Carbon

Of 25 constituents in streambed sediment samples analyzed for in April and September, including total metals and total organic carbon (excluding percent moisture, a physical measurement), 22 were detected in April, and 20 were detected in September, for a total of 24 constituents detected (table 10). Sodium was the only constituent analyzed for and not detected at any site. In April, the highest concentrations of 13 of 22 constituents detected (59 percent) were at site 4, including copper, lead, and zinc. Concentrations of 6 of 22 constituents (27 percent) were highest and concentrations of 13 constituents (59 percent) were lowest at site 2. Excluding arsenic, selenium, and silver, for which concentrations at all sites were less than the reporting limit, concentrations for 18 out of 19 constituents detected (95 percent) were greater at one of the sites influenced by the landfill (sites 2, 3, or 4) than at site 1. The exception was nickel, which was highest at site 1 (5.6 mg/kg).

In September, the lowest concentrations for 12 of the 20 constituents detected (60 percent) were in samples from site 1. The highest concentrations for 12 of the 20 constituents detected (60 percent), including cadmium, copper, mercury, and zinc, were at site 2. The highest concentrations for 6 of 20 constituents (30 percent) were detected in samples from site 3, while the highest concentration of lead (10 mg/L) was at site 4. Concentrations for all 20 constituents detected were higher at either site 2, 3, or 4 than at site 1. (Because some constituents were at equal concentrations at two sites, percentages do not sum to 100.)

Overall, these data show a change in the distribution of constituents associated with sediment between April and September. In April, most of the lowest concentrations were at site 2 and most of the highest concentrations at site 4, with a few high concentrations at site 3. In September, most of the lowest concentrations were at the reference site (site 1) and the highest concentrations were at site 2, with a few high concentrations at sites 3 and 4. In April, concentrations of several constituents increased from site 2 downstream to site 4, while in September, the opposite occurred: several constituents decreased from their highest concentrations at site 2 to site 4.

As with water samples, the relative percent differences in constituent concentrations between April and September streambed sediment samples were calculated by subtracting the concentration in April from that of September, then dividing by the concentration in April. The result was then multiplied by 100 to represent the relative change between the two sampling dates as a percentage (fig. 5). This approach serves to normalize the data around a value of zero. The greatest relative difference, indicating the greatest change from April to September, is seen at site 2. Medians are very close to zero at the other three sites, indicating little change in sediment concentration of metal constituents between April and September.

There are several possible reasons for the change in constituent concentrations in sediment at site 2. These include seasonality, including changes in temperature and DO concentration, as well as other factors that are not discernible from two sampling events. For example, in April, the lack of recent significant rainfall allowed the streams to reach a steady-state flow condition. Streamwater chemistry downstream of the PVC pipe probably was much like ground-water chemistry within the landfill, including a lower pH than at site 1 and very low DO concentrations. It is likely that conditions within the landfill were such that dissolved metal and nonmetal constituents remained in solution until they were discharged, and yellowboy was formed as a precipitate as the constituents became oxidized downstream. Because constituents remained either in solution or in the precipitate, concentrations in the streambed sediments were low at site 2 relative to concentrations at the other sites. Precipitation of the metals on sediment occurred downstream, as the DO concentration increased.

In September, the storm two days prior to sample collection disrupted the pre-existing steady-state conditions, but base-flow conditions and low DO concentrations were quickly re-established. However, the inflow of fresh water at the site changed water and sediment conditions so that they were no longer in a steady state. Most of the top layer of sediment and associated precipitate was washed away. The streambed sediment that was collected for sampling, although still very fine silt and (or) precipitate, was from deeper in the streambed.

Organic Compounds

Organic compounds detected in April and September in streambed sediment included both volatile organic and semivolatile organic compounds and one organochlorine pesticide (table 11). Six compounds within these groups

Table 10. Inorganic constituents, total organic carbon, and percent moisture in streambed sediment samples at Blue Ridge Parkway sampling stations, April and September, 1999

[mg/kg, milligrams per kilogram; µg/kg, micrograms per kilogram; ND, not detected; ASTM, American Society of Testing and Materials; %, percent]

Constituent	Method	Units	Reporting limit	Concentration, in units noted							
				April				September			
				Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
Aluminum	6010B	mg/kg	10	7,650	3,350	8,100	14,400	5,690[a]	10,600[a]	8,280[a]	7,260[a]
Antimony[b]	6020	µg/kg	200	ND	ND	ND	60.3[c]	ND	ND	ND	ND
Arsenic	6020	µg/kg	500	481[c]	1,060	319[c]	390[c]	680	1,100	510	540
Barium	6010B	mg/kg	1.0	62.3	77.2	74.2	83.6	61.3[a]	120[a]	94.5[a]	57.3[a]
Beryllium	6010B	mg/kg	0.2	0.71	0.63	1.0	1.1	0.79	1.5	1.3	1.0
Cadmium	6010B	mg/kg	0.5	ND	ND	ND	ND	0.24[c]	0.7	0.34[c]	0.33[c]
Calcium	6010B	mg/kg	20	675	1,120	1,130	1,160	657[a]	2,690[a]	1,850[a]	894[a]
Chromium	6010B	mg/kg	1.0	11.8	1.8	10.4	14.4	8.7[a]	9.8[a]	10.3[a]	10.3[a]
Cobalt	6010B	mg/kg	1.0	5.4	2.7	8.2	8.0	4.1[a]	5.6[a]	11.2[a]	6.6[a]
Copper	6010B	mg/kg	2.0	3.5	1.9[c]	4.2	7.0	3.7	5.6	5.5	5.5
Iron	6010B	mg/kg	10	15,900	34,700	17,900	23,400	14,100	42,200	21,000	18,800
Lead	6020	µg/kg	100	8,250	2,340	5,270	15,600	9.4	7.9	7.8	10
Magnesium	6010B	mg/kg	20	798	568	1,130	1,410	796[a]	1,970[a]	1,690[a]	1,410[a]
Manganese	6010B	mg/kg	1.0	278	73.6	760	383	230[a]	198[a]	1,090[a]	270[a]
Mercury	7471A	mg/kg	0.033	ND	ND	ND	ND	0.0056[c]	0.013[c]	0.0075[c]	ND
Molybdenum	6010B	mg/kg	2.0	ND	1.2[c]	ND	ND	ND	ND	ND	ND
Nickel	6010B	mg/kg	4.0	5.6	2.1[c]	4.6	4.5	2.4[c]	3.1[c]	4.7	3.2[c]
Potassium	6010B	mg/kg	500	430[c]	223[c]	500	878	457[c]	845	849	820
Selenium	6020	µg/kg	500	78.8[c]	114[c]	93.4[c]	76.8[c]	0.099[c]	0.15[c]	0.16[c]	0.074[c]
Silver	6010B	mg/kg	1.0	0.33[c]	0.46[c]	0.29[c]	0.37[c]	ND	ND	ND	ND
Sodium	6010B	mg/kg	500	ND	ND	ND	ND	ND	ND	ND	ND
Thallium[b]	6020	µg/kg	100	86.6[c]	39.5[c]	117	204	ND	ND	ND	ND
Total organic carbon	9060	mg/kg	2,000	9,820	36,800	3,970	1,380[c]	7,300	14,600	22,100	5,660
Vanadium	6010B	mg/kg	1.0	17.8	8.3	23.1	29	15.9[a]	24.9[a]	22.6[a]	20.0[a]
Zinc	6010B	mg/kg	2.0	59.7	33.9	37.6	63.6	52[a]	66.2[a]	41.1[a]	45.5[a]
Percent moisture	ASTM	%	0.2	38.6	88.6	28.3	41.3	40.1	61.6	51.3	31.8

[a] Serial dilution of a digestate in the analytical batch indicates that physical and chemical interferences are present

[b] Analysis in September using method 6010B with reporting limit of 1,000 µg/kg resulted in no detections of this constituent

[c] Estimated result–result is less than reporting limit

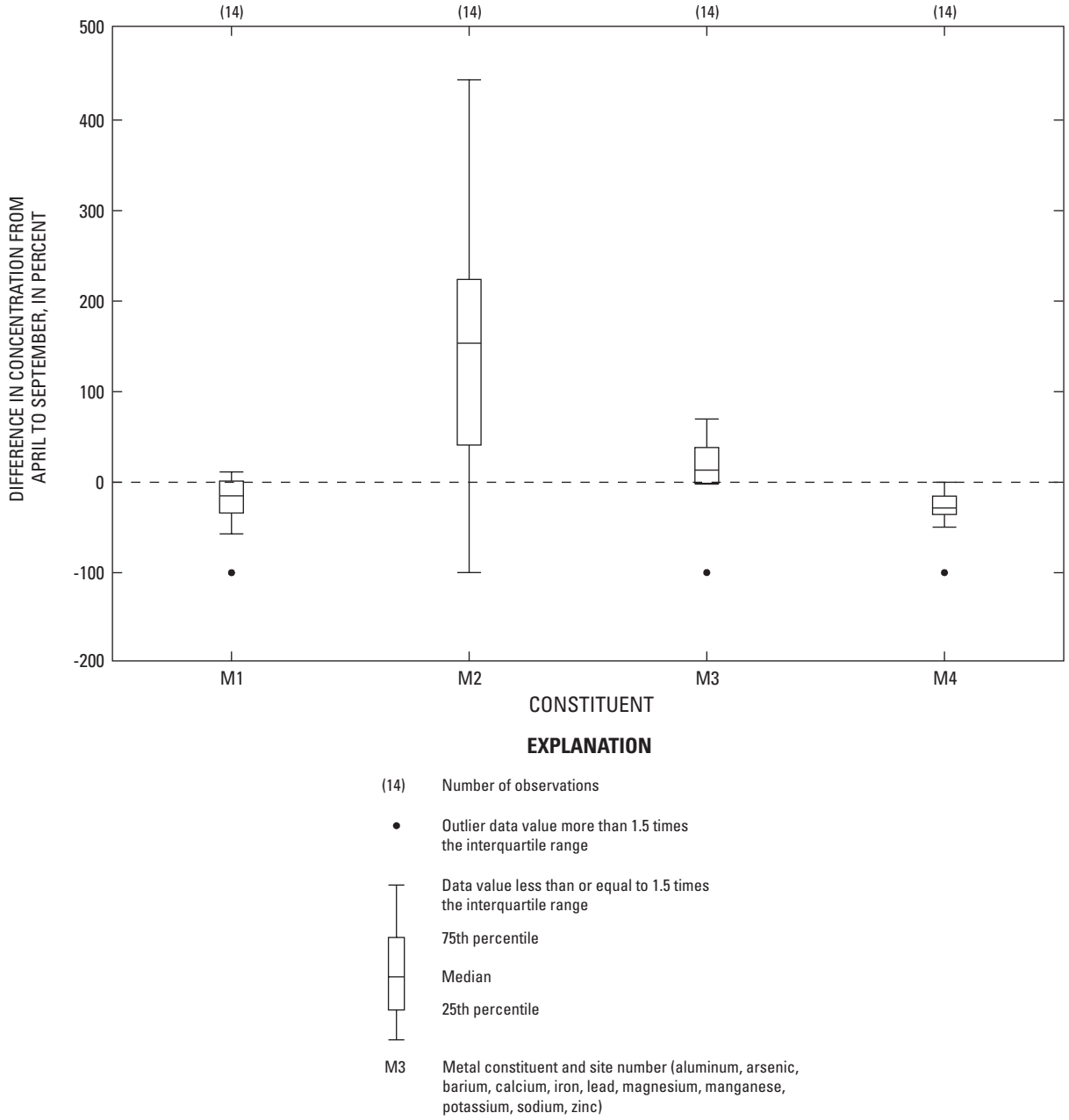


Figure 5. Ranges in percent difference in concentrations of inorganic constituents associated with streambed sediment between April 1999 sampling and September 1999 sampling, at sites near the Blue Ridge Parkway, Virginia.

Table 11. Organic compounds detected in streambed sediment samples at Blue Ridge Parkway sampling stations, April and September, 1999

[µg/kg, micrograms per kilogram; GS/MS, gas chromatography/mass spectrometry; GC, gas chromatography; ND, not detected; –, not determined]

Compound	Reporting limit	Concentration, in µg/kg							
		April				September			
		Site 1	Site 2	Site 3	Site 4	SIte 1	Site 2	Site 3	Site 4
Method 8260B–Volatile organic compounds analyzed by GC/MS									
1, 1-Dichloroethane	5.0	ND	15	ND	ND	ND	2.8[a]	ND	ND
1, 2-Dichloroethene (total)	5.0	ND	13	ND	ND	ND	1.4[a]	ND	ND
Acetone	20	4.8[a]	9.2[a]	ND	ND	ND	ND	ND	ND
Benzene	5.0	ND	2.4[a]	ND	ND	ND	ND	ND	ND
Chloroethane	10	ND	2.1[a]	ND	ND	ND	ND	ND	ND
cis-1,2-Dichloroethene	2.5	ND	13	ND	ND	ND	1.4[a]	ND	ND
Cyclotetrasiloxane, octamethl-	–	ND	ND	ND	ND	8[c,e]	ND	ND	ND
Methylene chloride	5.0	0.93[a,d]	3.5[a,d]	1.0[a,d]	0.98[a,d]	0.94[a,d]	0.58[a,d]	1[a,d]	0.73[a,d]
Tetrachloroethene	5.0	ND	18	ND	ND	ND	ND	ND	ND
Trichloroethene	5.0	ND	8.0	ND	ND	ND	0.82[a]	ND	ND
Vinyl chloride	10	ND	1.3[a]	ND	ND	ND	ND	ND	ND
Method 8270C–Semivolatile organic compounds analyzed by GC/MS[e]									
Gamma-sitosterol	–	ND	ND	ND	ND	ND	ND	3,600[a,c]	ND
1-Heptadecene	–	ND	ND	ND	ND	ND	950[a,c]	ND	ND
Cholesterol	–	ND	ND	ND	ND	ND	2,100[a,c]	ND	ND
Docosane	–	ND	ND	ND	ND	ND	900[a,c]	ND	ND
Stigmast-4-en-3-one	–	ND	ND	ND	ND	ND	1,900[a,c]	ND	ND
Method 8081A–Semivolatile organic compounds analyzed by GC (Organochlorine Pesticides)									
4, 4'-DDT	1.7	ND	ND	ND	7.5	ND	4.2	ND	ND
4, 4'-DDT (duplicated by laboratory)	1.7	ND	ND	ND	7.8	ND	5.3	ND	ND
4, 4'-DDD	1.7	ND	ND	ND	ND	ND	0.94[a]	ND	ND
4, 4'-DDD (duplicated by laboratory)	1.7	ND	ND	ND	ND	ND	1.1[a]	ND	ND

[a] Estimated result–result is less than reporting limit
[b] Confident identification–major ions and ratios largely agree
[c] Result measured against nearest internal standard assuming a response factor of 1
[d] Associated method blank contains the target analyte at a reportable limit
[e] Tentatively identified

were termed "tentatively identified" by the laboratory. Only those constituents that were confidently identified and were present at concentrations greater than their reporting limits are discussed below. Unknown compounds were detected at all sites, including the reference site, and were not included in this report. There are no aquatic life or human health criteria for organic constituents associated with sediment in Virginia.

In April, the pesticide 4,4'-DDT was detected at a concentration greater than its reporting limit at site 4, and 1,1-dichloroethane, and 1,2-dichloroethene were greater than their reporting limits at site 2. DDT is a compound with very low solubility that strongly adheres to sediment particles; little degradation is expected. Its use in the United States has been banned since the 1970s. The compounds 1,1-dichloroethane and 1,2-dichloroethene also were detected in water samples collected at site 2 in both April and September. Under anaerobic conditions as in a landfill, 1,1-dichloroethane and 1,2-dichloroethene are degradation products of trichloroethene and tetrachloroethene, both of which also were detected in water samples in both April and September at site 2.

In September, the only organic constituent detected at a concentration greater than its reporting limit was 4,4'-DDT, at site 2. Similar to the majority of metal and nonmetal constituents associated with streambed sediment, 4,4'-DDT was found at the farthest downstream site (site 4) in April and near the landfill (site 2) in September.

Quality Control Samples

The results of analyses of QC samples associated with streambed sediment for each sampling date are in Appendixes 3 and 4. For metals and nonmetals, the laboratory method blanks show the detection of cadmium and cobalt in April and of beryllium, iron, and manganese in September. The concentration of each of these constituents is less than the reporting limit for each constituent, so that no qualification of environmental data is necessary. In the results for the September data, analysts noted that physical and chemical interference was present. The constituents that may have been affected by this interference are noted in table 11. Duplicate sediment samples collected at site 2 were comparable to the results for the original samples.

For organic constituents, the laboratory method blank for sediment in April showed detection of four compounds, two of which were unknowns and are not included in this report. A compound that results from an aldol reaction, generally described as "aldol condensation product," was detected in the laboratory method blank, but in no environmental samples. Methylene chloride, on the other hand, was detected in all samples, probably as a contaminant from its use as a solvent in the analysis. In September, methylene chloride again was detected in the blank as well as in all samples. Other compounds detected in September were chloroform, which was detected in no other sample, and four unknown compounds. All compounds detected in QC samples were at concentrations less than their reporting limits. No qualification of the results of organic compounds in sediment is necessary. A duplicate sample was collected at site 2, and results were comparable to the original sample.

Ecotoxicology

Ecological sampling and toxicity testing were done to assess stream conditions at the five sampled sites with regard to the benthic macroinvertebrate community. These assessments included the number of organisms and the state of the benthic macroinvertebrate community, stream habitat conditions, and toxicity of the organisms to the water and sediment collected near the landfill.

Benthic Macroinvertebrates

From samples collected in April, six of nine benthic macroinvertebrate community metrics were determined to be significantly different from normal (Shapiro-Wilk Test, α=0.05) (table 12). Data transformation increased the number of metrics that were distributed normally from three to four. An analysis of variance (ANOVA) (α=0.05) was conducted on the normal data, and nonparametric statistics were used to analyze data that did not meet the assumption of normality (nonparametric one-way, or NPAR1Way ANOVA, α=0.05). An NPAR1Way analysis was conducted on both the transformed and untransformed data that failed the assumption of normality (table 12). A General Linear Model (GLM, α=0.05) on ranked data was used to determine whether there were significant relations among all sites (Least Squares Difference, or LSD, α=0.05) (table 13).

The ANOVA conducted on the four metrics where data were normally distributed determined that there were significant differences among sites for stonefly abundance, mayfly abundance, percent mayfly abundance and EPT abundance (table 12). Nonparametric statistics on non-normal data determined that the five remaining metrics also were significantly different from

Table 12. Statistical analysis of benthic macroinvertebrate metrics for samples collected at Blue Ridge Parkway sampling sites in April 1999

[ANOVA, analysis of variance; NPAR1Way ANOVA, nonparametric one-way analysis of variance; EPT, Ephemeroptera/Plecoptera/Trichoptera; α, probability of incorrectly rejecting the null hypothesis; <, actual value is known to be less than value shown; n.a., not applicable]

Benthic macroinvertebrate metric	Normality (Shapiro-Wilk Test, α=0.05)	Normality after transformation (α=0.05)	ANOVA (α=0.05)	NPAR1Way ANOVA[a] (α=0.05)	NPAR1Way ANOVA[b] (α=0.05)
Abundance	0.0075	0.0013[c]	n.a.	0.0051	<0.0001
Taxa richness	0.0072	0.0017[c]	n.a.	0.0051	<0.0001
Caddisfly abundance	0.0101	0.0485[c]	n.a.	0.0055	<0.0001
Stonefly abundance	0.0024	0.0989[c]	<0.0001	n.a.	0.0030
Mayfly abundance	0.2092	Not needed	<0.0001	n.a.	n.a.
Percent mayfly abundance	0.3507	Not needed	<0.0007	n.a.	n.a.
EPT abundance	0.1015	Not needed	<0.0001	n.a.	n.a.
Percent EPT abundance	0.0069	0.0023[d]	n.a.	0.0034	0.0001
EPT richness	0.0098	0.0001[c]	n.a.	0.0171	0.0001

[a] Statistics conducted on transformed data
[b] Statistics conducted on untransformed data
[c] Square root transformation
[d] Percent arcsine (Asin) square root transformation

Table 13. Ranking and statistical analysis of sites for nine benthic macroinvertebrate metrics at Blue Ridge Parkway sampling sites in April 1999.

[Sites are ranked from high to low for each metric with high values generally associated with good water-quality conditions. Each outlined dark gray block contains a group of sites that do not differ significantly from each other. Light gray blocks contain an individual site that is significantly different from other sites.]

Benthic macroinvertebrate metric	Ranking of Sites				
	High				Low
Abundance	1	3-BC	4	3	2
Taxa richness	1	3-BC	3	4	2
Caddisfly abundance	1	3-BC	3	4	2
Stonefly abundance	3-BC	3	1	4	2
Mayfly abundance	1	3-BC	4	3	2
Percent mayfly abundance	1	3-BC	3	4	2
EPT abundance	1	3-BC	3	4	2
Percent EPT abundance	3-BC	1	3	4	2
EPT richness	3-BC	1	4		2
			4	3	

each other. Using both parametric and nonparametric statistics, significant differences among sites were determined for all nine benthic macroinvertebrate metrics assessed in April.

Site 1 was ranked highest (least degraded) for six of the nine metrics; site 3-BC was ranked highest three times (table 13). Site 2 was ranked lowest for all nine benthic macroinvertebrate metrics, and was significantly lower than the other sites for eight of the nine metrics. No environmentally sensitive orders of EPT were collected at site 2, nearest the landfill, and the only species found in all four replicates was the dipteran *Ptychoptera* (Ptychopteridae), an organism that is highly tolerant to environmental stress (app. 5). Other tolerant organisms at site 2 included snails (Physidae), worms (Oligochaeta), and other chironomids.

The mean abundance and taxa richness metrics were much lower at site 2 relative to all sites sampled in April 1999 (table 14). For example, mean abundance and taxa richness were 12.5 and 3.0 at site 2 compared to 120 and 18.8 at site 1. Caddisflies, stoneflies, and mayflies were not found at site 2; numbers of caddisflies and mayflies were highest at site 1 relative to sites 3, 3-BC, and 4. Mean stonefly abundance (34.5 organisms) was highest at site 3-BC (table 14). Sites 1, 2, 3, and 4 had significantly lower numbers of stoneflies relative to site 3-BC. Site 1 had the highest number of mayflies (65) and percent mayflies, representing 54 percent of the sample. Sites 3, 3-BC, and 4 had similar numbers for mayflies (23.5–37.8) and percent mayflies (34.3–38.2 percent). The highest EPT abundance was at site 1 (93.3). Site 3-BC had the highest percent EPT (82.4 percent) due to the large number of stoneflies collected there, followed by site 1 (77.6 percent). EPT richness was the same (12.0) at sites 1 and 3-BC.

The same nine benthic macroinvertebrate community metrics were evaluated for samples collected in September 1999 as for the April 1999 samples. Samples collected in September showed a substantial overall decrease from April in mean abundance and taxa richness, so that statistical differences were minimized among the nine metrics (table 15). For samples collected in September, six of the nine benthic macroinvertebrate metrics were determined to be statistically different from normal (Shapiro-Wilk Test, α=0.05); data transformation increased the number of metrics that were distributed normally from three to five. An ANOVA (α=0.05) was conducted on the normal data while nonparametric statistics were used to analyze data that did not meet the assumption of normality (NPAR1Way ANOVA, α=0.05) (table 15). An NPAR1Way analysis was conducted on both the transformed and untransformed data that failed the assumption of normality. As in April, a General Linear Model (GLM, α=0.05) on ranked data was used to determine whether there were significant relations among all sites in September (LSD, α=0.05) (table 16).

The ANOVA determined that there were significant differences among sites for four of the five metrics that were tested parametrically, including caddisfly abundance, EPT abundance, percent EPT abundance, and EPT richness. The NPAR1Way ANOVA (α=0.05) on transformed data determined that there were significant differences among all four metrics analyzed nonparametrically, including total abundance, stonefly abundance, mayfly abundance, and percent mayfly abundance. In summary, the results of both parametric and nonparametric ANOVAs revealed significant differences among all benthic macroinvertebrate metrics sampled in September, except for taxa richness.

Site 4 was ranked highest (least degraded) for five of the nine benthic macroinvertebrate metrics, with site 3-BC ranked highest four times (table 16). Site 2 was ranked lowest for all nine parameters, and was significantly lower than the other parameters four of nine times. Mean abundance was highest at site 3-BC (35.5) and site 4 (33.5), and both sites had the highest mean taxa richness (11.3) (table 17). Sites 3-BC and 4 were higher than the other sites for caddisfly abundance, stonefly abundance, EPT abundance, percent EPT abundance, and EPT richness. The organisms that were collected in September at site 2 were similar to those collected in April, and included organisms in the families Corydalidae, Sialidae, Dytiscidae, Hydrophilidae, and Tipulidae. The dipteran *Ptychoptera* (Ptychopteridae) continued to have the highest abundance followed by chironomids (Chironomidae) and snails (Physidae).

Comparisons of April and September samples showed that mean abundance was reduced at all sites in September except site 2 where mean abundance (12.5) was the same as in April 1999 (table 17). Site 2, however, was still lower than all other sites in mean abundance and taxa richness; again, no caddisflies, stoneflies or mayflies were collected. The decrease in the number of organisms collected in September compared with April 1999 probably was due to the extremely dry conditions from June to September. These differences may also be due to natural seasonal variance in organism emergence and (or) migration downstream in summer. Limited flow and reduced dilution capacity typically contribute to low survival and reproduction during the summer months.

Table 14. Mean values of benthic macroinvertebrate community metrics at each site for samples collected at Blue Ridge Parkway sampling sites in April 1999

[EPT, Ephemeroptera/Plecoptera/Trichoptera]

Benthic macroinvertebrate metric	Mean values				
	Site 1	Site 2	Site 3	Site 3-BC	Site 4
Abundance	120	12.5	69.5	99.5	97.0
Taxa richness	18.8	3.0	13.5	16.0	13.0
Caddisfly abundance	15.5	0.0	4.75	10.0	2.5
Stonefly abundance	12.8	0.0	15.0	34.5	3.75
Mayfly abundance	65.0	0.0	23.5	37.8	33.3
Percent mayfly abundance	54.1	0.0	35.3	38.2	34.3
EPT abundance	93.3	0.0	43.3	82.3	39.5
Percent EPT abundance	77.6	0.0	63.7	82.4	40.7
EPT richness	12.0	0.0	8.5	12.0	9.75

Table 15. Statistical analysis of benthic macroinvertebrate metrics for samples collected at Blue Ridge Parkway sampling sites in September 1999

[ANOVA, analysis of variance; NPAR1Way ANOVA, nonparametric one-way analysis of variance; EPT, Ephemeroptera/Plecoptera/Trichoptera; α, probability of incorrectly rejecting the null hypothesis; <, actual value is known to be less than value shown; n.a., not applicable]

Benthic macroinvertebrate metric	Normality (Shapiro-Wilk Test, (α=0.05)	Normality after transformation (α=0.05)	ANOVA (α=0.05)	NPAR1Way ANOVA[a] (α=0.05)	NPAR1Way ANOVA[b] (α=0.05)
Abundance	0.0002	0.0371[c]	n.a.	0.0437	0.0436
Taxa richness	0.1392	Not needed	0.1254	n.a.	n.a.
Caddisfly abundance	0.0002	0.0555[c]	0.0139	n.a.	0.0740
Stonefly abundance	0.0001	0.0188[c]	n.a.	0.0411	0.2323
Mayfly abundance	0.0021	0.0267[c]	n.a.	0.0259	0.1005
Percent mayfly abundance	0.0111	0.0091[d]	n.a.	0.0139	0.0141
EPT abundance	0.0002	0.2073[c]	0.0030	n.a.	0.1548
Percent EPT abundance	0.1163	Not needed	0.0001	n.a.	n.a.
EPT richness	0.1711	Not needed	0.0019	n.a.	n.a.

[a] Statistics conducted on transformed data

[b] Statistics conducted on untransformed data

[c] Square root transformation

[d] Percent arcsine (Asin) square root transformation

Table 16. Ranking and statistical analysis of sites for nine benthic macroinvertebrate metrics at Blue Ridge Parkway sampling sites in September 1999.

[Sites are ranked from high to low for each metric with high values generally associated with good water-quality conditions. Each outlined dark gray block contains a group of sites that do not differ significantly from each other. Light gray blocks contain an individual site that is significantly different from other sites; EPT, Ephemeroptera/Plecoptera/Trichoptera]

Benthic macroinvertebrate metric	Ranking of Sites				
	High				Low
Abundance	3-BC	4	3	1	2
Taxa richness	4	3-BC	1	3	2
Caddisfly abundance	4	3-BC	1	3	2
		3-BC	1	3	
Stonefly abundance	3-BC	4	1	3	2
			1	3	
Mayfly abundance	3-BC	3	4	1	2
Percent mayfly abundance	3-BC	3	4	1	2
			4	1	
EPT abundance	4	3-BC	3	1	2
Percent EPT abundance	4	3-BC			2
		3-BC	1	3	
EPT richness	4	3-BC	1	3	2

Table 17. Benthic macroinvertebrate community metric averages at each site for samples collected in September 1999

[EPT, Ephemeroptera/Plecoptera/Trichoptera]

Benthic macroinvertebrate metric	Site 1	Site 2	Site 3	Site 3-BC	Site 4
Abundance	27.3	12.5	29.3	35.5	33.5
Taxa richness	10.8	5.75	10.3	11.3	11.3
Caddisfly abundance	5.0	0.0	3.5	7.75	14.5
Stonefly abundance	4.25	0.0	3.0	10.3	5.75
Mayfly abundance	1.0	0.0	4.25	5.0	3.5
Percent mayfly abundance	2.5	0.0	14.4	14.5	10.6
EPT abundance	10.3	0.0	10.8	23.0	23.8
Percent EPT abundance	38.2	0.0	35.3	56.2	66.9
EPT richness	5.0	0.0	3.75	6.5	6.75

Habitat Assessment

Habitat assessment was conducted in September 1999 at the five sampled sites and at the Sinking Creek reference site. The Sinking Creek reference site was rated Excellent, and sites 1, 3, and 4 were rated Good to Excellent, reflecting the similarity in habitat among these sites (table 18). These three sites are slightly impaired by sediment-laden runoff from the headwater regions of both the unnamed stream and the sampled tributary. Site 3-BC was rated Good, but received a lower score (100) due to sediment loading and scouring below the confluence of the sampled tributary and the unnamed stream.

Site 2, which is affected by extensive erosion along both stream banks and adjacent riparian zones, was rated Fair. Stream bank erosion at site 2 results from storm flow through the overflow pipe that extends down the embankment from the landfill sedimentation pond as well as from the sides of the embankment and outer perimeter of the landfill property. Temporary retaining fences and riprap installed at the base of the embankment have offered minimal protection against erosion. Under storm conditions, the sampled tributary receives base flow from ground water as well as overflow water from the sedimentation pond once it reaches holding capacity from the surrounding landfill surface. This increased flow and volume of water have eroded and destabilized the stream banks.

Field Measurements

Field measurements were made on water samples collected from the 4-in. PVC pipe at site 2 between November 1998 and November 1999 (table 19). The samples appeared to have little or no turbidity, but at times had a pungent odor. Specific conductance values ranged from 510 to 850 $\mu S/cm^2$; DO concentration was highest in July (6.0 mg/L) and lowest in August and November (3.6 mg/L). Values for pH ranged from a high of 7.6 in December to a low of 5.8 in August. Alkalinity determined in samples returned to the laboratory varied from 326 to 380 mg/L as calcium carbonate except for a value of 160 mg/L, determined after the water sample was aerated for use in a chronic toxicity test. Flow from the 4-in. pipe was measured using a stopwatch and a 1-L bottle, and ranged from a low of 0.0012 ft^3/s in August and November 1999 to 0.0021 ft^3/s in July 1999.

Water Column Toxicity Testing

Acute 48-hr water column toxicity tests were conducted 11 times, between November 1998 and November 1999, using water collected from the 4-in. PVC pipe at site 2. LC_{50} values ranged from 45.6 to 84.1 at 100-percent sample concentration (table 20). The water sample from site 2 was considered acutely toxic in 10 of the 11 tests when a 48-hr LC_{50} value was generated. All 11 acute tests had at least 30-percent mortality at 100-percent sample concentration, with the greatest mortality occurring in March and November 1999 when 90 percent of the test organisms died.

Chronic toxicity endpoint values, the "no observable adverse effects concentration" (NOAEC) and "lowest observable adverse effects concentration" (LOAEC) for survival and reproduction, were determined for *C. dubia* exposed over a 7-day period to water from site 2 (Fisher's Exact Test, Steel's Many-One Rank Test, α=0.05). The NOAEC is the lowest test concentration of the water from the PVC pipe at site 2 that was considered to be nontoxic for either survival or reproduction. The NOAEC for survival was 25-percent sample concentration and 12.5 percent for reproduction. This means that 12.5 parts of water from site 2 was diluted with 87.5 parts dilution water to cause no toxic effect to reproduction for the test organisms. The LOAEC indicated that survival of test organisms was impaired at 50-percent

Table 18. Habitat assessment of sites sampled near the Blue Ridge Parkway, September 1999, and for the Sinking Creek reference

Site	Habitat assessment score	Rating	Observations
Site 1	107	Good to Excellent	Some sediment deposition in pools
Site 2	59	Fair	Heavy sedimentation and erosion of banks
Site 3	107	Good to Excellent	Some sediment deposition in pools
Site 3-BC	100	Good	Some sediment deposition and scouring
Site 4	107	Good to Excellent	Some sediment deposition in pools
Sinking Creek reference site	117	Excellent	No visible signs of impairment

Table 19. Field measurements made in association with collection of water from the polyvinyl chloride pipe at site 2 for toxicity tests

[°C, degrees Celsius; µS/cm, microsiemens per centimeter, mg/L, milligrams per liter; PVC, polyvinyl chloride; ft^3/s, cubic feet per second; *, date when water chemistry, bottom sediment chemistry and benthic invertebrate samples were collected; –, no measurement made]

Date	Water temperature, in °C	Specific conductance, in µS/cm	Dissolved oxygen concentration, in mg/L	pH, in standard units	Alkalinity, in mg/L	Discharge from PVC pipe, in ft^3/s
11/29/98	–	600	–	6.3	326	0.0015
12/9/98	–	510	5.3	7.6	–	–
2/18/99	–	700	5.8	6.0	360	0.0015
2/19/99	–	700	4.8	6.0	340	–
3/12/99	–	720	4.8	6.1	340	0.0015
*4/26/99	–	690	–	6.5	160[a]	–
6/18/99	–	670	4.8	6.0	–	0.0015
7/24/99	18.8	690	6.0	6.1	–	0.0021
7/30/99	18.9	650	6.0	6.1	380	0.0021
8/2/99	18.7	620	4.2	5.8	360	–
8/26/99	17.5	660	3.6	6.0	330	0.0012
9/6/99	18.9	750	4.0	5.9	360	0.0018
*9/8/99	–	–	–	–	–	–
10/14/99	18.0	750	4.0	6.0	352	0.0015
11/28/99	17.0	850	3.6	6.0	360	0.0012

[a]Sample aerated prior to alkalinity measurement

Table 20. Results of 48-hour acute toxicity tests for water samples collected from the polyvinyl chloride pipe near site 2, Blue Ridge Parkway, Virginia

[LC_{50} value, the concentration that causes 50-percent mortality of the test organisms after a defined period of exposure; ft^3/s, cubic feet per second]

Test date	LC_{50} value	Estimated discharge, in ft^3/s	Test conducted	Mortality in 100-percent sample concentration, in percent
11/29/98	84.1	0.0015	Full acute[a]	65
1/26/99	72.6	.0014	Full acute	80
2/18/99	84.1	.0015	Full acute	65
3/12/99	45.6	.0015	Range finding[b]	90
6/18/99	None	.0015	Full acute	30
7/23/99	72.6[c]	.0021	Range finding	80
7/30/99	73.5	.0021	Full acute	80
8/26/99	70.7	.0012	Full acute	85
9/6/99	76.5	.0018	Full acute	80
10/14/99	74.9	.0015	Full acute	75
11/28/99	70.7	.0012	Full acute	90

[a]Full acute test is composed of five different dilutions of sample water and one control; four replicates are done, each with 20 organisms

[b]Range finding test is composed of 100-percent and 50-percent sample water and one control, and is used in determining a range of toxicity in preparation for the next full acute test

[c]Approximate LC_{50} value estimated from 80-percent mortality in a 100-percent water sample

site sample concentration, and reproduction was affected at 25-percent sample concentration.

Sediment Toxicity Testing

In April 1999, *Chironomus* (midge) survival ranged from 64 percent at site 4 to 98 percent at both site 1 and at the Sinking Creek reference site (table 21). Survival for chironomids in sediments at sites 3 and 4 was significantly lower (Fisher's Exact Test, α=0.05) than at the two reference sites.

Chironomid weight ranged from 3.60 mg at site 4 to 4.04 at Sinking Creek and 4.49 mg at site 1. The mean midge weight at site 2 was 3.72 mg. No significant differences were found among sites for chironomid weight (Dunnett's Test, α=0.05).

At site 2, survival was high (80 percent), and mean weight was comparable to that at other sites, including the Sinking Creek reference site. *Ceriodaphnia* had substantial mortality to the sample from site 2 after 2 days, while *Chironomus* survival was high after a 10-day test exposure. This suggests that the midge was highly tolerant to the conditions at site 2.

Daphnia survival of sediment toxicity tests in April ranged from 100 percent using Sinking Creek sediment and sediment from site 3, to 87.5 percent using sediment from sites 1, 2, and 4 (table 22) with no significant differences found among sites for survival (Fisher's Exact Test, α=0.05). *D. magna* reproduction was significantly lower at site 2, however, than at the other three sampling sites and at the Sinking Creek site. The mean number of neonates ranged from a high of 27.1 using Sinking Creek sediments to a low of 16.8 using sediment from site 2 (Dunnett's Test, α=0.05). *D. magna* has been reported to be a more sensitive test organism to environmentally stressed conditions than *C. tentans* (Yeager, 1994). That difference in sensitivity was confirmed in this study.

For samples collected in September, *D. magna* survival in the Sinking Creek reference sediments was 100 percent, with survival at 87.5 percent at sites 1 and 3, and 75 percent at site 4. No significant differences were observed among these four sites for survival. *D. magna* survival was significantly lower at site 2 at only 37.5 percent.

Mean neonate production in September ranged from a high of 23.1 in sediments and water from Sinking Creek to 13.4 at site 3. Sites 1 and 4 were similar, with 18.9 and 18.8 neonates produced, respectively (table 22). Site 2 had the lowest neonate production (6.25) and was significantly different from the other sites for reproduction. Toxicity testing using *Chironomus* was not conducted in September 1999 due to poor organism condition prior to testing.

Summary and Conclusions

Until its closure in 1995, the primary landfill for Roanoke City and County, Va., situated near the Blue Ridge Parkway, received a variety of solid wastes for nearly 20 years. This report presents the results of a study by the U. S. Geological Survey and Virginia Polytechnic Institute and State University, in cooperation with the National Park Service, to examine the effects of the closed landfill on the water chemistry, the streambed sediment chemistry, and the benthic macroinvertebrate community of an unnamed stream and a tributary to that stream. The primary water source for the tributary is a 4-inch polyvinyl chloride (PVC) pipe, which protrudes from the slope at the base of the embankment bordering the landfill. An expanse of precipitate in the stream near the PVC pipe indicated unusual stream conditions. The tributary flows through National Park Service land, and merges with the unnamed stream prior to discharging into the Roanoke River. Stream discharge was measured and water and streambed sediment samples collected at four sites on the stream and its tributary in April and September 1999. Water samples were analyzed for major ions, nitrate, total and dissolved metals, total dissolved solids, total organic carbon, and volatile and semivolatile organic compounds, including organochlorine pesticides and polychlorinated biphenyls (PCBs). Streambed sediment samples were analyzed for total metals, total organic carbon, percent moisture, and volatile and semivolatile organic compounds, including organochlorine pesticides and PCBs.

Field ecotoxicological measurements were made at the four sites sampled for water and streambed sediment and at one additional site; habitat quality was assessed and benthic macroinvertebrates were collected and evaluated using the Rapid Bioassessment Protocols of the U.S. Environmental Protection Agency. Water samples collected from the 4-inch PVC pipe at site 2, and sediment samples collected at site 2 from November 1998 to November 1999 were used to conduct 48-hour acute and 7-day chronic toxicity tests using selected laboratory test organisms. Two 10-day chronic toxicity tests of streambed sediments collected near the discharge pipe also were conducted.

In April, concentrations of 79 percent of inorganic constituents detected in water samples were higher at the site nearest the landfill than at all other sites, while in

Table 21. *Chironomus tentans* percent survival and mean weight, from 10-day chronic toxicity tests of streambed sediment samples collected near the Blue Ridge Parkway, and at the Sinking Creek reference site, April 1999

[mg, milligrams]

Site	Survival, in percent	Significant (α =0.05)	Mean weight, in mg	Significant (α =0.05)
Site 1	98	No	4.49	No
Site 2	80	Yes	3.72	No
Site 3	100	No	4.03	No
Site 4	64	Yes	3.60	No
Sinking Creek reference site	98	No	4.04	No

Table 22. *Daphnia magna* percent survival and mean neonate production, from 10-day chronic toxicity tests of streambed sediment samples collected near the Blue Ridge Parkway, and at the Sinking Creek reference site, April and September 1999

Site	April				September			
	Survival, in percent	Significant (α =0.05)	Mean number of neonates	Significant (α =0.05)	Survival, in percent	Significant (α =0.05)	Mean number of neonates	Significant (α =0.05)
Site 1	87.5	No	20.4	No	87.5	No	18.9	No
Site 2	87.5	No	16.8	Yes	37.5	Yes	6.25	Yes
Site 3	100	No	24.1	No	87.5	No	13.4	No
Site 4	87.5	No	19.4	No	75	No	18.8	No
Sinking Creek reference site	100	No	27.1	No	100	No	23.1	No

September, highest concentrations were distributed between the landfill site (52 percent) and the next site downstream (42 percent). This is an indication that constituents were discharged from the landfill into the stream. The changed distribution of constituents in September may be a result of a storm that occurred two days before sampling, although prior to sampling, water levels had returned to low levels that had existed prior to the storm. Water at the site near the landfill showed little change in median concentrations of total metals, dissolved metals, and nonmetals from April to September, and had low dissolved oxygen and relatively low pH, indicating a consistent ground-water source for these constituents. Concentrations of many inorganic constituents in water remained higher at the farthest downstream site than the reference site in April and September.

In contrast, concentrations of constituents associated with sediment were lowest near the landfill in April and increased at downstream sites. These conditions were probably a consequence of low pH-low dissolved oxygen waters within the landfill that allowed some inorganic constituents (such as metals) to remain in solution near the landfill, resulting in low concentrations in the streambed sediments until exposed to atmospheric oxygen. The constituents in solution precipitated out onto sediment particles and the streambed itself as the dissolved oxygen concentration increased downstream; the highest concentrations for 59 percent of constituents detected in streambed sediment in April, including lead, zinc, and copper, occurred at the site farthest downstream, near the Roanoke River. In September, 60 percent of higher constituent concentrations associated with sediment were closest to the landfill, and concentrations of many constituents decreased downstream. Higher streamflows resulting from the storm prior to sampling probably scoured out the pool and the surficial layer of precipitate near the landfill along with the streambed. This redistribution of sediments may have disrupted the water-sediment chemical equilibrium.

Most of the 17 organic compounds detected in water were at the site near the landfill. Organic constituents detected were primarily industrial and (or) manufacturing solvents, and included volatile organic and semivolatile organic compounds, some of which had been detected in ground-water monitoring wells at the periphery of the landfill. Because of their volatility, the compounds were not detected in water at sites downstream of the landfill. A total of 17 discrete organic compounds were detected in sediment samples in either April or September, and concentrations of most were below their respective reporting limits. Organic compounds detected above their reporting limits in sediment in April included trichloroethene and tetrachloroethene, along with their degradation products, 1, 1-dichloroethane and 1,2-dichloroethene, at the site near the landfill; and 4,4' DDT, at the most downstream site. In September, 4,4' DDT was detected at the site closest to the landfill.

The site closest to the landfill (site 2) not only showed limited macroinvertebrate abundance but also had minimal taxa richness (0-3 in April and 5.75 in September 1999). Contaminated sediments impaired the habitat quality, thus reducing numbers of the most sensitive insect orders. Mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera), or EPT, were especially affected. The benthic macroinvertebrate community also appeared to be affected at the site on the sampled tributary just before the confluence with the unnamed stream (site 3), especially in April 1999, with only 58 percent of the abundance there relative to the reference site. In the September 1999 sampling, however, abundance and taxa richness metrics were slightly higher at this site than at the reference site, perhaps due to the limiting drought conditions at the reference site. There was no detectable difference in the macroinvertebrate community metrics along the unnamed stream from site 1 to site 3-BC to site 4 for either sampling period.

Overall, evaluation of nine benthic macroinvertebrate community metrics indicated significant effects on the macroinvertebrates only at the site closest to the landfill. The main groupings of macroinvertebrates found at this site consisted of snails, worms, and dipterans, all representing tolerant taxa; the sensitive EPT orders were absent. All benthic macroinvertebrate community metrics indicated significantly better conditions at the reference site in comparison to the site nearest the landfill. The reference site averaged as many as 93.2 organisms, ranging from 84 to 102 among four replicate samples. Acute toxicity tests indicated toxic conditions in water samples from the 4-inch PVC pipe 10 out of 11 times between November 1998 and November 1999. Test organism mortality in water samples from the landfill at 100-percent concentration ranged from 65 to 90 percent and generated 48-hr LC_{50} values from 45.6 to 84.1 percent. Chronic water-column testing indicated impairment of *Ceriodaphnia dubia* at 50-percent sample concentration, with reproductive impairment occurring down to 25-percent sample concentration. Results from sediment toxicity tests with *Daphnia magna* indicated significant differences for reproduction in sediment from the site close to the landfill in relation to the others in the watershed. The three most notable factors indicating stressed and (or) impacted conditions in the stream near the land-

fill consisted of (1) the layer of fine metal oxide precipitate in the streambed at and below the site nearest the landfill; (2) the significantly depressed numbers of benthic macroinvertebrates, particularly of sensitive or pollution-intolerant groups; and (3) the consistent acute toxicity of water to *Ceriodaphnia dubia*.

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Appendixes 1-6

Appendix 1. Results of quality assurance samples for inorganic constituents and organic carbon in water at Blue Ridge Parkway sampling sites, April and September 1999

[µg/L, micrograms per liter; ND, not detected; –, not analyzed]

Analyte	Method number	Reporting limit, in µg/L	Concentration, in µg/L					
			April			September		
			Site 2 replicate	Method blank	Equipment blank	Site 2 replicate	Method blank	Equipment blank
Nonmetals								
Dissolved solids, total	160.1	10,000	468,000	ND	–	395,000	7[a]	–
Organic carbon, total	9060	1,000	5,900	ND	–	4,700	620[a]	–
Chloride	300.0A	3,000	52,600[b]	ND	–	24,700	940[c]	–
Fluoride	300.0A	1,000	240[a]	ND	–	230[a]	ND	–
Sulfate	300.0A	5,000	4,000[a]	ND	–	2,500[a]	ND	–
Metals								
Aluminum, dissolved	6010B	100	54[a]	43[a]	53[a]	ND	ND	ND
Aluminum, total	6010B	100	27[a]	52[a]	–	ND	ND	–
Antimony, dissolved	6020	2	ND	0.54[a]	ND	ND	ND	ND
Arsenic, dissolved	6020	5	1.1[a]	ND	ND	0.96[a]	ND	ND
Arsenic, total	6020	5	0.91[a]	ND	–	0.94[a]	ND	–
Barium, dissolved	6010B	10	540	ND	ND	550	ND	ND
Barium, total	6010B	10	540	ND	–	560	ND	–
Calcium, dissolved	6010B	200	70,300	ND	ND	65,000	ND	ND
Calcium, total	6010B	200	69,100	ND	–	64,700	ND	–
Cobalt, dissolved	6010B	10	22	ND	ND	25	ND	ND
Cobalt, total	6010B	10	19	ND	–	26	ND	–
Iron, dissolved	6010B	100	8,970	ND	ND	11,700	10[a]	25[a]
Iron, total	6010B	100	9,100	7.7[a]	–	11,700	ND	–
Lead, dissolved	6020	1	0.13[a]	ND	ND	0.082[a]	ND	ND
Lead, total	6020	1	0.094[a]	ND	–	ND	ND	–
Magnesium, dissolved	6010B	200	37,000	ND	14[a]	31,900	ND	ND
Magnesium, total	6010B	200	36,200	24[a]	–	31,800	ND	–
Manganese, dissolved	6010B	10	3,200	ND	ND	3,300	ND	ND
Manganese, total	6010B	10	3,200	ND	–	3,300	ND	–
Potassium, dissolved	6010B	5,000	5,600	ND	ND	4,700[a]	ND	ND
Potassium, total	6010B	5,000	5,400	ND	–	4,800[a]	ND	–
Sodium, dissolved	6010B	5,000	36,000	600[a]	980[a]	23,400	680[a]	640[a]
Sodium, total	6010B	5,000	35,800	1,700[a]	–	23,000	ND	–
Vanadium, total	6010B	10	ND	ND	–	1.7[a]	ND	–
Zinc, dissolved	6010B	20	3.3[a]	ND	ND	6.1[a]	ND	3.7[a]
Zinc, total	6010B	20	5.2[a]	ND	–	7[a]	3.5[a]	–

[a] Estimated result-result is less than reporting limit

[b] Elevated reporting limit due to high analyte levels

[c] Associated method blank contains the target analyte at a reportable level

Appendix 2. Quality assurance samples collected for organic constituents in water at Blue Ridge Parkway sampling stations, April and September 1999

[µg/L, micrograms per liter; GC/MS, gas chromatography/mass spectrometry]

Analyte	Reporting limit, in µg/L	Concentration, in µg/L						
		April				September		
		Site 2 replicate	Equipment blank	Trip blank	Laboratory method blank	Equipment blank	Trip blank	Laboratory method blank
Method 8260B–Volatile organic compounds analyzed by GC/MS								
1,1-Dichloroethane	2	28	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	2	2.4	ND	ND	ND	ND	ND	ND
cis-1,2-Dichloroethene	2	59	ND	ND	ND	ND	ND	ND
trans-1,2-Dichloroethene	1	1.2	ND	ND	ND	ND	ND	ND
1,2-Dichloroethene (total)	2	60	ND	ND	ND	ND	ND	ND
1,2-Dichloropropane	2	2.5	ND	ND	ND	ND	ND	ND
Benzene	2	9.7	ND	ND	ND	ND	ND	ND
Chlorobenzene	2	0.72[a]	ND	ND	ND	ND	ND	ND
Chloroethane	4	5.4	ND	ND	ND	ND	ND	ND
Ethylbenzene	2	8.2	ND	ND	ND	ND	ND	ND
Methylene chloride	2	4.6	ND	ND	0.37[a]	ND	0.37[a,b]	ND
Tetrachloroethene	2	8.1	ND	ND	ND	ND	ND	ND
Toluene	2	18	ND	ND	ND	ND	ND	ND
Trichloroethene	2	16	ND	ND	ND	ND	ND	ND
Vinyl chloride	4	6.5	ND	ND	ND	ND	ND	ND
Xylenes (total)	2	56	ND	ND	ND	ND	ND	ND
Method 8270C–Semivolatile organic compounds analyzed by GC/MS								
1,4-Dichlorobenzene	10	10	ND	ND	ND	ND	ND	ND

[a] Estimated value-value is less than reporting limit

[b] Associated method blank contains the target analyte at a reportable level

Appendix 3. Results of quality assurance samples collected for inorganic constituents, total organic carbon, and percent moisture in streambed sediment at Blue Ridge parkway sampling sites, April and September 1999

[mg/kg, milligrams per kilograms; µg/kg, micrograms per kilogram; ND, not detected; – analysis not done or reported at different level for that constituent; ASTM, American Society of Testing and Materials]

Analyte	Method	Units	Reporting limit	April		September	
				Laboratory method blank	Site 2 replicate	Laboratory method blank	Site 2 replicate
Aluminum	6010B	mg/kg	10	ND	3,630	ND	9,970[a]
Arsenic	6020	µg/kg	500	ND	1,190	–	–
Arsenic	6020	mg/kg	10	–	–	ND	1.0
Barium	6010B	mg/kg	1.0	ND	86.1	ND	113[a]
Beryllium	6010B	mg/kg	0.2	ND	0.62	0.093[b]	1.5
Cadmium	6010B	mg/kg	0.2	0.062[b]	ND	ND	0.55
Calcium	6010B	mg/kg	20	ND	1260	ND	2,850[a]
Chromium	6010B	mg/kg	1.0	ND	2.0	ND	9.5[a]
Cobalt	6010B	mg/kg	1.0	0.22[b]	3.1	ND	5.3[a]
Copper	6010B	mg/kg	2.0	ND	1.9[b]	ND	5.7
Iron	6010B	mg/kg	10	ND	38,500	2.6[b]	41,200
Lead	6020	µg/kg	100	ND	2,680	–	–
Lead	6020	mg/kg	0.1	–	–	ND	8.6
Magnesium	6010B	mg/kg	20	ND	628	ND	2,080[a]
Manganese	6010B	mg/kg	1.0	ND	82.9	0.065[b]	193[a]
Mercury	7471A	mg/kg	0.033	ND	ND[b]	ND	0.011[b]
Molybdenum	6010B	mg/kg	2.0	ND	1.2[b]	ND	ND[b]
Nickel	6010B	mg/kg	4.0	ND	1.9[b]	ND	3.0
Potassium	6010B	mg/kg	500	ND	263[b]	ND	844
Selenium	6020	µg/kg	500	ND	173	–	–
Selenium	6020	mg/kg	0.50	–	–	ND	0.15[b]
Silver	6010B	mg/kg	1.0	ND	0.57[b]	ND	ND
Thallium	6020	ug/kg	100	ND	44.6	ND	ND
Total Organic Carbon	9060	mg/kg	2,000	ND	36,800	ND	12,500
Vanadium	6010B	mg/kg	1.0	ND	8.9	ND	25.7[a]
Zinc	6010B	mg/kg	2.0	ND	34.7	ND	70.9[a]
Percent Moisture	ASTM	%	0.2	–	88.8	–	65.6

[a] Serial dilution of a digestate in the analytical batch indicates that physical and chemical interferences are present

[b] Estimated result -result is less than reporting limit

Appendix 4. Results of quality assurance samples collected for organic constituents in streambed sediment at Blue Ridge sampling sites, April and September 1999

[ug/kg, micrograms per kilogram; GC/MS, gas chromatography/mass spectrometry; ND, not detected; –, not determined]

Analyte	Reporting limit	Concentration, in µg/kg			
		April		September	
		Method blank	Site 2 replicate	Method blank	Site 2 replicate
Method 8260B–Volatile organic compounds analyzed by GC/MS					
1,1-Dichloroethane	5.0	ND	15	ND	2.9[a]
1,2-Dichloroethene (total)	5.0	ND	12	ND	1.6[a]
1,2-Dichloropropane	5.0	ND	0.65[a]	ND	ND
Acetone	20	ND	11[a]	ND	ND
Benzene	5.0	ND	1.7[a]	ND	ND
Chloroethane	10	ND	1.7[a]	ND	ND
Chloroform	5	ND	ND	1.3[a]	ND
cis-1,2-Dichloroethene	2.5	ND	12	ND	1.6[a]
Methylene chloride	5.0	1.2[a]	2.7[a,b]	4.6[a]	0.79[a,b]
Tetrachloroethene	5.0	ND	16	ND	ND
Trichloroethene	5.0	ND	7.0	ND	0.83[a]
Method 8270C–Semivolatile organic compounds analyzed by GC/MS					
Aldol condensation product	–[c]	32,000[a]	ND	ND	ND
Method 8081A–Semivolatile organic compounds analyzed by GC (Organochlorine Pesticides)					
beta-BHC	1.7	ND	ND	ND	0.8[a]

[a] Estimated result-result is less than reporting limit

[b] Method blank contamination-the associated method blank contains the target analyte at a reportable level

[c] Result was measured against nearest internal standard assuming a response factor of 1

Appendix 5. Benthic macroinvertebrates collected at Blue Ridge Parkway sites and resultant summary statistics, April 1999

[A-D, replicate identifier; TOT, replicate total; AVG, average; –, not found]

Taxon	Family	Genus	Site 1					Site 2					Site 3					Site 3-BC					Site 4				
			A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT
Gastropoda	Physidae	*Physella*	1	–	1		2	–	–	7	3	10	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
Oligochaeta	–	–		–	–	–	–	2	–	8	1	11	1	5	–	2	8	–	–	1	–	1	–	–	–	–	–
Decapoda	Cambaridae	–	2	3	3	3	11	–	–	–	–	–	3	–	2	1	6	–	–	1	–	1	1	–	1	–	2
Collembola	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Ephemeroptera	Baetidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	–	4
Ephemeroptera	Baetidae	*Labiobaetis*	–	–	–	–	–	–	–	–	–	–	–	6	11	4	21	3	–	9	–	12	–	6	11	8	25
Ephemeroptera	Baetidae	*Paracloeodes*	2	4	2	3	11	–	–	–	–	–	–	7		24	31	2	2	2	2	8	2	–	2	6	10
Ephemeroptera	Ephemeridae	*Ephemera*	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	1	–	–	1	–	–	1	1	2
Ephemeroptera	Ephemerellidae	*Ephemerella*	21	38	22	27	108	–	–	–	–	–	3	4	1	7	15	16	23	16	27	82	7	10	6	8	31
Ephemeroptera	Ephemerellidae	*Eurylophella*	1	2	1	1	5	–	–	–	–	–	–	–	1	–	1	–	1	–	–	1	2	4	1	–	7
Ephemeroptera	Heptageniidae	*Stenonema*	6	3	10	8	27	–	–	–	–	–	3	1	–	–	4	7	5	4	5	21	–	12	5	1	18
Ephemeroptera	Leptophlebiidae	*Leptophlebia*	1	2	–	1	4	–	–	–	–	–	–	–	1	1	2	4	–	–	–	4	–	2	–	3	5
Ephemeroptera	Siphlonuridae	*Ameletus*	35	18	20	32	105	–	–	–	–	–	–	1	11	7	19	4	17	1	–	22	12	10	3	6	31
Odonata	Cordulegastridae	*Cordulegaster*	5	2	4	4	15	–	–	–	–	–	–	2	1	–	3	–	–	–	–	–	–	1	1	1	3
Odonata	Gomphidae	*Stylogomphus*	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	1	–	1	–	–	–	–	–
Plecoptera	Capniidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	2	–	–	–	–	–
Plecoptera	Nemouridae	*Amphinemura*	5	4	6	5	20	–	–	–	–	–	10	19	22	3	54	10	31	4	40	85	1	6	–	–	7
Plecoptera	Peltoperlidae	*Tallaperla*	4	10	5	5	24	–	–	–	–	–	–	–	2	–	2	11	10	11	7	39	–	1	–	–	1
Plecoptera	Perlidae	*Acroneuria*	1	2	1	2	6	–	–	–	–	–	–	–	–	–	–	2	1	–	–	3	–	–	–	–	–
Plecoptera	Perlidae	*Eccoptura*	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	3	–	1	–	4	–	2	–	1	3
Plecoptera	Perlodidae	*Isoperla*	–	–	–	–	–	–	–	–	–	–	1	1	2	–	4	2	1	2	–	5	–	2	–	2	4
Megaloptera	Corydalidae	*Nigronia*	1	3	4	3	11	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	–	–	–	–
Megaloptera	Sialidae	*Sialis*	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Trichoptera	Brachycentridae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	2	–	–	–	–	–
Trichoptera	Hydropsychidae	*Cheumatopsyche*	6	7	8	7	28	–	–	–	–	–	–	1	1	–	2	5	4	6	9	24	–	1	–	–	1
Trichoptera	Hydropsychidae	*Hydropsyche*	–	–	–	–	–	–	–	–	–	–	3	–	10	1	14	–	–	–	–	–	–	2	–	3	5
Trichoptera	Limnephilidae	*Pycnopsyche*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Trichoptera	Philopotamidae	*Wormaldia*	1	2	2	2	7	–	–	–	–	–	–	–	–	–	–	–	1	2	–	3	1	–	1	–	2
Trichoptera	Rhyacophilidae	*Rhyacophila*	7	5	7	8	27	–	–	–	–	–	1		1	1	3	3	4	3	1	11	–	–	–	1	1
Coleoptera	Elmidae	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	1	1
Coleoptera	Hydrophilidae	–	–	–	–	–	–	1	–	–	–	1	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–
Diptera	Chironomidae	–	10	10	12	8	40	1	6	–	–	7	7	28	39	5	79	5	12	20	12	49	75	35	60	50	220
Diptera	Ptychopteridae	*Ptychoptera*	–	–	–	–	–	2	12	3	4	21	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Appendix 5. Benthic macroinvertebrates collected at Blue Ridge Parkway sites and resultant summary statistics, April 1999—Continued

[A-D, replicate identifier; TOT, replicate total; AVG, average; –, not found]

Taxon	Family	Genus	Site 1					Site 2					Site 3					Site 3-BC					Site 4				
			A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT
Diptera	Simuliidae	–	2	2	1	3	8	–	–	–	–	–	–	–	–	–	–	1	–	2	–	3	–	–	–	–	–
Diptera	Tipulidae	*Antocha*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–
Diptera	Tipulidae	*Tipula*	4	5	6	4	19	–	–	–	–	–	1	2	1	–	4	2	4	3	2	11	1	2	–	–	3
		Replicate and site totals	115	123	115	127	480	6	18	18	8	50	35	78	108	57	278	81	120	90	107	398	102	101	93	92	388
		Summary Statistic	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**
		Abundance	115	123	115	127	120	6	18	18	8	12.5	35	78	108	57	69.5	81	120	90	107	99.5	102	101	93	92	97
		Taxa richness	19	19	18	19	18.75	4	2	3	3	3	12	13	17	12	13.5	17	17	19	11	16	9	17	12	14	13
		Caddisfly (Trichoptera) abundance	14	14	17	17	15.5	–	–	–	–	–	4	1	12	2	4.75	8	11	11	10	10	1	3	2	4	2.5
		Stonefly (Plecoptera) abundance	10	16	12	13	12.75	–	–	–	–	–	11	20	26	3	15	29	44	18	47	34.5	1	11	–	3	3.75
		Mayfly (Ephemeroptera) abundance	66	67	55	72	65	–	–	–	–	–	6	19	26	43	23.5	36	49	32	34	37.75	23	48	29	33	33.25
		Percent mayfly	57.39	54.47	47.82	56.69	54.09	0	0	0	0	0	17.14	24.35	24.07	75.43	35.25	44.44	40.83	35.55	31.77	38.15	22.54	47.52	31.18	35.86	34.28
		EPT abundance	90	97	84	102	93.25	–	–	–	–	–	21	40	64	48	43.25	73	104	61	91	82.25	25	62	31	40	39.5
		EPT richness	12	12	11	13	12	–	–	–	–	–	6	8	12	8	8.5	14	15	12	7	12	6	13	9	11	9.75
		Percent EPT	78.26	78.86	73.04	80.31	77.62	0	0	0	0	0	60	51.28	59.25	84.21	63.68	90.12	86.66	67.77	85.04	82.4	24.5	61.38	33.33	43.47	40.67

Appendix 6. Benthic macroinvertebrates collected at Blue Ridge Parkway sites and resultant summary statistics, September 1999

[A-D, replicate identifier; TOT, replicate total; AVG, average; –, not found]

Taxon	Family	Genus	Site 1					Site 2					Site 3					Site 3-BC					Site 4				
			A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT
Gastropoda	Physidae	*Physella*	–	–	–	–	–	1	1	5	1	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oligochaeta	–	–	–	–	4	–	4	–	4	–	–	4	–	–	2	1	3	–	–	–	–	–	–	–	–	–	–
Decapoda	Cambaridae	–	1	4	7	2	14	–	–	–	–	–	9	5	2	–	16	4	3	6	2	15	1	3	4	1	9
Ephemeroptera	Baetidae	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–
Ephemeroptera	Baetidae	*Labiobaetis*	–	–	1	–	1	–	–	–	–	–	–	2	–	–	2	5	–	–	3	8	–	–	–	–	–
Ephemeroptera	Baetidae	*Paracloeodes*	–	–	1		1	–	–	–	–	–	6	3	3	–	12	–	–	1	–	1	–	–	–	–	–
Ephemeroptera	Ephemeridae	*Ephemera*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	1	–	–	–	1
Ephemeroptera	Ephemerellidae	*Ephemerella*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ephemeroptera	Ephemerellidae	*Eurylophella*	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	–	–	–	–	–	–	–	1	–	1
Ephemeroptera	Heptageniidae	*Leucrocuta*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–
Ephemeroptera	Heptageniidae	*Stenonema*	–	–	2	–	2	–	–	–	–	–	–	–	–	–	–	6	2	–	1	9	6	1	2	3	12
Odonata	Calopterygidae	*Calopteryx*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	–	–	4	–	–	–	–	–
Odonata	Cordulegastridae	*Cordulegaster*	–	–	3	3	6	–	–	–	–	–	3	–	–	1	4	–	1	–	–	1	–	–	–	–	–
Odonata	Gomphidae	*Stylogomphus*	–	–	1	2	3	–	–	–	–	–	1	1	3	1	6	–	–	–	–	–	1	–	–	–	1
Plecoptera	Capniidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plecoptera	Leuctridae	–	–	–	1	4	5	–	–	–	–	–	–	5	–	–	5	–	1	–	–	1	–	–	2	1	3
Plecoptera	Nemouridae	*Amphinemura*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plecoptera	Peltoperlidae	*Tallaperla*	–	–	–	1	1	–	–	–	–	–	–	1	2	1	4	24	1	2	1	28	3	1	4	5	13
Plecoptera	Perlidae	*Acroneuria*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	1	2	–	3
Plecoptera	Perlidae	*Eccoptura*	–	2	5	2	9	–	–	–	–	–	–	–	–	2	2	1	–	1	1	3	2	–	–	2	4
Plecoptera	Perlodidae	*Isoperla*	2	–	–	–	2	–	–	–	–	–	–	–	–	1	1	5	3	–	1	9	–	–	–	–	–
Megaloptera	Corydalidae	*Nigronia*	–	–	–	–	–	1	–	2	1	4	–	3	1	–	4	4	1	1	1	7	1	1	1	–	3
Megaloptera	Sialidae	*Sialis*	–	–	–	–	–	–	1	1	–	2	–	–	–	–	–	1	1	2	–	4	–	–	–	–	–
Trichoptera	Hydropsychidae	*Cheumatopsyche*	–	–	1	3	4	–	–	–	–	–	–	8	3	3	14	12	–	1	6	19	6	–	–	7	13
Trichoptera	Hydropsychidae	*Hydropsyche*	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–	6	–	–	–	6		1	11	1	13
Trichoptera	Limnephilidae	*Pycnopsyche*	3	5	3	1	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trichoptera	Odontoceridae	–	–	1	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trichoptera	Philopotamidae	*Wormaldia*	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–	4	–	–	1	5	3	4	15	8	30
Trichoptera	Rhyacophilidae	*Rhyacophila*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	1	1	2
Coleoptera	Dytiscidae	–	–	–	–	–	–	1	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–		
Coleoptera	Elmidae	–	–	–	–	2	2	–	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	1	1
Coleoptera	Hydrophilidae	–	–	–	–	–	–	–	–	1	–	1	1	1	1	–	3	–	–	–	–	–	–	–	–	–	
Coleoptera	Psephenidae	*Psephenus*	–	–	1	–	1	–	–	–	–	–	–	–	–	1	1	1	–	–	–	1	1	–	–	–	1
Diptera	Chironomidae	–	12	4	5	5	26	3	1	3	5	12	6	5	9	8	28	10	4	1	1	16	5	6	2	6	19
Diptera	Ptychopteridae	*Ptychoptera*	–	1	–	1	2	7	3	3	1	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diptera	Simuliidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	2

Appendix 6. Benthic macroinvertebrates collected at Blue Ridge Parkway sites and resultant summary statistics, September 1999—Continued

[A-D, replicate identifier; TOT, replicate total; AVG, average; –, not found]

Taxon	Family	Genus	Site 1					Site 2					Site 3					Site 3-BC					Site 4				
			A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT	A	B	C	D	TOT
Diptera	Tipulidae	*Antocha*	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	–	–	–	–	–	–	–	–	–	–
Diptera	Tipulidae	*Hexatoma*	1	–	1	1	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Diptera	Tipulidae	*Tipula*	2	–	4	1	7	2	1	–	–	3	–	2	3	1	6	2	–	–	–	2	1	–	1	–	2
		Replicate and site totals	21	19	40	29	105	15	11	15	9	50	26	37	30	24	98	91	17	15	19	142	31	18	49	36	134
		Summary Statistic	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**	**A**	**B**	**C**	**D**	**AVG**
		Abundance	21	19	40	29	27.25	15	11	15	9	12.5	26	37	30	24	29.25	91	17	15	19	35.5	31	18	49	36	33.5
		Taxa richness	6	8	15	14	10.75	6	6	6	5	5.75	6	12	11	12	10.25	17	9	8	11	11.25	12	8	14	11	11.25
		Caddisfly (Trichoptera) abundance	3	8	4	5	5	–	–	–	–	–	–	8	3	3	3.5	23	–	1	7	7.75	9	5	27	17	14.5
		Stonefly (Plecoptera) abundance	2	2	6	7	4.25	–	–	–	–	–	–	6	2	4	3	30	5	3	3	10.25	5	2	8	8	5.75
		Mayfly (Ephemeroptera) abundance	–	–	4	–	1	–	–	–	–	–	6	6	3	2	4.25	12	2	1	5	5	7	1	3	3	3.5
		Percent mayfly	–	–	10	–	2.5	0	0	0	0	0	23.07	16.21	10	8.33	14.4	13.18	11.76	6.67	26.31	14.48	22.58	5.56	6.12	8.33	10.64
		EPT abundance	5	10	14	12	10.25	–	–	–	–	–	6	20	8	9	10.75	65	7	5	15	23	21	8	38	28	23.75
		EPT richness	2	5	7	6	5	–	–	–	–	–	1	6	3	5	3.75	10	4	4	8	6.5	6	5	8	8	6.75
		Percent EPT	23.8	52.63	35	41.37	38.2	0	0	0	0	0	23.07	54.05	26.66	37.5	35.32	71.42	41.17	33.33	78.94	56.22	67.74	44.44	77.55	77.77	66.87