

Prepared in cooperation with the
Gloucester County Department of Public Works—Planning Division

Arsenic, Metals, and Nutrients in Runoff from Two Detention Basins to Raccoon Creek, New Jersey Coastal Plain, 2008

Scientific Investigations Report 2011–5017

Arsenic, Metals, and Nutrients in Runoff from Two Detention Basins to Raccoon Creek, New Jersey Coastal Plain, 2008

By Julia L. Barringer, Zoltan Szabo, Jennifer L. Bonin, and Craig K. McGee

Prepared in cooperation with the
Gloucester County Department of Public Works—Planning Division

Scientific Investigations Report 2011–5017

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit <http://www.usgs.gov> or call 1-888-ASK-USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit <http://www.usgs.gov/pubprod>

To order this and other USGS information products, visit <http://store.usgs.gov>

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this report is in the public domain, permission must be secured from the individual copyright owners to reproduce any copyrighted materials contained within this report.

Suggested citation:

Barringer, J.L., Szabo, Zoltan, Bonin, J.L., and McGee, C.K., 2011, Arsenic, metals, and nutrients in runoff from two detention basins to Raccoon Creek, New Jersey Coastal Plain, 2008: U.S. Geological Survey Scientific Investigations Report 2011-5017, 28 p.

Contents

Abstract.....	1
Introduction.....	1
Purpose and Scope	2
Description of Study Area	2
Geology, Soils, and Streamwater Chemistry.....	2
Land Use.....	4
Methods.....	4
Collection of Water Samples	4
Collection of Soil Samples.....	7
Analysis of Samples	7
Streamflow Measurements	7
Quality-Assurance Measures.....	7
Arsenic, Metals, and Nutrients in Streamwater and in Runoff at Two Detention Basins	9
Estates 1	9
Estates 2	9
Differences in Water Chemistry, Estates 1 and 2, September 2008.....	11
Arsenic and Metals in Soils at and near Two Detention Basins.....	12
Estates 1	12
Estates 2	13
Possible Sources and Transport of Arsenic, Metals, and Nutrients to the Basins and Stream.....	14
Summary and Conclusions.....	18
Acknowledgments.....	18
References Cited.....	19
Appendix 1. Major and trace elements, organic carbon, and nutrients in water samples from two detention basins and their outfalls, at Estates 1 and 2, and from Raccoon Creek immediately upstream from the outfalls, Gloucester County, New Jersey, May and September 2008.....	24
Appendix 2. Major and trace elements in soils and sediments from Estates 1 and 2, Gloucester County, New Jersey, June–October, 2008	27

Figures

1. Map showing geologic formations within the Raccoon Creek watershed, Gloucester County, New Jersey, and locations of streamwater and soil sediment sampling sites.....	3
2. Map showing land use within the Raccoon Creek watershed, Gloucester County, New Jersey, and locations of streamwater and soil sediment sampling sites.....	5
3. Graph showing discharge at Raccoon Creek streamgaging station 01477120, Gloucester County, New Jersey, from May 6 through May 18, 2008	6
4. Graph showing discharge at Raccoon Creek streamgaging station 01477120, Gloucester County, New Jersey, from September 1 through September 8, 2008.....	6
5. Graph showing concentrations of total arsenic (As), chromium (Cr), copper (Cu), and lead (Pb) in runoff and streamwater at Estates 2, Gloucester County, New Jersey, during May and September storms, 2008.....	9
6. Graph showing concentrations of ammonia + organic nitrogen, ammonia, nitrite + nitrate, and total phosphorus in runoff and streamwater at Estates 2, Gloucester County, New Jersey, during May and September storms, 2008	10
7. Graph showing concentrations of total arsenic (As), chromium (Cr), and lead (Pb) in unfiltered samples of runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, September 2008.....	11
8. Graph showing concentrations of nitrogen species in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, September 2008	11
9. Graph showing concentrations of arsenic (As), lead (Pb), copper (Cu), iron (Fe), and antimony (Sb) in Raccoon Creek bankside soils at Estates 1, Gloucester County, New Jersey, 2008.....	12
10. Graph showing concentrations of arsenic (As) normalized to organic carbon (OC), aluminum (Al), and iron (Fe) in Raccoon Creek bankside soils at Estates 1, Gloucester County, New Jersey, 2008.....	13
11. Graph showing relation of concentrations of arsenic (As), beryllium (Be), chromium (Cr) and vanadium (V) to iron (Fe) in glauconitic sediments from Estates 2, Gloucester County, New Jersey, 2008.....	14
12. Graph showing relation of concentrations of dissolved arsenic (As), copper (Cu), chromium (Cr), and vanadium (V) to concentrations of dissolved organic carbon (DOC) in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, May and September 2008	16
13. Graph showing relation of particulate arsenic (As), lead (Pb), and phosphorus (P) to particulate iron (Fe) in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, May and September 2008	16

Tables

1. Analytical methods and lower reporting limits for selected constituents.....	8
2. Pearson's correlation coefficients for selected dissolved constituents in runoff and streamwater, Estates 1 and 2, Gloucester County, New Jersey, May and September 2008.....	17
3. Pearson's correlation coefficients for selected constituents in particulate form in runoff and streamwater at Estates 1 and 2, Gloucester County, New Jersey, May and September 2008.....	17

Conversion Factors and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter (cm)
inch (in)	25,400	micrometer (μm)
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi ²)	2.590	square kilometer (km ²)
Flow rate		
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)

SI to Inch/Pound

Multiply	By	To obtain
Volume		
liter (L)	0.2642	gallon (gal)
Mass		
microgram (μg)	0.000000035	ounce, avoirdupois (oz)
milligram (mg)	0.0000353	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Chemical unit abbreviations

μg/L	micrograms per liter (equivalent to parts per billion)
mg/L	milligrams per liter (equivalent to parts per million)
mg/kg	milligrams per kilogram (equivalent to parts per million)

Chemical element abbreviations

Al	Aluminum	Cr	Chromium	Na	Sodium
As	Arsenic	Cu	Copper	Ni	Nickel
B	Boron	Fe	Iron	P	Phosphorus
Ba	Barium	Hg	Mercury	Pb	Lead
Be	Beryllium	K	Potassium	Sb	Antimony
Ca	Calcium	Mg	Magnesium	SO ₄	Sulfate
Cd	Cadmium	Mn	Manganese	V	Vanadium
Cl	Chloride	N	Nitrogen	Zn	Zinc

(This page intentionally left blank.)

Arsenic, Metals, and Nutrients in Runoff from Two Detention Basins to Raccoon Creek, New Jersey Coastal Plain, 2008

By Julia L. Barringer¹, Zoltan Szabo¹, Jennifer L. Bonin¹, and Craig K. McGee²

Abstract

Arsenic (As) concentrations in the waters of Raccoon Creek in southern New Jersey commonly exceed the State's Surface Water Quality Standard (SWQS) for freshwater of 0.017 microgram per liter ($\mu\text{g/L}$). In order to assess contributions of As from residential runoff to the creek, samples of runoff water were collected from a detention basin in each of two residential developments underlain by different geologic formations and at the outlets of those basins. Samples of streamwater also were collected from Raccoon Creek adjacent to the developments. The samples were analyzed to determine concentrations of As, selected metals, organic carbon, and nutrients. Soil samples in and downgradient from the basins also were collected and analyzed.

Concentrations of As in unfiltered water samples of runoff from the basin underlain by glauconitic clays generally were higher (up to 4.35 $\mu\text{g/L}$) than in runoff from the basin underlain by predominantly quartz sands and silts (up to 2.68 $\mu\text{g/L}$). Chromium (Cr) concentrations also were higher in runoff from the basin underlain by glauconitic clays than in runoff from the basin underlain by quartz sand and silt. In addition, Cr concentrations were higher in the glauconitic soils than in the quartz-rich soils.

Metals such as aluminum (Al), iron (Fe), lead (Pb), and manganese (Mn) in the runoff and in the streamwater were mostly in particulate form. Arsenic, most metals, and phosphorus (P), however, were mostly in dissolved form in runoff but in particulate form in the streamwater. Total organic carbon concentrations in the runoff ranged from about 10 to nearly 16 milligrams per liter (mg/L). Given such levels of organic carbon and strong correlations between concentrations of some metals and organic carbon, it may be that many of the metals were complexed with dissolved organic carbon and transported in that form in the runoff.

Although underlying geologic materials and soils appear to be major contributors of As to the streamwater, As also could have been contributed from lead arsenate pesticide residues. The residential development underlain by quartz-rich sediments formerly had been an orchard where such pesticides may have been used. The substantial inputs of As to runoff at this site may be attributable to this former land use, although Pb concentrations were about the same in runoff from both sites. The streamwater at both sites, however, contained Pb concentrations well above those in runoff, indicating that there are additional inputs of Pb, perhaps from roadside soils, upstream from the two sampling sites in this study.

Positive relations between concentrations of As and some metals with dissolved organic carbon in runoff and streamwater indicate that complexation with organic carbon may provide a mechanism by which these constituents can be transported. Sorption of As, Pb, and P to Fe hydroxides may be indicated by the observed positive relation of particulate As, Pb, and P to particulate Fe, however, representing an additional mechanism for transport of these constituents.

Introduction

Concentrations of As, a metalloid, commonly exceed the New Jersey Surface Water Quality Standard (SWQS) of 0.017 $\mu\text{g/L}$ for freshwater (New Jersey Department of Environmental Protection, 2009) in the waters of streams that drain to the Delaware River in the Inner Coastal Plain of New Jersey. Although the streams typically rise among the quartz-rich sands of the Miocene Cohansey and Kirkwood Formations, below their headwaters these streams are underlain by, and incised into, glauconitic sediments of mainly marine origin, which range in age from Early Tertiary through Late Cretaceous periods. The glauconite (a gray to green mineral with clay- or mica-like structure) and soils developed on these sediments have been shown to be rich in As and other trace elements (Dooley, 1998; 2001).

¹ U.S. Geological Survey

² Camden County Soil Conservation District

Former and existing land uses also may be contributors to the As, metal, and nutrient loads of these streams. Consequently, regional and local assessments of the sources, distributions, and fates of As, metals, and nutrients in streamwater are ongoing where the Surface Water Quality Standards for these constituents are exceeded. One aim of such assessments is to distinguish between geologic sources and land-use-related sources, such as runoff from existing and former agricultural land, and from roads and other impervious surfaces. Identifying the source contributions of As and metals to streamwaters is particularly challenging in rapidly urbanizing areas where both geologic and anthropogenic sources are present. Yet it is precisely these areas where concern regarding the source and fate of these contaminants is greatest and effect of land-use and water-resource management (such as stormwater runoff management) is greatest.

Raccoon Creek, in Gloucester County, southwestern New Jersey, is one of several Coastal Plain streams where the waters contain As at levels that commonly exceed the SWQS. Local As-rich geologic materials and activities related to agriculture are thought to be possible sources of As to the streamwater. It has been shown that natural As levels in soils of orchard areas elsewhere in the New Jersey Coastal Plain were increased by applications of arsenical pesticides to the fruit trees during the early to mid-20th century (Barringer and others, 1998). Substantial areas of land within the Raccoon Creek watershed have been devoted to orchards during the 20th century. Some of these orchards were replaced by residential development during the 1990s and early 2000s, and runoff from disturbed soils in these areas may be a source of As-rich sediment and water to the stream.

In addition to As, runoff can contribute metals, such as Cd, Cu, Hg, Pb, and Zn, and nutrients to streams; any natural (geologic) contributions of these constituents can be enhanced by inputs of anthropogenic origin. Dust and runoff from surfaces where motor vehicles travel or are parked can contain elevated levels of Cd, Cu, Pb, and Zn (Morrison and others, 1984; Hares and Ward, 1999; Barbarosa and Hvitved-Jacobsen, 1999; Councell and others, 2004; Lin and others, 2005) and may be sources of metals to the stream. In a study of urban inputs of metals to surface waters, Rice (1999) found that the sum of concentrations of four metals in stream sediments (Cu + Hg + Pb + Zn) correlated well with population density.

Stormwater-management practices are designed to mitigate the effects of runoff containing undesirable levels of constituents (As, metals, N, P, and other potential contaminants) on the quality of streamwater. For management practices to be effective, measurement of the constituents present in runoff, particularly in areas where structures such as storm drains and detention basins have been installed to direct, contain, or sequester contaminants, is needed. The current study was undertaken by the U.S. Geological Survey (USGS) in cooperation with the Planning Division of the Gloucester County Department of Public Works (GCPD). Funding for this study was provided by USGS and New Jersey Department of

Environmental Protection (NJDEP) through a U.S. Environmental Protection Agency (USEPA) 319(h) Non-Point Source Pollution Control and Management Implementation grant to the Camden County Soil Conservation District (CCSCD) and the GCPD. The study was designed to provide information in support of the development of a Stormwater Management Plan for the watershed of Raccoon Creek (hereafter, the creek is referred to as RAC). Further, the study complements a regional effort by the USGS, in cooperation with the NJDEP, to determine sources of As, as well as metals and nutrients, to RAC and other Coastal Plain streams.

The primary objective of this study was to determine levels of As in stormwater runoff to detention basins and in the runoff from them to the RAC and to identify likely sources of As. Other objectives included gathering data on associated metals and nutrients in order to more completely describe the likely sources of As to the stream and the processes involved in As mobility. For this study, concentrations of As and metals also were determined in soils bordering the RAC channel, in particular those developed on the marine sediment substrate and those upgradient adjacent to a former orchard area.

Local, detailed investigations in individual watersheds such as the RAC lead to greater understanding of how variation in the local landscape, such as geology, land use, degree of residential development, degree of impermeable surface, and other variables affect the distributions of As, metals, and nutrients in streamwater; these investigations will be an integral part of the larger ongoing regional study.

Purpose and Scope

This report presents the chemistry of runoff water to, and runoff from, two detention basins and associated streamwater. One basin was sampled twice, during two rain events in May and September 2008, the other in September 2008. Concentrations of As and metals in soils and sediments in the vicinity of the basins also are presented. Differences in chemistry of runoff and soils or sediments between the basins are evaluated in terms of differences in land use and geology.

Statistics for As and metals in runoff and streamwater are listed in tables. Concentrations of selected constituents in runoff, streamwater, soils, and sediments are shown in illustrations.

Description of Study Area

Geology, Soils, and Streamwater Chemistry

Raccoon Creek (RAC) rises in an area of the New Jersey Coastal Plain underlain by sediments of terrestrial and marginal marine origins—the Cohansy and Kirkwood Formations, respectively. Downstream, to its confluence with the Delaware River, the stream traverses outcroppings of glauconite-bearing deposits of marine origin, beginning

with the Vincentown Formation and continuing down-section through the Merchantville Formation (Owens and Sohl, 1969) (fig. 1). The outcrop areas of these marine formations are regionally extensive, as they stretch from the southwest border of New Jersey at Delaware Bay toward the northeast in bands that parallel the Delaware River for about 100 mi. Because some of the marine sediments are particularly clay-rich (the Hornerstown, Navesink, Marshalltown and Merchantville Formations) and do not function as aquifers, some reaches of the westward draining Coastal Plain streams receive little or no groundwater as base flow. About 71.6 percent of flow in Raccoon Creek is base flow (Vincent DePaul, U.S. Geological Survey, written commun., 2008), slightly less than that of streams draining to the Atlantic Ocean that are underlain entirely by the Cohanse and Kirkwood Formations.

Concentrations of As have been found to range from 7 to 136 milligrams per kilogram (mg/kg, or parts per million) in the New Jersey Coastal Plain glauconites derived from geologic materials and soils (Dooley, 2001). The glauconitic soils, which range from less than 2 percent to 40 percent of glauconite (Keenan and Muñiz, 2007), tend to be enriched in As over the levels found in the parent (geologic) materials. Concentrations range from 13 to 131 mg/kg for whole soils (Dooley, 2001). In areas where orchards existed or still exist, applications of lead-arsenate pesticide on the fruit trees may have amplified the concentrations of naturally occurring As in soils, as shown in central New Jersey (Barringer and others, 1998) and elsewhere in the United States, for example, in western Massachusetts (Newton and others, 2006). In addition to As, concentrations of Sb have been found to be elevated in

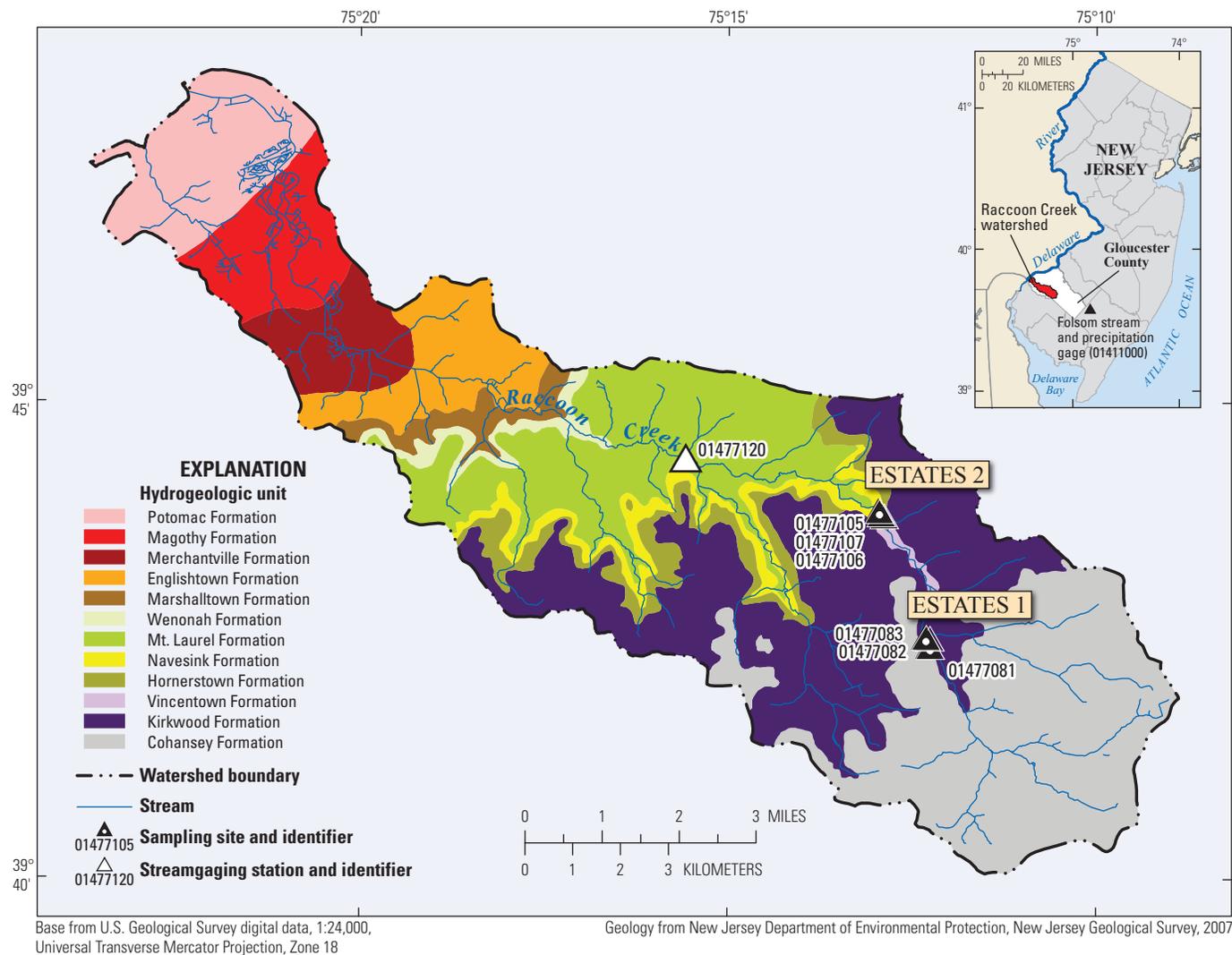


Figure 1. Geologic formations within the Raccoon Creek watershed, Gloucester County, New Jersey, and locations of streamwater and soil sediment sampling sites.

soils where lead arsenate pesticides have been used (Wagner and others, 2003). Nevertheless, it appears that at least some of the reported instances of highly elevated As concentrations in soils on glauconite-rich substrates are attributable to geologic contributions of As, rather than to agricultural inputs, because As concentrations increase with depth in the soil and proximity to the As-bearing geologic substrate (Kevin Schick, New Jersey Department of Environmental Protection, written commun., 1997).

Glauconitic soils also can contain substantial concentrations (greater than 100 mg/kg) of Cr and V, which have been found to be readily extractable (Dooley, 2001). These glauconitic soils are easily disturbed, and clay-sized particles derived from streambank erosion tend to remain suspended in water (Monmouth County Health Department, 2006). It appears likely the soils developed on the marine formations can contribute As, as well as Cr and V, to runoff that enters the RAC.

Near the headwaters, the pH of RAC waters is slightly acidic to neutral. Water-quality data (available at <http://waterdata.usgs.gov/nj/nwis/qw/>) from sampling at the USGS gage Raccoon Creek near Swedesboro, NJ (site 01477120), which is downstream from the sites sampled in this study, indicate the pH of streamwater since 2000 has ranged from 6.8 to 7.5, with a median value of 7.1. Nitrite + nitrate concentrations have ranged from 0.22 and 2.32 mg/L (as N), but these are extreme outlier values; concentrations typically range from 1 to 2 mg/L (as N). Data collected from 1965 to the present also indicate that chloride concentrations in RAC streamwater have increased over time and now generally exceed 20 mg/L. Recent sampling to determine phosphorus levels in the RAC (Camden County Soil Conservation District 2008) indicates concentrations of orthophosphate, total phosphate, and total phosphorus generally are less than 0.1 mg/L in water upstream from the current study area but exceed 0.1 mg/L at sites downstream from the study area at high flow.

The two grass-lined detention basins (USGS sampling sites 01477082 and 01477106; figs. 1 and 2) chosen for investigation in the current study are located at two recently developed residential areas that border the RAC. The farther upstream residential area (hereafter referred to as Estates 1) is underlain by sediments of the basal Kirkwood Formation. Soils on the low-relief land at Estates 1 are predominantly well-drained sandy loams, identified as belonging to the Downer and Sassafras soil series, with moderately well-drained sandy loams of the Woodstown-Glassboro Complex near the stream (Keenan and Muñiz, 2007).

The second residential area (hereafter referred to as Estates 2), which is downstream from Estates 1, is underlain by glauconitic clays of the Navesink Formation; as some of these clays are green in color, part of this area may be underlain by the Hornerstown Formation, which unconformably overlies the Navesink Formation. At Estates 2, soils underlying the upland, residential area are sandy loams of the glauconite-bearing (2–5 percent glauconite) Freehold soil series and the Sassafras series. Near the stream, the detention basin is

within sandy loams of the Collington series, with up to 20 percent glauconite (Keenan and Muñiz, 2007).

Land Use

Land use within the RAC watershed has been mainly agricultural (fig. 2) with much of the area occupied by orchards. In recent years, however, the balance has shifted towards increased residential (suburban) land use. In the newly developed areas, detention basins commonly have been installed to capture runoff.

The mixture of the remaining agricultural land and newly developed residential areas has resulted in a complex mosaic of land uses within the RAC watershed. Urbanized areas, some of which date to the 18th or 19th centuries, are few. The watershed contains a variety of known contaminated sites, most of which are clustered near the downstream, tidal portion of the stream, rather than in the area sampled for the current study. The part of the watershed sampled for this study contains five known contaminated sites, most of which are near tributaries, or are farther than 0.5 mi from the mainstem.

Aerial photographs from the 1930s to 2002 indicate Estates 1 was developed on former orchard land. Land use, prior to the development of Estates 2, appears to have been agricultural but was not orchard land.

Methods

Collection of Water Samples

Samples of runoff were collected in the two detention basins (sampling site 01477082, hereafter E1B and site 01477106, hereafter E2B) adjacent to the RAC and from the basins' outlets to the RAC (site 01477083, hereafter E1O and site 01477107, hereafter E2O) during storms (see figs. 1 and 2). Streamwater from the RAC immediately upstream of E1O and E2O also was collected during the same storms; these stream sites (01477081 and 01477105, respectively (figs. 1 and 2) are referred to as E1C and E2C, respectively. Samples were collected at Estates 2 on May 16, 2008, when at least 0.5 in. of rain fell as measured at the rain gage at site 01411000 on the Great Egg Harbor River at Folsom, New Jersey. Previously, a combined total of about 3 in. of rain had fallen from May 8 through May 12, followed by a three-day interval of no precipitation. Peak flows on the RAC (fig. 3) from this period were recorded at the downstream gage (01477120, see fig. 1 for location) on May 9, 13, and 16. The streamwater sample (E2C) at Estates 2 was collected at 12:50 on the descending limb of the hydrograph at that site, as peak flow was being recorded at that time at the downstream streamgage (01477120). Samples were collected during the storm on the rising limb of the hydrograph (fig. 4) at both

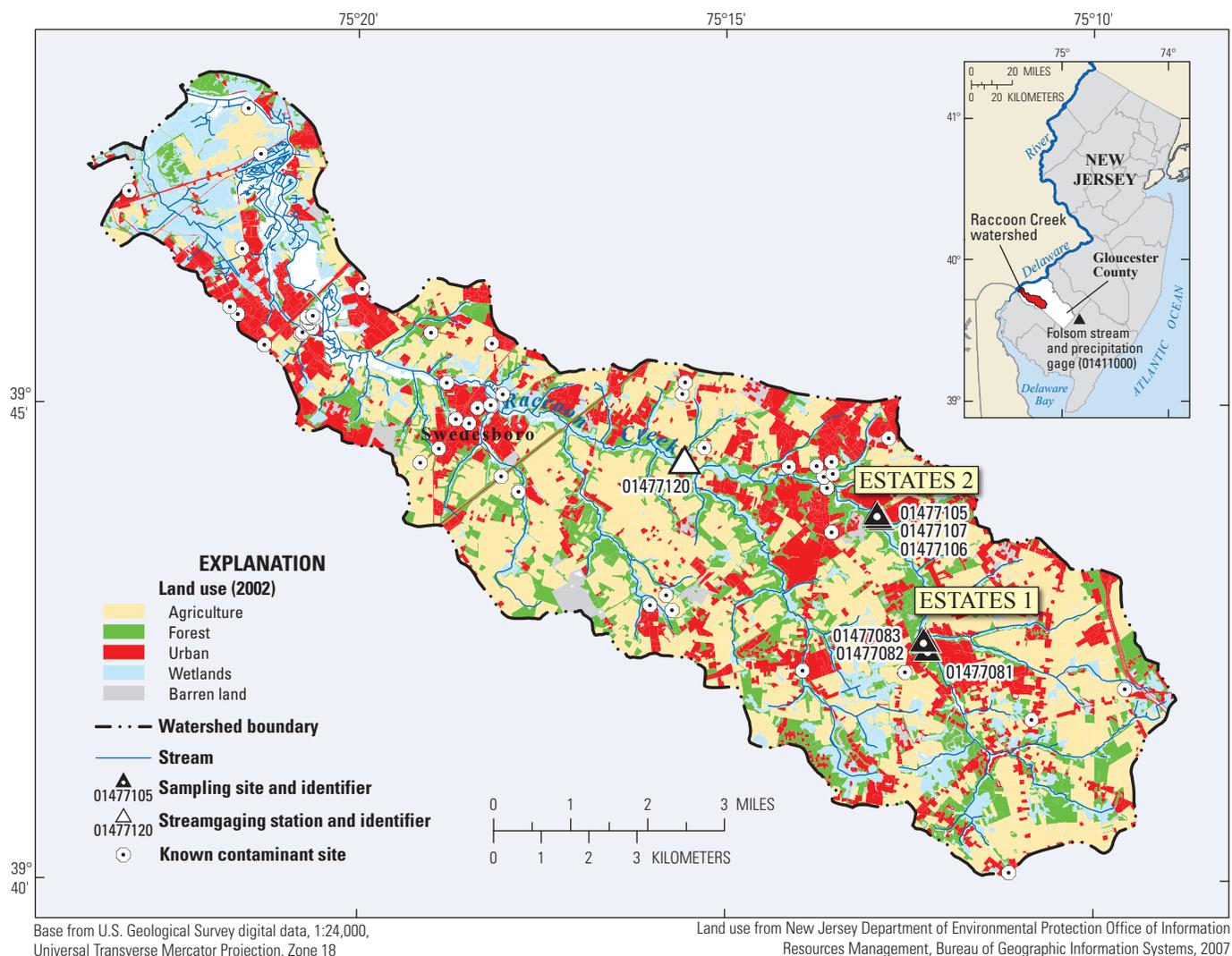


Figure 2. Land use within the Raccoon Creek watershed, Gloucester County, New Jersey, and locations of streamwater and soil sediment sampling sites.

Estates 1 and Estates 2 on September 6, 2008, during a storm in which nearly 2 in. of rain fell following nearly a month of virtually no precipitation.

Water samples were collected as grab samples. Nitrile-gloved personnel from the CCSCD, the Gloucester County Soil Conservation District (GCSCD), and the USGS collected samples in acid-washed bottles. Four to five samples were collected from water that was pooling in the detention basins, working from downstream to upstream to avoid contamination of subsequent samples. At each basin, a sample of water issuing from the outlet to the RAC also was collected, and a series of five grab samples was collected from midway in the water column, immediately upstream of each outlet along a cross

section of the RAC at each site. Sample bottles were labeled with site identification, date, time, and numbers keyed to field maps of individual sample locations. All samples were chilled, and kept in the dark until further sample processing at the USGS New Jersey Water Science Center (NJWSC) laboratory.

For each sampling site, the basin sample set and stream sample set were each composited in an acid-washed churn using ultraclean protocols (Horowitz and others, 1994; Ivahnenko and others, 1996; Wilde and others, 2004). Water samples were filtered through an in-line 0.45- μm pore-size filter. Whatman capsule filters were used in May 2008. Owing to unavailability of capsule filters after the May sampling, Aquaprep disc filters were used in September; clogging of pores due



USGS 01477120 Raccoon Creek near Swedesboro NJ

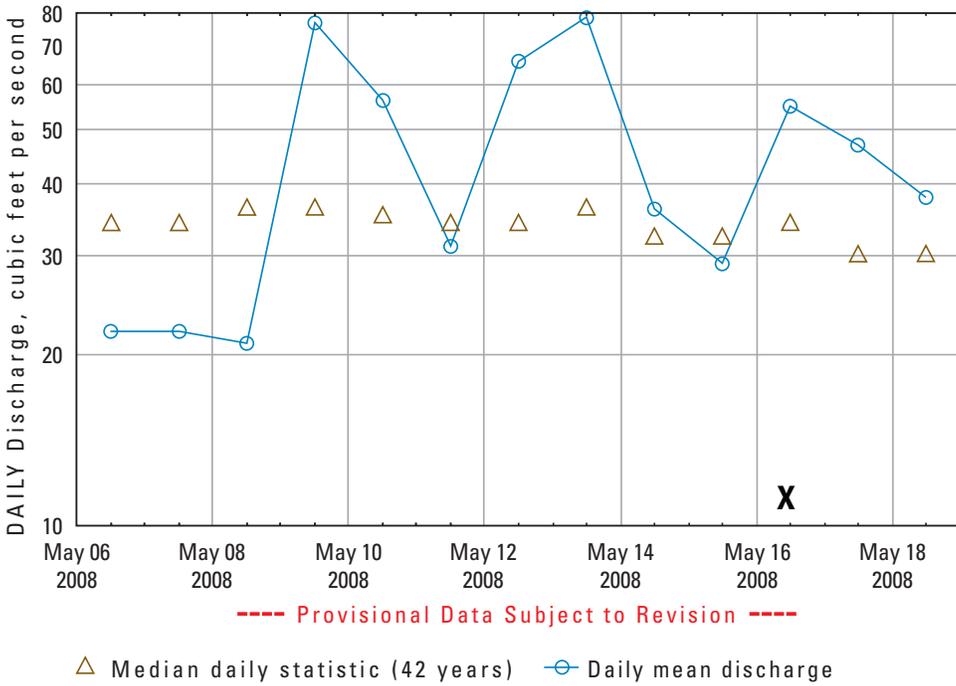


Figure 3. Discharge at Raccoon Creek streamgaging station 01477120, Gloucester County, New Jersey, from May 6 through May 18, 2008. Sampling at Estates 2 conducted on May 16, 2008, from 11:05 to 12:50, is indicated by X on graph.



USGS 01477120 Raccoon Creek near Swedesboro NJ

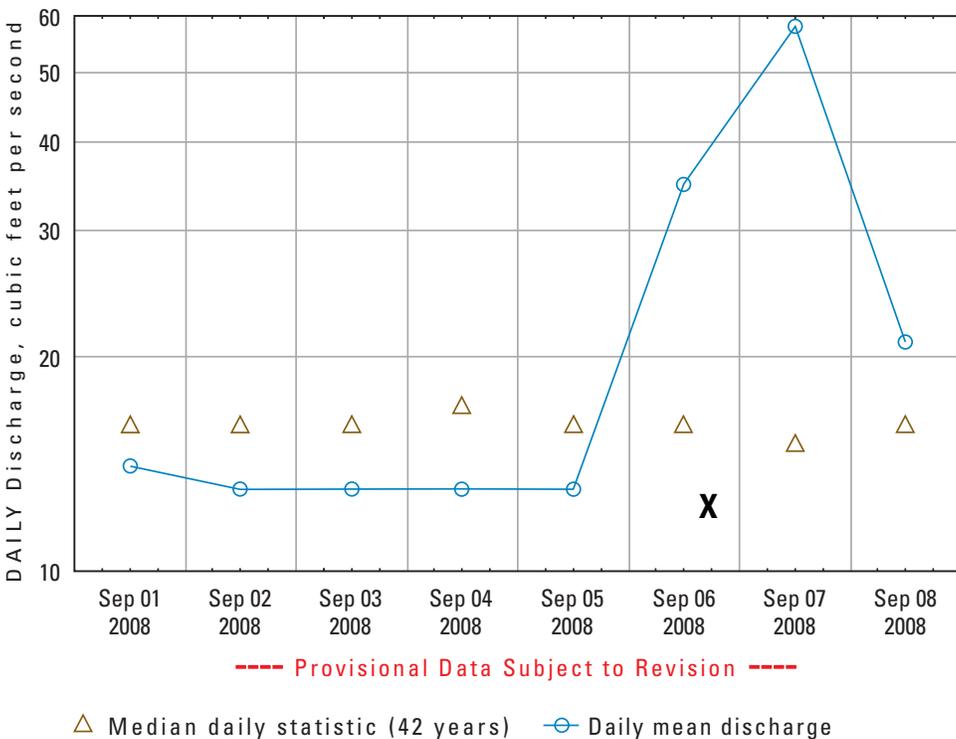


Figure 4. Discharge at Raccoon Creek streamgaging station 01477120, Gloucester County, New Jersey, from September 1 through September 8, 2008. Sampling at Estates 1 and 2, conducted on September 6, 2008, from 16:15 to 18:10, is indicated by X on graph.

to the small surface area of the disc filters may have produced a low bias for constituents in filtered samples collected in September. Personnel processing samples wore nitrile gloves that were changed between steps in the process and between samples. Sample processing and preservation with ultra-pure acids was done inside chambers of polyethylene sheeting on polyvinyl chloride frames; the chamber sheeting was changed between samples. All equipment used for collection and processing of aqueous samples was acid-washed (5 percent HCl) and rinsed with de-ionized water.

Collection of Soil Samples

Samples of detention-basin soils and clays were collected by using either a 1-m-long stainless-steel corer with pre-cleaned butyl acetate liners, as described by Barringer and others (1998), or a clean stainless-steel bucket auger. RAC bankside soils were collected at Estates 1 by coring. Detention-basin soils/sediments at Estates 2 were collected with the corer, but samples of RAC bankside soils were collected from the subsurface with a clean auger in a previously dug pit because cobbles and gravel near the surface precluded coring, and only the subsurface sample could be collected. The soil/sediment cores and auger samples were subsampled according to change in grain size, geologic material, or soil horizon, and sieved to less than 2 mm using pre-cleaned plastic sieves.

Analysis of Samples

Unfiltered and filtered water samples collected in May 2008 from the detention basin, outfall, and stream at Estates 2 were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, CO, for As, selected metals, nutrients, and organic carbon, both dissolved (DOC) and total (TOC) (Brenton and Arnett, 1993; Faires, 1993; Fishman, 1993; Clesceri and others, 1998; Garbarino and others, 2006). Streamwater samples collected at Estates 1 and 2 in September 2008 were analyzed for the same constituents. Samples also were analyzed for Hg and major cations and anions—the major elements in filtered samples only. The soil and sediments were completely digested, using hydrochloric, nitric, hydrofluoric, and perchloric acids, and hydrogen peroxide (Arbogast, 1996; Briggs and Meier, 2002), and analyzed for total As, a suite of total metals, and carbon (Brown and Curry,

2002; Brown and others, 2002) by the USGS Geologic Discipline Research Laboratory in Denver. Analytical methods are summarized in table 1.

Streamflow Measurements

Staff gages were installed by personnel from the CCSCD at the two RAC stream sampling sites (01477105 (E1C) and 01477081 (E2C)). Stream discharge at each site was measured immediately following the collection of the water samples by personnel from the CCSCD, using a type AA current meter with top set wading rod, following USGS procedures (Carter and Davidian, 1968). Rating curves (not shown) were developed for both sampling sites by CCSCD personnel (Craig McGee, Camden County Soil Conservation District, written commun. 2008).

Quality-Assurance Measures

Results of analyses of equipment blanks (acid-washed tubing, Whatman capsule filters, and Aquaprep disc filters) collected during spring and fall 2008 indicated that nearly all constituents were undetected in the blank water. Exceptions were Al and B, present at concentrations slightly above their respective lower reporting limits but well below the concentrations found in environmental samples.

For water samples collected during September 2008, in which all major ions were analyzed, cation/anion balances were computed. Percent differences between cations and anions were less than 5 percent for all samples, indicating acceptable analyses for those samples.

Two subsamples (TC-2, and TC-2R) of the core from the Estates 2 detention basin were analyzed as replicates. Concentrations of most of the metals were closely similar, with relative percent differences within 10 percent. The relative percent difference in As concentrations in these sediment samples, however, was about 24 percent. Measurements of As may have been less precise than those of some other constituents (recovery on sediment standards ranged from 96.6 to 125 percent (LaDonna Choate, U.S. Geological Survey, written commun., 2009)), but the difference in As concentrations may stem, in part, from inhomogeneity of the replicate samples with respect to As-bearing minerals.

Table 1. Analytical methods and lower reporting limits for selected constituents

[LRL, Lower reporting limit; ANC, acid-neutralizing capacity; N, nitrogen; P, phosphorus; u, unfiltered sample; f, filtered sample; ICP/AES, inductively coupled plasma atomic emission spectrometry; ICP/OES, inductively coupled plasma optical emission spectrometry; ICP/MS, inductively coupled plasma/mass spectrometry; cICP/MS, collision/reaction cell ICP/MS; IR, infrared spectrometry; CVAFS, cold-vapor atomic fluorescence spectrometry; mg/L, milligrams per liter; µg/L, micrograms per liter; µg/g, micrograms per gram]

Constituent	Method	LRL
Major ions, water, in mg/L		
Calcium	ICP/AES	0.04
Magnesium	ICP/AES	0.02
Potassium	ICP/OES	0.02
Sodium	ICP/AES	0.12
ANC (as CaCO ₃)	Titration	6
Chloride	Ion chromatography	0.12
Fluoride	Ion chromatography	0.12
Silica	Colorimetry	0.20
Sulfate	Ion chromatography	0.18
Ammonia + organic N (as N)	Photometry	0.14
Ammonia (as N)	Colorimetry	0.02
Nitrite + nitrate (as N)	Colorimetry	0.04
Nitrite (as N)	Colorimetry	0.002
Orthophosphate (as P)	Colorimetry	0.006
Phosphorus (u, f)	Colorimetry	0.040, 0.04
Dissolved organic carbon	IR	0.4
Total organic carbon	IR	0.40
Trace elements, water, in µg/L		
Aluminum (u, f)	ICP/MS ^a	2, 1.6
Arsenic (u, f)	cICP/MS ^a	0.12, 0.12
Barium (u, f)	ICP/MS ^a	0.6
Boron (f)	ICP/AES	1.2
Cadmium (u, f)	ICP/MS ^a	0.14, 0.04
Chromium (u, f)	cICP/MS ^a	0.4, 0.12
Copper (u, f)	cICP/MS ^a	1.2, 1
Iron (u, f)	ICP/AES	6, 8
Lead (u, f)	ICP/MS ^a	0.06, 0.08
Manganese (u, f)	ICP/AES	0.8, 0.4
Mercury (u, f)	CVAFS	0.010, 0.010
Nickel (u, f)	cICP/MS ^a	0.12, 0.2
Vanadium (u, f)	cICP/MS ^a	0.10, 0.04
Zinc (u, f)	cICP/MS ^a	2, 1.8
Soils/sediments, in µg/g		
Major, trace elements	ICP/MS ^b	0.004–4
Carbon	Combustion/titration ^c	100

^a Garbarino and others, 2006; Faires, 1993.

^b Arbogast, 1996; Briggs and Meier, 2002.

^c Brown and Curry, 2002, for total carbon, also Brown and others, 2002, for carbonate carbon; organic carbon is determined by difference between total and carbonate carbon. See <http://water.usgs.gov/pubs/twri/> for other method references.

Arsenic, Metals, and Nutrients in Streamwater and in Runoff at Two Detention Basins

Estates 1

On September 6, 2008, runoff collected within detention basin E1B contained 2.68 $\mu\text{g/L}$ of total (unfiltered) As; concentrations were slightly lower at the outfall (E1O) and in the stream (E1C) (appendix 1). The differences appear to be outside expected analytical error (about ± 6 percent), and likely represent an actual decrease from basin to outfall. Total Cr and Pb concentrations were substantially lower than the As concentration in the runoff, but Pb concentrations in the streamwater were substantially higher than those in the runoff. Particulate As concentrations (unfiltered minus filtered concentrations) were negligible in both the basin and outfall samples but were large (1.62 $\mu\text{g/L}$) in the sample from the stream (E1C) at the Estates 1 site. Thus, As in the runoff water was almost entirely in the operationally defined “dissolved” form, which could include colloids small enough to pass through the 0.45- μm pore-size filters used in this study.

The pattern shown by As was present for the metals Ba, Cd, Cr, Cu, Ni, V, and Zn; these were in mostly dissolved form in the runoff but in mostly particulate form in the stream. For the metals Al, Fe, and Mn, the pattern differed. More than 50 percent of the Al, Fe, and Mn in runoff in the basin and at the outfall was particulate, likely indicating that Fe- and Mn-oxide-coated clay particles are an important component of the runoff. Small differences in concentrations of TOC and DOC in the runoff indicate that, although organic particles were present, most organic carbon was dissolved. Mercury was not detected in the runoff (< 0.010 $\mu\text{g/L}$) but was detected in the streamwater from E1C at 0.018 $\mu\text{g/L}$ (appendix 1).

Ammonia concentrations were low and organic N was the dominant N species in the runoff samples; concentrations were slightly higher in runoff than in the stream (E1C) immediately upstream from the outfall (E1O). The nitrite + nitrate concentration was slightly higher in the streamwater than in the runoff to the basin (E1B) but about the same as the concentration in the outfall (E1O) sample. On the basis of the difference in concentrations between unfiltered and filtered samples (appendix 1), some of the P in runoff was present in particulate form, but most was in dissolved form, as orthophosphate. In the streamwater, however, most of the P was in particulate form. The preponderance of dissolved forms in the basin runoff samples apparently indicates that some filtering of particles occurs as water moves over the lawn area surrounding the detention basin. Additionally, with relatively little movement of water as the basin fills, some particles bearing P, As, and many of the metals may settle out, although fine particles containing Al, Fe, and Mn (clays and Fe and Mn hydroxides) apparently remain in suspension. Water that collects in the basin includes

the precipitation, in which any As, metals, and N species would be predominantly in dissolved form, and which would cause dilution of the runoff collecting in the basin. Chloride and sulfate concentrations in the runoff samples were slightly less than half those in the RAC streamwater sample at E1C, as were Na concentrations. Concentrations of Ca and Mg, on the other hand, were about the same in the runoff samples as those in the streamwater (appendix 1).

Estates 2

In samples from May 16, 2008, a negligible difference between concentrations of As in unfiltered and filtered samples indicated that runoff to the RAC from the detention basin (E2B) through its outfall (E2O) carried relatively little particulate As (≤ 0.1 $\mu\text{g/L}$). Concentrations of total As in the runoff samples were only slightly higher (1.63 $\mu\text{g/L}$ at E2B and 2.21 $\mu\text{g/L}$ at E2O) than the total As concentration of the streamwater itself (1.39 $\mu\text{g/L}$ at E2C) (appendix 1, fig. 5). (Although relatively little of the As and accompanying metals was particulate, colloids of a size less than 0.45 μm could have been present in the filtered samples.) Concentrations of Al, Fe, and Mn, which were mostly in particulate form, were lower in water from the basin (E2B) and the outfall (E2O) than they were in the streamwater. Substantial amounts of Cu and Pb in runoff to the basin were in particulate form, although this

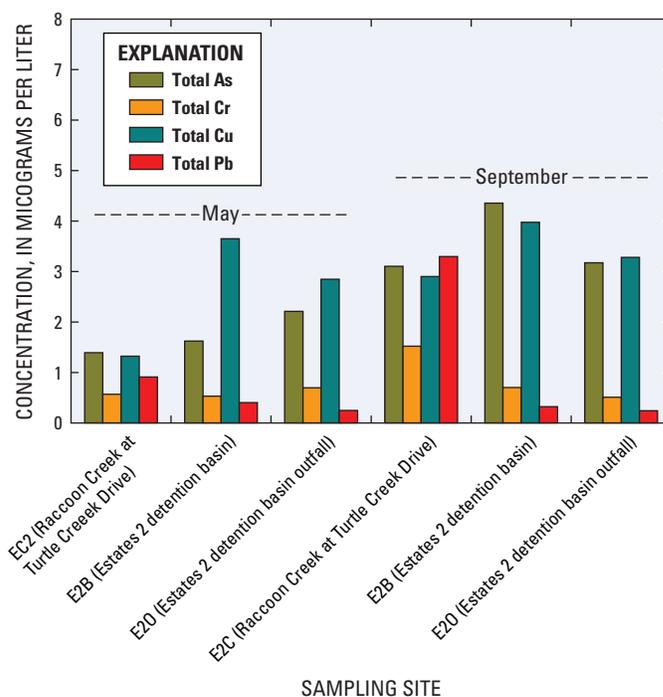


Figure 5. Concentrations of total arsenic (As), chromium (Cr), copper (Cu), and lead (Pb) in runoff and streamwater at Estates 2, Gloucester County, New Jersey, during May and September storms, 2008.

was not the case in runoff issuing from the outfall. Particulate organic carbon (POC) constituted a larger proportion of TOC in these runoff samples than in streamwater at E2C (immediately upstream from E2O), and TOC concentrations in the runoff samples were higher than the concentration in streamwater at E2C.

During the September 6 precipitation event, runoff exiting basin E2B to the RAC at E2O was observed to be greater than in May, in part, because of the intensity of the September storm and, in part, because sampling in May took place during the waning of the storm, whereas sampling in September took place at the peak of the storm. Another critical difference between conditions in May and September was that, unlike the soils in May, the soils surrounding the basin were dry in September because of a lack of rain during the preceding month. The preceding dryness would induce overland flow and reduce infiltration, as the soils would have required wetting before becoming permeable. During the peak of the September storm, the detention basin at Estates 2 was filled briefly with water that exceeded 3 ft in depth.

In September, almost none of the As in Estates 2 runoff was particulate. Concentrations of total As at the Estates 2 basin and outfall were substantially higher (4.35 and 3.17 $\mu\text{g/L}$, respectively) than they had been in the previous May (1.63 and 2.21 $\mu\text{g/L}$, respectively). In the RAC at E2C (immediately upstream from E2O outfall), however, nearly 70 percent of the total As concentration was particulate in form, and concentrations of both total and dissolved As were more than double the concentrations measured in May (appendix 1). Concentrations of total (unfiltered) Cr, Cu, and Pb were substantially higher in streamwater and slightly higher in runoff to the basin in September than in May; concentrations of these constituents were about the same in runoff at the basin outfall during both storms (fig. 5).

In both May and September, concentrations of P in runoff from E2B and E2O were slightly lower in filtered samples than in unfiltered samples, and, thus, were mostly in dissolved form (appendix 1). In the stream at E2C, however, the P concentration was higher in the unfiltered sample than in the filtered sample; consequently, more of the P was particulate, especially in September. Total P concentrations were, overall, higher in September than in May (fig. 6). In contrast, concentrations of N species were higher in runoff in May than in September (fig. 6); the higher organic N may have been released from vegetation during a spring growing season, and residential fertilizer use in the spring may have contributed N species.

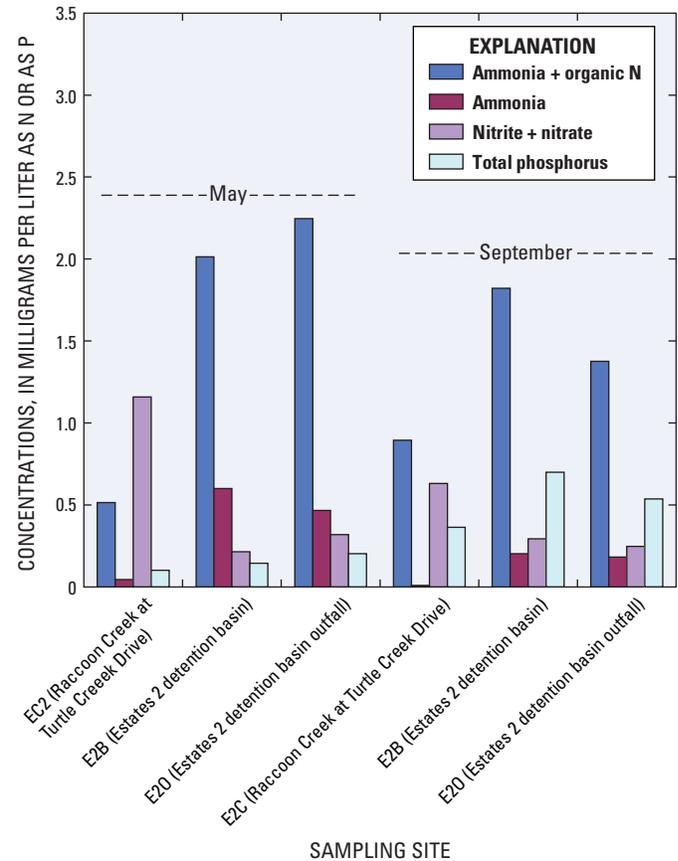


Figure 6. Concentrations of ammonia + organic nitrogen, ammonia, nitrite + nitrate, and total phosphorus in runoff and streamwater at Estates 2, Gloucester County, New Jersey, during May and September storms, 2008.

Because concentrations of many constituents in unfiltered and filtered runoff water generally are similar, clogging of the filter pores does not appear to have caused a bias in the runoff samples. In the streamwater, where particulate concentrations of many constituents are high, clogging may have introduced a bias, but such a bias cannot be assessed because the Estates 2 streamwater sample from September was collected during substantially higher flow, presumably with more suspended particles, than the sample in May.

Differences in Water Chemistry, Estates 1 and 2, September 2008

During the September 2008 storm, in the runoff samples from basin E2B and at the outfall E2O, total As concentrations were 4.35 and 3.17 $\mu\text{g/L}$, respectively; these concentrations were substantially higher than the concentrations in runoff samples from Estates 1 (fig. 7). Total Cr concentrations also were higher in the runoff samples from Estates 2 in September than they were in the runoff samples from Estates 1, but total Pb concentrations were about the same (fig. 7). The concentration of Pb in the streamwater, however, was substantially higher at sampling site E1C at Estates 1 than the concentration at E2C at Estates 2, indicative of sources of Pb upstream from Estates 1.

At Estates 2, the metals, with the exception of Al, Fe, and Mn, exhibited a pattern similar to that of As, being mostly in dissolved form in runoff but mostly in particulate form in streamwater, as was the case at Estates 1. In the stream, suspended particles (organic matter, clay and silt particles) are

vehicles for transporting As and metals in the streamwater. It appears, however, that water entering and exiting both of the detention basins contained most metals either in a dissolved phase or on colloids and that the particles were mainly composed of Al-, Fe-, and Mn-bearing mineral phases, presumably clays and metal hydroxides. TOC and DOC concentrations were similar in runoff to and from both basins, the organic carbon being mostly in dissolved form. Concentrations of organic carbon in streamwater were higher in the RAC at E1C than at E2C, and substantially more of the carbon was in particulate form at E1C, probably indicating that greater amounts of organic material entered the stream upstream from EC1 than at EC2.

Of the N species present, organic N dominated all the water samples from Estates 1 and 2; nitrite + nitrate concentrations were substantially lower in runoff at Estates 2 than at Estates 1 (fig. 8), particularly at the outfall E2O. Nitrite + nitrate concentrations in the RAC streamwater at E1C and E2C immediately upstream from both outfalls were similar, however. Chloride and sulfate concentrations generally were higher in both streamwater and runoff at Estates 2 than they were at Estates 1, as were concentrations of Na.

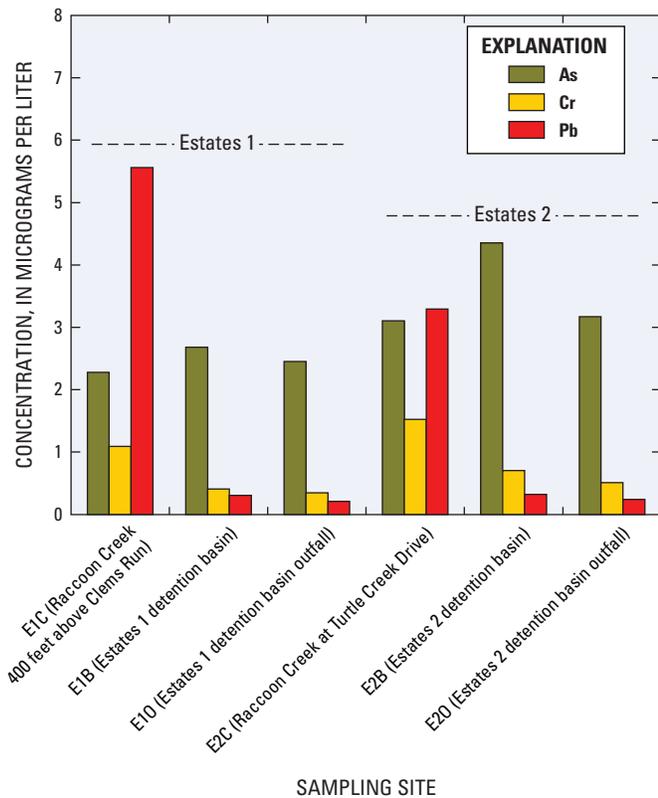


Figure 7. Concentrations of total arsenic (As), chromium (Cr), and lead (Pb) in unfiltered samples of runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, September 2008.

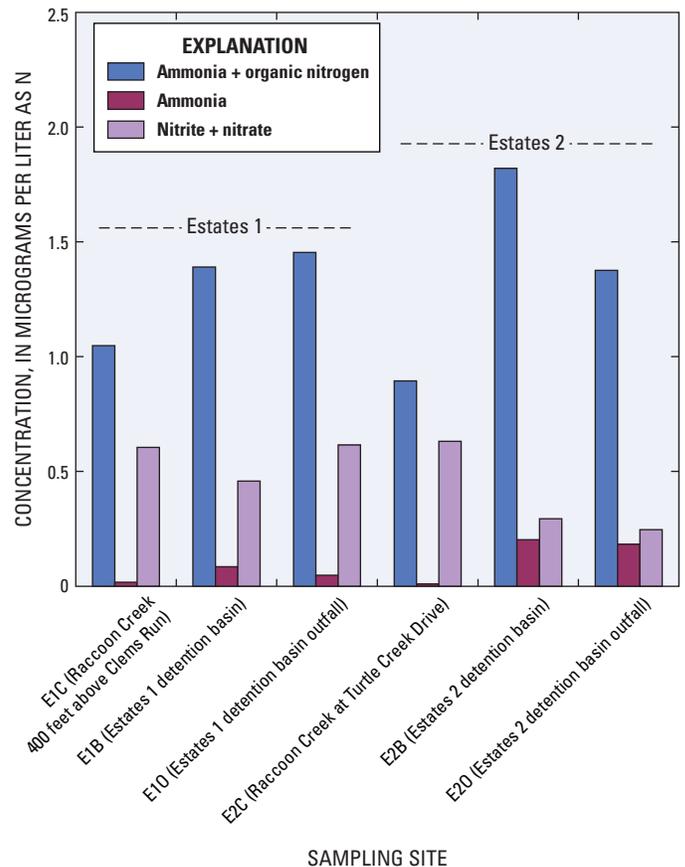


Figure 8. Concentrations of nitrogen species in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, September 2008.

Arsenic and Metals in Soils at and near Two Detention Basins

Estates 1

The bankside soils/sediments (hereafter referred to as sediments) at Estates 1 near the basin outfall have some features resembling soils (upper layers high in organic matter) but incorporate overbank deposits with contributions from overland runoff and are underlain by the geologic parent materials. These sediments were composed mainly of dark gray micaceous fine sands, silts, and clays. Some lignite was present below a depth of about 24 in., and reducing conditions were indicated by a strong hydrogen sulfide smell.

Concentrations of As and total metals such as Cu, and Fe, were highest in sample R-1a, which included the uppermost 15 in. of sediment or, in the case of Pb, in R-1b, which included sediments below 15 in. to about 20 in. (fig. 9). The concentration of Sb also was highest in the uppermost 15 in. (fig. 9); Sb has been shown to be enriched in orchard soils to which arsenical pesticides have been applied (Wagner and others, 2003); consequently, elevated Sb concentrations in concert with elevated As concentrations may be an indicator of arsenical pesticide residues. Concentrations of As and the above metals were lower in the deeper sediment samples R-1c and R-1d, which included sediments in the 36- to 40-in. interval, and the 40- to 43-in. interval, respectively.

Arsenic—as the oxidized species arsenate—is known to sorb to Fe (and Al) hydroxides (Manning and Goldberg, 1996; Raven and others, 1998; Jain and Loeppert, 2000; Stollenwerk, 2003). In orchard soils, both As and Pb from lead arsenate pesticide applications have been shown to bind tightly to humic acids present in the organic matter of soils (Newton and others, 2006). Nevertheless, Pb appears to be less mobile in soils and sediments than does As (Peryea and Creger, 1994; Asher, 2009). The higher concentration of Pb from about 15 to 20 in. below the surface in the bankside sediments may reflect earlier atmospheric inputs from use of leaded gasoline; these emissions peaked in about 1970 (Juracek and Ziegler, 2006).

The concentrations of total P and organic carbon (OC) showed a vertical distribution similar to that of As (appendix 2). Phosphate (mostly represented by total P concentrations), which behaves chemically in a manner similar to that of arsenate, is known to sorb to Fe hydroxides and may inhibit As sorption (Stollenwerk and others, 2007; Zeng and others, 2008; Campbell and others, 2008). Because of competition with As for sorption sites, application of phosphate in fertilizers has been proposed as a means by which As is mobilized in soils (Peryea and Creger, 1994).

A standard procedure for evaluating reactive chemical constituents such as As in sediments is to normalize to (divide by) a more conservative element (one that does not sorb or participate in redox reactions) such as Al (Horowitz and others, 1988). Further, As and many of the metals introduced by runoff to the soils and sediments lining the stream would be expected to be sorbed to or complexed by either

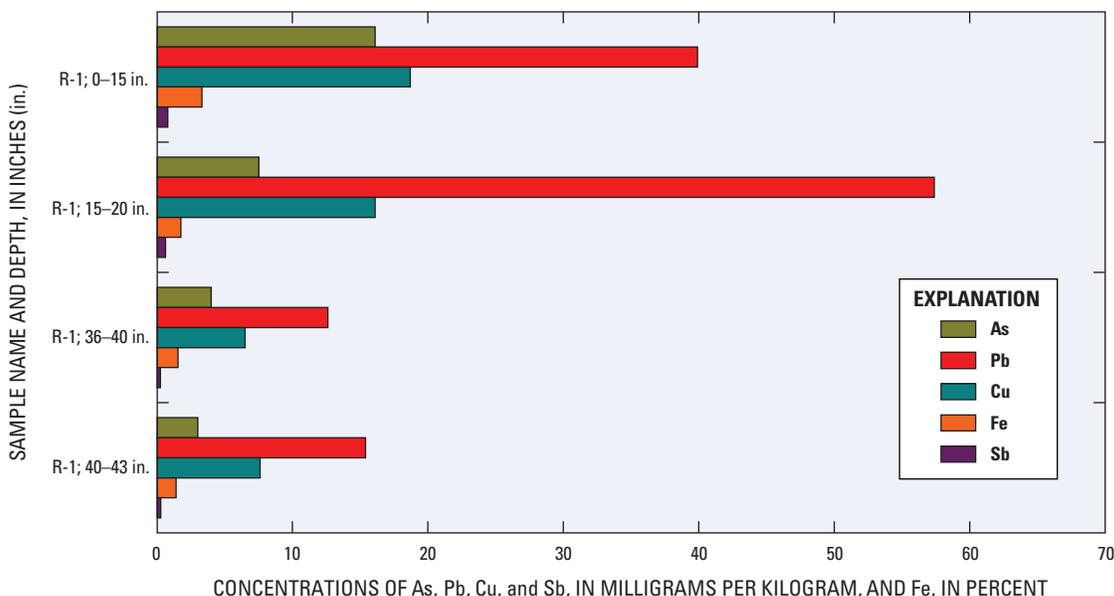


Figure 9. Concentrations of arsenic (As), lead (Pb), copper (Cu), iron (Fe), and antimony (Sb) in Raccoon Creek bankside soils at Estates 1, Gloucester County, New Jersey, 2008. Fe concentrations are shown as percent, for scaling purposes.

Fe-hydroxides or by clays (represented by Al) or by organic matter (essentially represented by OC). The normalization helps in identifying where As and metals concentrations are high because concentrations of the materials to which they are sorbed or complexed also are high. Arsenic was strongly and positively related to both Fe ($R^2 = 0.97$, $p = 0.01$) and OC ($R^2 = 0.95$, $p = 0.02$) in the sediments from the Estates 1 bankside core. When normalized to Fe and Al (representing As as a function of Fe hydroxides and clays) As concentrations were highest in the surficial soils/sediments and decreased with depth (fig. 10). The same pattern was seen for P, which also would be likely to sorb to Fe hydroxides.

The vertically decreasing concentrations of As and P normalized to Fe and Al (representing concentrations of Fe and Al hydroxides and clays to which both constituents are likely to be sorbed) with depth probably represent some introduction of both As and P by runoff to the upper layers of the bankside sediments at Estates 1, rather than a distribution that arose from geologic inputs alone, as it is clear that, when As and P concentrations are considered as a function of Fe and Al concentrations, there is more As and P in the upper layers than in the lower layers. Strong statistical relations of As to OC, also P to OC, may exist simply because concentrations of all three constituents are highest in the uppermost layers of the bankside sediments and decrease with depth.

Metals such as Cu and Pb are likely to be complexed by organic matter (Schnitzer and Kerndorff, 1981), and Cu and Pb concentrations were higher in the upper, more organic-rich samples R-1a and R-1b. When normalized to OC, because OC

concentrations are relatively low in the deeper samples R-1c and R-1d, the distributions of Cu and Pb indicated relatively little change with depth, perhaps indicating that their inputs to the bankside sediments have occurred with fewer recent pulses than those of As and P.

Insofar as Estates 1 was developed on former orchard land in which both arsenical pesticides and phosphorus-containing fertilizers may have been used, it seems plausible that residues of these chemicals could be carried by runoff to the streambank soils and sediments and likely to the stream itself. The layers in the bankside sediments derive from inputs of soils and sediment from overland runoff and from stream deposition during high water, and thus, the vertical distribution of constituents such as As, P, and also the metals could be considered a representation of historical inputs.

Estates 2

Given the nature of soils and bankside sediments at Estates 2, no cores with visible layering were collected; thus vertical distributions of constituents cannot be compared with those of the bankside core at Estates 1. Soil/sediment samples collected within the basin at Estates 2 show that the basin is underlain directly by dark green and gray glauconitic clays of the Hornerstown Formation and, possibly, the Navesink Formation, as the basin is located on or close to the contact between the two units. The sandy soils of the upland residential area that drain to the basin include the Freehold series, which contains moderate amounts of clays and glauconite,

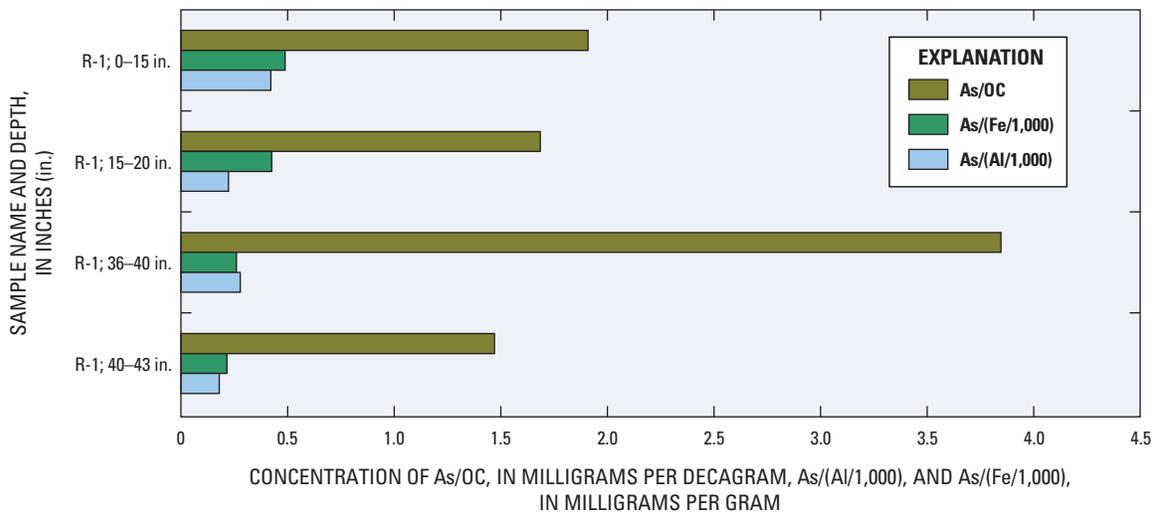


Figure 10. Concentrations of arsenic (As) normalized to organic carbon (OC), aluminum (Al), and iron (Fe) in Raccoon Creek bankside soils at Estates 1, Gloucester County, New Jersey, 2008. Fe and Al are divided by 1,000 for scaling purposes.

and the Sassafras series, which contains little or no glauconite (Keenan and Muñiz, 2007). Soils in the wetlands along the bank of the RAC at Estates 2 are described as loamy sands of the Collington soil series by Keenan and Muñiz (2007). On the streambank, the loamy materials were intermixed with gravels down to about 18 in.; below that depth, loamy sands graded into glauconite-rich clays. The clays are encountered at a depth of about 48 in. along the streambank and underlie the stream channel at this location.

The As concentration in the bankside loamy sand at a depth of about 19–22 in. was 12 mg/kg (appendix 2), slightly less than the concentration of As (16.1 mg/kg) in the surficial bankside sediments (sample R-1a) at Estates 1, but more than the As concentration (7.5 mg/kg) in the sample (R-1b) from below 15 in. to about 20 in. at Estates 1. The glauconite-rich clay beneath the detention basin contained about 24 to 45 mg/kg of As; these concentrations of As were at least twice those encountered in the bankside sediments (which did not contain glauconite) at Estates 1. Concentrations of Cr and V also were generally higher in the glauconitic soils/sediments at Estates 2 than in the sediments at Estates 1, likely reflecting the geologic contributions of these constituents to soil/sediment chemistry at Estates 2.

Concentrations of As, Be, Cr, and V—all of which are present at high concentrations in soils and sediments with high glauconite content (Dooley, 1998; 2001)—generally increased as concentrations of Fe in the soils/sediments increased (fig. 11.) The relations of As and Be with Fe, in particular, were strongly linear. Glauconite is a mineral with the nominal formula of $(K,Na)(Mg,Fe^{+2})_{0.33}(Fe^{+3},Al)_{1.67}[(Si,Al)_4O_{10}](OH)_2$ (Gaines and others, 1997) that contains substantial amounts of Fe in two valence states, and the positive relations shown in figure 11 appear to indicate that most of the As and Be are contributed to the soils and sediments at Estates 2 by glauconites (and accompanying micas). The Cr and V appears to be contributed mainly by these geologic materials as well.

Possible Sources and Transport of Arsenic, Metals, and Nutrients to the Basins and Stream

Volume-weighted As concentrations in precipitation in southern New Jersey ranged from 0.069 µg/L to 0.16 µg/L, about the same as in more urban areas in northern and central New Jersey (Reinfelder and others, 2004). These concentrations are low, relative to an area such as suburban northern Virginia (about 0.5 µg/L or less; Rice and others, 2002; Conko and others, 2004). It appears that As deposited by precipitation on the Raccoon Creek watershed, as a whole, and in the detention basins in particular, is probably negligible in comparison with the concentrations of As delivered to the RAC streamwater in runoff and by suspended sediment.

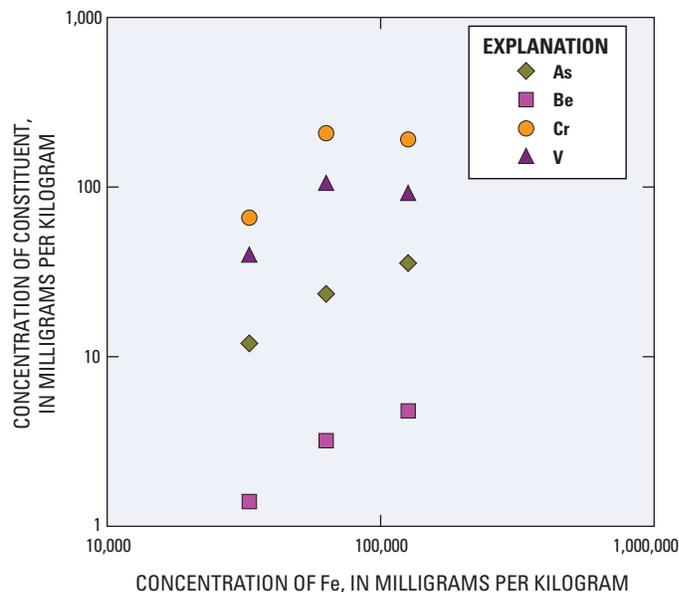


Figure 11. Relation of concentrations of arsenic (As), beryllium (Be), chromium (Cr) and vanadium (V) to iron (Fe) in glauconitic sediments from Estates 2, Gloucester County, New Jersey, 2008.

It is likely that some of the As and Cr in the runoff at Estates 2 is derived from the soils developed on As- and Cr-rich geologic materials because, during the storm in September, concentrations of both constituents were higher in water from the detention basin at Estates 2 (fig. 7), where the soils are rich in these elements, than in water from the basin at Estates 1, where obvious inputs of Cr are lacking and inputs of As may not derive solely from geologic materials. Surface and shallow subsurface runoff in some areas upgradient from the basin at Estates 2 passes through Freehold soils, which can contain up to 10 percent glauconite (Keenan and Muñiz, 2007). Runoff to and within the basin (E2B) at Estates 2 runs directly over the glauconitic clays (in which the basin's grass is rooted), and near the stream, subsurface flow to the RAC passes through the Collington soils along the banks, which can contain 10 to 40 percent glauconite. Given the relatively low concentrations of particulate As and Cr in the runoff samples, it appears that most of the contributions of these constituents either are in dissolved form or as colloids, which probably indicates substantial filtering of particles by grassy terrain leading to the basin and filtering and (or) settling within the basin.

The likely sources of As at Estates 1 could be both geologic and anthropogenic. In silty and clayey units of the basal Kirkwood Formation, As concentrations in pore waters have

been found to be quite high (6.2–37.4 $\mu\text{g/L}$; Szabo and others, 2006), indicating a potential geologic source. Additionally, the land upon which Estates 1 was developed was formerly an orchard; consequently, lead arsenate pesticide residues may be present in the soils. Elsewhere, in the northern Coastal Plain of central New Jersey, As was enriched from background levels of about 5 mg/kg up to about 40 mg/kg in acidic sandy soils in orchards where pesticide residues were present (Barringer and others, 1998). There, the As was mainly associated with Fe in the uppermost mineral horizon (the A horizon) (Barringer and others, 1998) because oxidized As (arsenate) tends to sorb to iron hydroxides at a pH of less than 7 (Wilkie and Hering, 1996). The highest concentrations of As and Sb in the bank-side sediments at Estates 1 may be indicative of runoff bearing pesticide residues from the orchards that were once adjacent to the stream.

Although the As and Fe concentrations in the surficial glauconitic soil sample from the detention basin (core TC-1) were lower than in the deeper sample (TC-2; appendix 2), concentrations of Ba, Cu, Na, P, and Pb were all substantially higher in the surficial sample than in the deep samples. This distribution could indicate that these metals, but not As, accumulate in the surficial soils within the basin, brought in by runoff. The metals then are sorbed to, or incorporated within, the existing soil particles. Likely sources for these constituents in runoff are vehicular traffic, roadsalt, and fertilizers.

Concentrations of Pb in runoff to and from the basin at Estates 1 were about the same or slightly lower than those in runoff to and from the basin at Estates 2. Concentrations of Pb, mostly particulate, were higher, however, in the RAC streamwater at E1C during the September event than those downstream at E2C. A pulse of Pb to the stream during a major runoff event apparently is initiated upstream from Estates 1. Because the E2C site was sampled an hour later than the E1C site (both on the rising limb of the hydrograph from the gage at 01477120), the higher Pb concentrations may not have reached the downstream E2C site by the time of sampling. It is also possible that runoff and tributary water that contained lesser amounts of Pb from areas between the two sites diluted the streamwater at E2C. Only simultaneous sampling at the two sites throughout a storm would resolve this question. Such intensive sampling was beyond the scope of the current investigation.

The source(s) of what appears to be a Pb pulse in streamwater at E1C is not known. With residential development creating greater areas of impervious surfaces, runoff may contain more vehicle-related metals than it once did. Orchards where lead arsenate may have been used remain in the upper part of the watershed, but most do not abut the stream. Soil disturbance during residential development of former orchard land, such as at Estates 1, may be a factor. Some former orchard areas have been cleared but not yet developed, and Pb-bearing particles may now be washed to the stream at a greater rate than formerly. Concentrations of Cd (mostly in particulate form) also were higher in the RAC streamwater at the two stream sampling sites than in the runoff from either basin to

the stream. This distribution may be indicative of a vehicular source for both Cd and Pb, whereby metal-bearing particles wash from road surfaces into the stream at bridge crossings and where roads are adjacent to the stream channel.

The relatively high concentrations of Cu in runoff waters in and from both detention basins could be indicative of inputs from vehicles and, perhaps, Cu leaching from chromated copper arsenate (CCA) treated lumber (Stook and others, 2005), possibly used in decks on nearby houses. If the latter contributes Cu to runoff, any As and Cr contributed by CCA-treated lumber would be hard to distinguish from the geologic inputs of As and Cr at the Estates 2 site because both constituents are major components of soils developed on, and glauconitic clays within, the Hornerstown and Navesink Formations (Dooley, 1998, 2001), one or both of which underlie the detention basin.

On the basis of nutrient concentrations in water samples collected during the September storm, runoff to and from the basin at Estates 1 contains greater concentrations of nitrite + nitrate than does runoff at Estates 2; this may reflect greater agricultural inputs at Estates 1. Nevertheless, nutrients in the stream also can derive from areas other than Estates 1 and 2; these likely include farm fields and orchards still in production. Like As and the metals, P in the streamwater was mostly in particulate form, probably sorbed to Fe, Al, and Mn hydroxide particles for which it has a known affinity (Zhou and others, 2005).

In the runoff at both sites, molar concentrations of Na and Cl were nearly the same. This could be an indication of roadsalt effects because the moles of Na in roadsalt sodium chloride (NaCl) are equivalent to the moles of Cl. Retention of roadsalt from winter applications can lead to Cl accumulation in watersheds (Kelly and others, 2008, and sources cited therein). Consequently, Cl from residual roadsalt probably continues to make its way to the detention basins throughout the year. In the streamwater, however, molar concentrations of Cl were greater than those of sodium. Although Na can be removed from solution by ion exchange, the change in Na/Cl balance may indicate that other sources of Cl—probably residues of agricultural chemicals such as KCl (see, for example, Nakano and others, 2008)—are contributing to the Cl content of streamwater during rain/runoff events.

Concentrations of SO_4 were substantially higher in streamwater than in runoff at both sites. Consequently, it appears that residential development contributes relatively little SO_4 to the stream. Much of the SO_4 in the streamwater could derive from runoff from agricultural land in the watershed, as fertilizers can contain substantial amounts of sulfate (Nakano and others, 2008).

Overall, although the detention basins do contribute As, metals, and nutrients (also Cl and SO_4) to the RAC, the concentrations of these constituents in the stream during high flow indicate the cumulative inputs upstream from the two basins substantially outweigh contributions from the individual basins. On the basis of differences in concentrations between unfiltered and filtered water samples, there clearly are particles

greater than 0.45 μm in the runoff, but these appear to contain mostly Al, Fe, and Mn, which are interpreted as indicative of clays and Fe-, Mn, and Al-hydroxide particles. With the exception of some particulate Pb, however, most of the metals appeared to be in dissolved or colloidal form, particularly in samples collected in September. The DOC in the runoff may have complexed and transported some of the metals in dissolved form rather than in particulate form.

Metal ions Cr^{3+} , Fe^{3+} , Al^{3+} , Pb^{2+} , and Cu^{2+} all form complexes with fulvic acids (major components of organic matter in soils) at about pH 7, as demonstrated by Schnitzer and Kerndorff (1981). At Estates 1 and 2, the pH of runoff, which was measured in the laboratory, was about 7. Complexation of some of the metals by organic acids appears likely at the circumneutral pHs of the runoff and streamwater; this likelihood is supported by a strong positive relation (Pearson's r greater than 0.85) between DOC, dissolved As, dissolved P, and dissolved Cu in both runoff and streamwater (fig. 12; table 2). Metals in anionic form such as Cr and V also show a positive relation to DOC (fig. 12). A recent study shows that As, as the oxidized form arsenate (As (V)), binds strongly to humic acids (another major component of organic matter) at pH 7 (Buschmann and others, 2006). Consequently, complexation by DOC may be the means by which dissolved As and some other dissolved constituents are transported. Particulate As and Pb, and particulate P also show a strong relation to particulate Al, Fe, and Mn (fig. 13; table 3), indicating that sorption to mobile Al-, Fe-, or Mn-hydroxide particles and clays may provide an alternate means of transport for these constituents and some of the other metals. At the roughly neutral pHs of runoff in this part of the RAC watershed, much of the anionic As and P (probably also Cr) would still be sorbed to metal hydroxides, whereas these anions would desorb at higher pHs (see, for example, Manning and Goldberg, 1996; Darland and Inskeep, 1997; Dixit and Hering, 2003). Cationic metals, on the other hand, would have an affinity for clay particles, although the presence of organic matter can, for some metals, affect the degree of sorption (Schmitt and others, 2002).

Concentrations of some constituents were lower in water from outfalls E1O and E2O than those in water from the basins (E1B and E2B), indicating the basins probably trap some As, metals, and nutrients. Nevertheless, concentrations at their outfalls indicate most of the As and metals in water within the basins ultimately is delivered to areas that abut the stream channel or to the stream itself. The particle load in the stream reflects far greater inputs of particles to the water column, overall, from both runoff and fine bed sediments that are suspended during high-flow conditions than would be likely in the runoff alone from the residential area, where filtering through the surrounding lawns and some settling of particles may occur as the detention basins gradually fill.

Runoff to the RAC probably is greater at Estates 2 than at Estates 1 as a result of (1) the clays underlying parts of the development, the detention basin, and the bankside soils at Estates 2, and (2) a slightly larger area of paved impervious surface in surrounding developments at Estates 2. Both areas

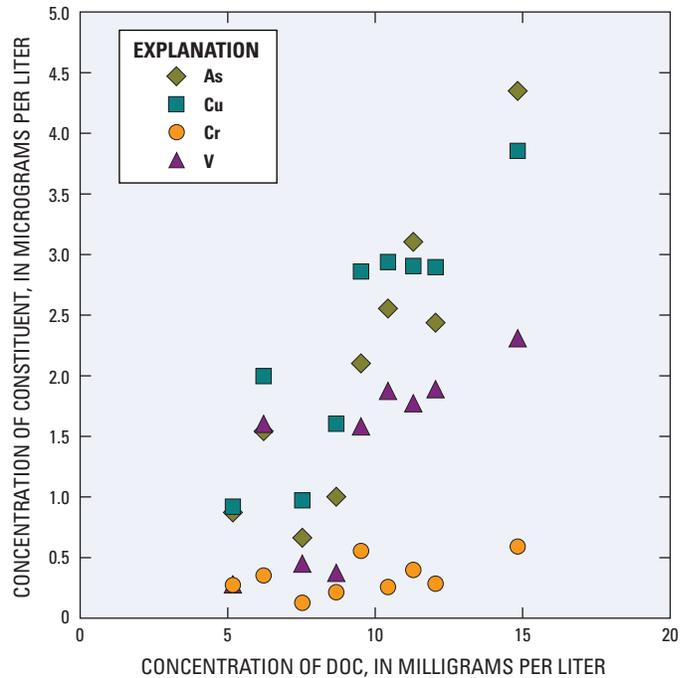


Figure 12. Relation of concentrations of dissolved arsenic (As), copper (Cu), chromium (Cr), and vanadium (V) to concentrations of dissolved organic carbon (DOC) in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, May and September 2008.

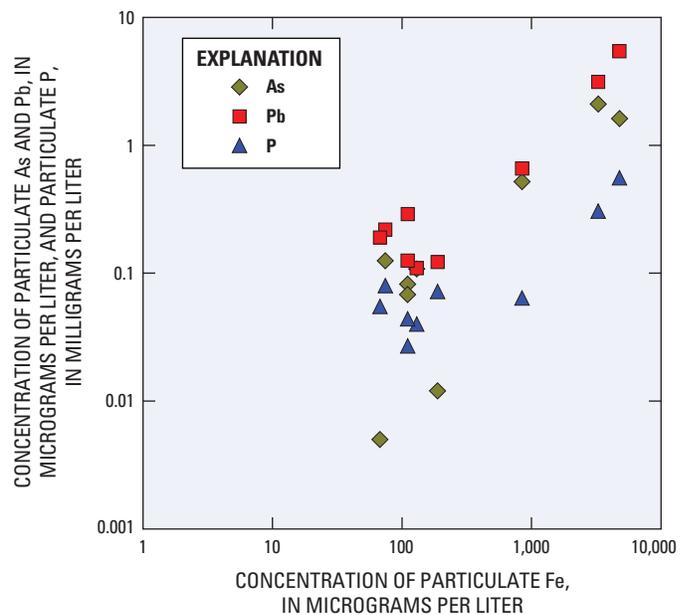


Figure 13. Relation of particulate arsenic (As), lead (Pb), and phosphorus (P) to particulate iron (Fe) in runoff to, and streamwater in, Raccoon Creek, Gloucester County, New Jersey, May and September 2008. (Note the log scale on both axes.)

Table 2. Pearson's correlation coefficients for selected dissolved constituents in runoff and streamwater, Estates 1 and 2, Gloucester County, New Jersey, May and September 2008.

[P, phosphorus; OC, organic carbon; Al, aluminum; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Fe, iron; Pb, lead; V, vanadium: diss, dissolved]

	Pdiss	OCdiss	Aldiss	Asdiss	Cddiss	Crdis	Cudiss	Fediss	Pbdiss	Vdiss
Pdiss	1									
OCdiss	0.883	1								
Aldiss	-0.079	-0.025	1							
Asdiss	0.883	0.897	0.198	1						
Cddiss	0.145	0.269	0.549	0.255	1					
Crdis	0.387	0.539	0.657	0.739	0.553	1				
Cudiss	0.860	0.890	0.164	0.949	0.473	0.744	1			
Fediss	-0.532	-0.586	0.502	-0.523	-0.069	-0.275	-0.643	1		
Pbdiss	-0.572	-0.517	0.637	-0.407	-0.008	-0.030	-0.546	0.944	1	
Vdiss	0.847	0.763	0.069	0.892	0.331	0.671	0.943	-0.712	-0.650	1

Table 3. Pearson's correlation coefficients for selected constituents in particulate form in runoff and streamwater at Estates 1 and 2, Gloucester County, New Jersey, May and September 2008.

[particulate concentration = unfiltered concentration – filtered concentration; P, phosphorus; OC, organic carbon; Al, aluminum; As, arsenic; Cr, chromium; Cu, copper; Fe, iron; Mn, manganese; Pb, lead; V, vanadium; part, particulate]

	Ppart	OCpart	Alpart	Aspart	Crpart	Cupart	Fepart	Mnpart	Pbpart	Vpart
Ppart	1									
OCpart	0.898	1								
Alpart	0.907	0.725	1							
Aspart	0.852	0.643	0.992	1						
Crpart	0.836	0.632	0.986	0.996	1					
Cupart	0.638	0.719	0.686	0.652	0.673	1				
Fepart	0.979	0.856	0.966	0.928	0.913	0.691	1			
Mnpart	0.969	0.818	0.982	0.953	0.942	0.683	0.995	1		
Pbpart	0.992	0.899	0.937	0.887	0.873	0.705	0.993	0.983	1	
Vpart	0.870	0.659	0.891	0.882	0.871	0.512	0.889	0.914	0.859	1

contain land that has been cleared but not developed from which sediment can be eroded and transported.

Because the Hornerstown and Navesink Formations form a confining unit, not an aquifer, percolation of As-bearing runoff waters to groundwater is unlikely at Estates 2. At Estates 1, however, where soils are sandier, some percolation is likely. Moreover, during bankside soil sampling at Estates 1, hydrogen sulfide odors, indicative of reducing conditions, were detected at a depth of about 2 ft. During a major rain event, the soils beneath the detention basin at Estates 1 would be saturated as the basin fills, and reducing conditions could develop there as well. Where such conditions develop, any sorbed As present as arsenate (As (V)) could be reduced to arsenite (As (III)), which might then become mobile, particularly if

organic matter is present (Redman and others, 2002). Additional sampling would be needed to confirm this supposition.

The water-quality sampling and flow measurements made during the September 2008 rain event indicate that there was a substantial increase in streamflow over the short distance (2.44 mi) from Estates 1 to Estates 2; input from several tributaries that enter the RAC between Estates 1 and 2 probably accounts for much of the increase. Instantaneous discharge was 8.5 ft³/s at Estates 1 at 1700 hours and 40 ft³/s at Estates 2 at 1830 hours. Flow peaked at about 58 ft³/s at the streamgage 3.7 mi. downstream (01477120, fig. 4) about 18 hours later than the flow measured at Estates 2. Consequently, flow measured at Estates 1 and 2 would have been on the rising limb of the hydrograph. Given only 1.5 hours time difference and

a distance of 2.44 mi, the flow measurement at Estates 2 was probably made earlier relative to peak flow than that made at Estates 1; that is, the same points on a hydrograph showing the storm wave at Estates 1 probably would not be seen on a hydrograph at Estates 2 because the same part of the RAC mainstem storm wave would not yet have reached Estates 2 in 1.5 hours.

In addition to runoff, streamwater upstream from and at Estates 1 also receives groundwater discharge from the basal part of the Kirkwood-Cohansey aquifer system, whereas at Estates 2, minimal if any discharge would be expected from the clay-rich sediments of the confining unit formed by the Hornerstown and Navesink Formations. At Estates 2, the streamflow apparently is composed of runoff and surface water coming from upstream on the mainstem and the tributaries.

During the September storm, the total As load in the stream at Estates 1 was about 0.05 kg/day; the load in the stream at Estates 2 was 0.30 kg/day. The inputs of As in the vicinity of Estates 2 appear to have resulted in higher concentrations in the streamwater and a greater load than at Estates 1 at the times of sampling. Nevertheless, without serial sampling at both sites during the same storm, the loads cannot be compared for equivalent points on the hydrograph.

The As load at Estates 2 apparently was amplified by greater streamflow arising, in part, from inputs from the tributaries and, in part, from greater local runoff inputs (partly because of the clay substrate that blocks percolation) than the runoff inputs to streamflow at Estates 1.

Inputs of constituents to the RAC from areas upstream from Estates 1 cannot be discounted, however. Particulate concentrations of several metals were high, and As concentrations were substantial in the streamwater just upstream from the Estates 1 basin. Runoff from currently inactive residential development construction sites probably contributes to particle loadings because the watershed currently contains bulldozed areas with little vegetation in addition to a greater amount of impervious surface than was present prior to the last two decades of the 20th century.

Summary and Conclusions

Samples of runoff were collected from two detention basins, their outfalls, and the Raccoon Creek immediately upstream from the outfalls. Sampling sites at Estates 2, underlain by glauconitic soils and geologic materials that are naturally enriched in As, were sampled twice, once during a rain event that was part of a 4-day wet period and once during a rainfall of 2.4 in. that followed a month of dry conditions. Sampling sites at Estates 1, underlain by soils and sediments composed mainly of quartz sand, were sampled once during the larger rain event. Before residential development, the area at Estates 1 was an orchard; the area at Estates 2 was farm fields.

The concentrations of As in runoff collected at Estates 1 and Estates 2 differed substantially during the same rain event; concentrations were highest at Estates 2. Although there may be arsenical pesticide residues in the soil at Estates 1 that contributed to the moderately high As concentrations in runoff there, the higher concentrations at Estates 2 indicate that the geologic inputs of As to runoff and to the stream probably outweigh those contributed by former land use. The Estates 2 sampling site is underlain by a confining unit (the Hornerstown and Navesink Formations); therefore, percolation of As-rich waters to groundwater within the detention basin probably is not an issue there. It may be an issue, however, in the basin at the upstream Estates 1 site where soils and underlying sediments are sandy and more permeable than those at Estates 2. September 2008 stormflow samples at both sites were collected on the rising limb of the hydrograph but not at equivalent points on the hydrograph. At the times of collection and streamflow measurements, the total As load at Estates 2 in September 2008 was 6 times that at Estates 1, reflecting not only greater inputs of As at Estates 2, but greater discharge arising from water in the tributaries entering the RAC upstream from Estates 2 and greater runoff because of the clay substrate.

Runoff to and from the detention basins contains metals, such as Cr and Cu, the main sources of which appear to be geologic and anthropogenic, respectively. Runoff from roads may be an important source of Pb to the stream, and runoff from surrounding agricultural areas appears to be a major source of nutrients, chloride, and sulfate. Because most of the chemical constituents sampled within the basins and at the outfalls were primarily in dissolved form, it appears that some filtering and settling of particles occurs along the paths to and within the basins. The metals and nutrients present in the streamwater, however, were mostly in particulate form—particles that were delivered by runoff from areas other than the detention basins and from suspended bed sediments.

Positive relations between As and some metals with DOC indicate that complexation with organic carbon may be one mode of transport for As and some of the metals in runoff and in the streamwater. Sorption of As, Pb, and P to Fe hydroxides may be indicated by the positive relation of particulate As, Pb, and P with particulate Fe, providing a second mode of transport.

Acknowledgments

Thanks go to Michael Haberland of NJDEP, and Charles Romig and Richard Westergaard of GCPD, for their administrative assistance. The authors thank the homeowners' associations who permitted sample collection within their basins. The authors are grateful to personnel of the CCSCD and the GCSCD, to volunteer James McGee who assisted with field work, and to Chasity Williams of CCSCD for help with data and record management.

References Cited

- Arbogast, B.F., 1996, Analytical methods manual for the Mineral Resources Survey Program: U.S. Geological Survey Open-File Report 96-525, 248 p.
- Asher, Elizabeth, 2009, Impact of land use on the mobilization of lead arsenate pesticides applied to historical orchard lands. Geological Society of America Abstracts with Programs, 44th Annual Meeting, Northeastern Section, Portland, Maine, March 22-24, 2009, p. 9.
- Barbarosa, A.E., and Hvitved-Jacobsen, T., 1999, Highway runoff and potential for removal of heavy metals in an infiltration pond in Portugal: The Science of the Total Environment, v. 235, p. 151-159.
- Barringer, J.L., Szabo, Zoltan, and Barringer, T.H., 1998, Arsenic and metals in soils in the vicinity of the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 98-4016, 251 p.
- Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved organic carbon by uv-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92-480, 12 p.
- Briggs, P.H., and Meier, A.L., 2002, The determination of forty-two elements in geological materials by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 02-223-I, 14 p.
- Brown, Z.A., and Curry, K.J., 2002, Total carbon by combustion: U.S. Geological Survey Open-File Report 02-223-R, 4 p.
- Brown, Z.A., Papp, Clara, Brandt, Elaine, and Aruscavage, Phillip, 2002, Carbonate carbon by coulometric titration: U.S. Geological Survey Open-File Report 02-223-S, 6 p.
- Buschmann, J., Kappeler, A., Lindauer, U., Kistler, D., Berg, M., and Sigg, L., 2006, Arsenite and arsenate binding to dissolved humic acids: Influence of pH, type of humic acid, and aluminum: Environmental Science and Technology, v. 40, p. 6015-6020.
- Campbell, K.M., Root, R., O'Day, P.A., and Hering, J.G., 2008, A gel probe equilibrium sampler for measuring arsenic porewater profiles and sorption gradients in sediments: I. Laboratory development: Environmental Science and Technology, v. 42, p. 497-503.
- Carter, R.W., and Davidian, J., 1968, General procedure for gaging streams: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3 Applications of Hydraulics, chap. A6, 13 p.
- Camden County Soil Conservation District (CCSCD), 2008, Raccoon Creek water quality and bacteria monitoring, Raccoon Creek, WMA 18: Unpublished report by the Camden County Soil Conservation District, available at the Gloucester County Department of Public Works, Planning Division, Clayton, New Jersey.
- Clesceri, L.S., Greenberg, A.E., Eaton, A.D., eds., 1998, Method 5310 B, Standard methods for analysis of water and wastewater (20th ed.): Denver, CO, American Public Health Association.
- Conko, K.M., Rice, K.C., and Kennedy, M.M., 2004. Atmospheric wet deposition of trace elements to a suburban environment, Reston, Virginia, USA: Atmospheric Environment, v. 38, p. 4025-4033.
- Council, T.B., Duckenfield, K.U., Landa, E.R., and Callander, E., 2004, Tire-wear particles as a source of zinc to the environment: Environmental Science and Technology, v. 38, p. 4206-4214.
- Darland, J.E., and Inskeep, W.P., 1997, Effects of pH and phosphate competition on the transport of arsenate: Journal of Environmental Quality, v. 26, p. 1133-1139.
- Dixit, Suvasis, and Hering, J.G., 2003. Comparison of arsenic (V) and arsenic (III) sorption on iron oxide minerals: Implications for arsenic mobility: Environmental Science and Technology, v. 37, p. 4182-4189.
- Dooley, J. H., 1998., Comprehensive chemistry of select greensand from the New Jersey Coastal Plain: New Jersey Geological Survey Technical Memorandum 98-1, 20 p.
- Dooley, J.H., 2001, Baseline concentrations of arsenic, beryllium and associated elements in glauconite and glauconitic soils in the New Jersey Coastal Plain: New Jersey Geological Survey Investigation Report, on file at New Jersey Department of Environmental Protection, Trenton, N.J.
- Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.
- Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.
- Gaines, R.V., Skinner, H.C.W., Foord, E.E., Mason, B., and Rosenzweig, A., 1997, Dana's new mineralogy: New York, John Wiley and Sons.

- Garbarino, J.R., Kanagy, L.K., and Cree, M.E., 2006, Determination of elements in natural water, biota, sediment, and soils samples using collision/reaction cell inductively coupled plasma-mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, sec. B, chap. 1.
- Hares, R.J., and Ward, N.I., 1999, Comparison of the heavy metals content of motorway stormwater following discharge into wet biofiltration and dry detention ponds along the London orbital (M25) motorway: *The Science of the Total Environment*, v. 235, p. 169–178.
- Horowitz, A.J., Elrick, K.A., and Callender, Edward, 1988, The effect of mining on the sediment-trace element geochemistry of cores from the Cheyenne River arm of Lake Oahe, South Dakota, U.S.A.: *Chemical Geology*, v. 67, p. 17–33.
- Horowitz, A.J., Demas, C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94–0539, 57 p.
- Ivahnenko, T., Szabo, Z., and Hall, G.S., 1996, Use of an ultra-clean sampling technique with inductively coupled plasma mass-spectrometry to determine trace-element concentrations in water from the Kirkwood-Cohansey aquifer system, Coastal Plain, New Jersey: U.S. Geological Survey Open-File Report 96–142, 37 p.
- Jain, A. and Loeppert, R.H., 2000, Effect of competing anions on the adsorption of arsenate and arsenite by ferrihydrite: *Journal of Environmental Quality*, v. 29, p. 1422–1430.
- Juracek, K.E., and Ziegler, A.C., 2006, The legacy of leaded gasoline in bottom sediment of small rural reservoirs: *Journal of Environmental Quality*, v. 35, p. 2092–2102.
- Keenan, S.C., and Muñiz, E., 2007, Soil survey of Gloucester County, New Jersey: National Cooperative Soil Survey, Washington D.C., U.S. Department of Agriculture, 570 p.
- Kelly, V.R., Lovett, G.M., Weathers, K.C., Findlay, S.E.G., Strayer, D.I., Burns, D.J., and Likens, G.E., 2008, Long-term sodium chloride retention in a rural watershed: Legacy effects of road salt on streamwater concentration: *Environmental Science and Technology*, v. 42, p. 410–415.
- Lin, C-C, Chen, S-J, Huang, K-L., Hwang, W-I, Chang-Chien, G-P, and Lin, W-Y, 2005, Characteristics of metals in nano/ultrafine/fine/coarse particles collected beside a heavily trafficked road: *Environmental Science and Technology*, v. 39, p. 8113–8122.
- Lord, D.G., Barringer, J.L., Johnsson, P.A., Schuster, P.F., Walker, R.L., Fairchild, J.E., Sroka, B.N., and Jacobsen, Eric, 1990, Hydrogeochemical data from an acidic deposition study at McDonalds Branch in the New Jersey Pinelands, 1983–86: U.S. Geological Survey Open-File Report 88–500, 132 p.
- Manning, B.A., and Goldberg, S., 1996, Modeling competitive adsorption of arsenate with phosphate and molybdate on oxide minerals: *Soil Science Society of America Journal*, v. 60, p. 121–131.
- Monmouth County Health Department, 2006, Glauconite (Greensands) and TMDLs, accessed November 15, 2006 at [http://www.visitmonmouth.com/health/GIS/303\(d\)TMDL/glauconite.htm](http://www.visitmonmouth.com/health/GIS/303(d)TMDL/glauconite.htm).
- Morrison, G.M.P., Revitt, D.M., Ellis, J.B., Balmer, P., and Svensson, G., 1984, Heavy metal partitioning between the dissolved and suspended solid phases of stormwater runoff from a residential area: *The Science of the Total Environment*, v. 33, p. 287.
- Nakano, T., Tayasu, I., Yamada, Y., Hosono, T., Igeta, A., Hyodo, F., Ando, A., Saitoh, Y., Tanaka, T., Wada, E., and Yachi, S., 2008, Effect of agriculture on water quality of Lake Biwa tributaries, Japan: *Science of the Total Environment*, v. 389, p. 132–148.
- New Jersey Department of Environmental Protection, 2009, Standard for arsenic (total), accessed December 28, 2010, at <http://www.state.nj.us/dep/standards/pdf/7440-38-2.pdf>.
- Newton, K., Amarasiriwardena, D., and Xing, B., 2006, Distribution of soil arsenic species, lead, and arsenic bound to humic acid molar mass fractions in a contaminated apple orchard: *Environmental Pollution*, v. 143, p. 197–205.
- Owens, J.P., and Sohl, N.F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, in Subitsky, S., ed., *Geology of selected areas in New Jersey and Pennsylvania and guidebook of excursions*: New Brunswick, N.J., Rutgers University Press, p. 235–278.
- Peryea F.J. and Creger, T.L., 1994, Vertical distribution of lead and arsenic in soils contaminated with lead arsenate pesticide residues: *Water, Air, and Soil Pollution*, v. 78, p. 297–306.
- Raven, K.P., Jain, A., and Loeppert, R.H., 1998, Arsenite and arsenate adsorption on ferrihydrite: Kinetics, equilibrium, and adsorption envelopes: *Environmental Science and Technology*, v. 32, p. 344–349.

- Redman, A.D., Macalady, D.L., and Ahmann, D., 2002, Natural organic matter affects arsenic speciation and sorption onto hematite: *Environmental Science and Technology*, v. 36, p. 2889–2896.
- Reinfelder, J.R., Totten, L.A., and Eisenreich, S.J., 2004, The New Jersey Atmospheric Deposition Network (NJADN): Final Report to the New Jersey Department of Environmental Protection, on file in Trenton, NJ, and Rutgers University, New Brunswick, NJ.
- Rice, K.C., 1999, Trace-element concentrations in streambed sediment across the conterminous United States: *Environmental Science and Technology*, v. 33, p. 2499–2504.
- Rice, K.C., Conko, K.M., and Hornberger, G.M., 2002, Anthropogenic sources of arsenic and copper to sediments in a suburban lake, northern Virginia: *Environmental Science and Technology*, v. 36, p. 4962–4967.
- Schmitt, D., Taylor, H.E., Aiken, G.R., Roth, D.A., and Frimmel, F.H., 2002, Influence of natural organic matter on the adsorption of metal ions onto clay minerals: *Environmental Science and Technology*, v. 36, p. 2932–2938.
- Schnitzer M., and Kerndorff, H., 1981, Reactions of fulvic acid with metal ions: *Water, Air, and Soil Pollution*, v. 15, p. 97–108.
- Stollenwerk, K.G., 2003, Geochemical processes controlling transport of arsenic in groundwater: A review of adsorption: *in* Welch, A.H., and Stollenwerk, K.G., eds., *Arsenic in ground water: Geochemistry and occurrence*: Boston, MA, Kluwer Academic Publishing, p. 1–25.
- Stollenwerk, K.G., Breit, G.N., Welch, A.H., Yount, J.C., Whitney, J.W., Foster, A.L., Uddin, M.N., Majumder, R.K., and Ahmed, N., 2007, Arsenic attenuation by oxidized aquifer sediments in Bangladesh: *Science of the Total Environment*, v. 379, p. 133–150.
- Stook, Kristin, Tolaymat, Thabet, Ward, Marnie, Dubey, Brajesh, Townsend, Timothy, Solo-Gabriele, Helena, and Bitton, Gabriel, 2005, Relative leaching and aquatic toxicity of pressure-treated wood products using batch leaching tests: *Environmental Science and Technology*, v. 39, p. 155–163.
- Szabo, Zoltan, Keller, E.A., and Defawe, R.M., 2006, Pore-water quality in the clay-silt confining units of the Lower Miocene Kirkwood Formation and hypothetical effects on water quality in the Atlantic City 800-foot Sand, northeastern Cape May County, New Jersey, 2001: U.S. Geological Survey Scientific Investigations Report 2006–5134, 26 p.
- Wagner, S.E., Peryea, F.J., Filby, R.A., 2003, Antimony impurity in lead arsenate pesticide enhances the antimony content of old orchard soils: *Journal of Environmental Quality* 32, p. 736–738.
- Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., 2004, Processing of water samples (version 2.1). U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, accessed March 5, 2008, at <http://pubs.water.usgs.gov/twri9A5/>.
- Wilkie, J.A., and Hering, J.G., 1996, Adsorption of arsenic on hydrous ferric oxide: effects of adsorbate/adsorbent ratios and co-occurring solutes. *Colloids and Surfaces, A.: Physicochemical and Engineering Aspects*, v. 107, p. 97–110.
- Zeng, H., Fisher, B., and Giammar, D.E., 2008, Individual and competitive adsorption of arsenate and phosphate to a high-surface-area iron oxide-based sorbent: *Environmental Science and Technology*, v. 42, p. 147–152.
- Zhou, A., Tang, H., and Wang, D., 2005, Phosphorus adsorption on natural sediments: Modeling and effects of pH and sediment composition: *Water Research*, v. 39, p. 1245–1254.

(This page intentionally left blank.)

Appendixes 1–2

Appendix 1. Major and trace elements, organic carbon, and nutrients in water samples from two detention basins and their outfalls, at Estates 1 and 2, and from Raccoon Creek immediately upstream from the outfalls, Gloucester County, New Jersey, May and September 2008.

[E, estimated concentration (below the lower reporting limit); <, less than; na, not analyzed; NAVD88, North American Datum of 1988]

Station number	Site name (USGS station name)	Date of sample collection	Sample start time	Altitude of land surface, NAVD 88 (feet)	Drainage area (square miles)	pH, water, unfiltered, laboratory (standard units)	Specific conductance, water, unfiltered, laboratory (microsiemens per centimeter at 25 degrees Celsius)
01477081	E1C (Raccoon Creek 400 ft above Clems Run, Ewan, NJ)	20080906	1700	55	6.45	7.12	154
01477082	E1B (Estates 1 detention basin, Ewan, NJ)	20080906	1615	65	0.07	7.38	115.4
01477083	E1O (Estates 1 detention-basin outfall, Ewan, NJ)	20080906	1630	60	0.07	6.86	123.3
01477105	E2C (Raccoon Creek at Turtle Creek Dr. at Mullica Hill, NJ)	20080516	1250	35	12.8	na	na
01477106	E2B (Estates 2 detention basin at Mullica Hill, NJ)	20080516	1105	53	0.07	na	na
01477107	E2O (Estates 2 detention-basin outfall at Mullica Hill, NJ)	20080516	1150	40	0.07	na	na
01477105	E2C (Raccoon Creek at Turtle Creek Dr. at Mullica Hill, NJ)	20080906	1800	35	12.8	7.21	178.1
01477106	E2B (Estates 2 detention basin at Mullica Hill NJ)	20080906	1810	53	0.07	7.14	147.3
01477107	E2O (Estates 2 detention-basin outfall at Mullica Hill, NJ)	20080906	1805	40	0.07	7.32	119.7

Site name	Calcium, water, filtered (milligrams per liter)	Magnesium, water, filtered (milligrams per liter)	Potassium, water, filtered (milligrams per liter)	Sodium, water, filtered (milligrams per liter)	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory (milligrams per liter as calcium carbonate)	Chloride, water, filtered (milligrams per liter)	Fluoride, water, filtered (milligrams per liter)	Silica, water, filtered (milligrams per liter as SiO ₂)	Sulfate, water, filtered (milligrams per liter)
E1C	14.6	2.99	3.82	6.01	26.3	14.5	0.081E	4.57	19.9
E1B	12.1	1.83	6.22	3.26	33.8	6.41	0.179	3.42	6.58
E1O	12.7	2.09	6.81	3.63	34.5	7.01	0.168	3.66	7.77
E2C	na	na	na	na	na	na	na	na	na
E2B	na	na	na	na	na	na	na	na	na
E2O	na	na	na	na	na	na	na	na	na
E2C	16.2	3.20	5.50	6.58	24.9	17.8	0.111E	6.23	24.2
E2B	10.9	3.33	7.65	7.40	31.2	14.8	0.181	2.30	8.45
E2O	8.64	2.74	5.94	5.53	24.5	11.5	0.127	1.96	7.59

Appendix 1. Major and trace elements, organic carbon, and nutrients in water samples from two detention basins and their outfalls, at Estates 1 and 2, and from Raccoon Creek immediately upstream from the outfalls, Gloucester County, New Jersey, May and September 2008.—Continued

[E, estimated concentration (below the lower reporting limit); <, less than; na, not analyzed; NAVD88, North American Datum of 1988]

Site name	Ammonia plus organic nitrogen, water, unfiltered (milligrams per liter as nitrogen)	Ammonia, water, filtered (milligrams per liter as nitrogen)	Nitrate plus nitrite, water, filtered (milligrams per liter as nitrogen)	Nitrite, water, filtered (milligrams per liter as nitrogen)	Orthophosphate, water, filtered (milligrams per liter as phosphorus)	Phosphorus, water, filtered (milligrams per liter as phosphorus)	Phosphorus, water, unfiltered (milligrams per liter as phosphorus)	Organic carbon, water, filtered (milligrams per liter)	Organic carbon, water, unfiltered (milligrams per liter)
E1C	1.05	0.018E	0.605	0.005	0.071	0.078	0.635	7.53	19.3
E1B	1.39	0.084	0.458	0.026	0.541	0.562	0.642	10.4	11.922
E1O	1.45	0.048	0.615	0.029	0.553	0.591	0.663	12.1	13.54
E2C	0.52	0.046	1.158	0.017	0.029	0.038E	0.102	5.18	6.628
E2B	2.01	0.600	0.215	0.010	0.098	0.117	0.144	6.22	9.969
E2O	2.25	0.467	0.32	0.013	0.126	0.162	0.202	9.52	12.758
E2C	0.90	<0.02	0.631	0.009	0.045	0.057	0.363	8.68	12.505
E2B	1.82	0.202	0.294	0.023	0.587	0.644	0.699	14.8	15.762
E2O	1.38	0.183	0.247	0.017	0.445	0.492	0.536	11.3	12.627

Site name	Aluminum, water, filtered (micrograms per liter)	Aluminum, water, unfiltered, recoverable (micrograms per liter)	Arsenic, water, filtered (micrograms per liter)	Arsenic, water, unfiltered (micrograms per liter)	Barium, water, filtered (micrograms per liter)	Barium, water, unfiltered, recoverable (micrograms per liter)	Boron, water, filtered (micrograms per liter)	Cadmium, water, filtered (micrograms per liter)	Cadmium, water, unfiltered (micrograms per liter)
E1C	16.4	741	0.663	2.28	37.4	81.0	19.8	<0.04	0.261
E1B	26.3	92.1	2.56	2.68	8.34	9.16	13.1	0.069	0.083
E1O	28.1	63.1	2.44	2.45	9.62	10.5	15.3	0.082	0.111
E2C	56.0	263	0.872	1.39	57.8	62.1	24.1	0.058	0.129
E2B	28.2	102	1.54	1.63	5.17	6.17	12.7	0.054	0.098
E2O	55.3	125	2.10	2.21	9.59	10.5	25.2	0.117	0.150
E2C	25.1	794	1.00	3.10	47.7	64.7	38.5	0.075	0.353
E2B	43.0	105	4.35	4.35	10.7	11.4	36.7	0.063	0.084
E2O	33.9	85.0	3.11	3.17	8.28	9.09	26.7	0.057	0.065

Appendix 1. Major and trace elements, organic carbon, and nutrients in water samples from two detention basins and their outfalls, at Estates 1 and 2, and from Raccoon Creek immediately upstream from the outfalls, Gloucester County, New Jersey, May and September 2008.—Continued

[E, estimated concentration (below the lower reporting limit); <, less than; na, not analyzed; NAVD88, North American Datum of 1988]

Site name	Chromium, water, filtered (micrograms per liter)	Chromium, water, unfiltered, recoverable (micrograms per liter)	Copper, water, filtered (micrograms per liter)	Copper, water, unfiltered, recoverable (micrograms per liter)	Iron, water, filtered (micrograms per liter)	Iron, water, unfiltered, recoverable (micrograms per liter)	Lead, water, filtered (micrograms per liter)	Lead, water, unfiltered, recoverable (micrograms per liter)	Manganese, water, filtered (micrograms per liter)
E1C	0.127	1.09	0.972E	2.63	129	4,910	0.119	5.56	5.08
E1B	0.257	0.409	2.94	2.94	68.9	143	0.088	0.307	0.678
E1O	0.285	0.348E	2.90	2.91	78.2	266	0.089	0.211	0.647
E2C	0.274	0.568	0.920E	1.32	642	1,490	0.255	0.913	31.9
E2B	0.353	0.532	2.00	3.65	41.1	152	0.111	0.402	0.702
E2O	0.555	0.699	2.86	2.85	117	247	0.140	0.249	4.52
E2C	0.215	1.52	1.61	2.90	234	3,510	0.160	3.29	8.32
E2B	0.591	0.704	3.86	3.98	60.1	128	0.134	0.324	0.551
E2O	0.398	0.508	2.91	3.28	66.7	177	0.115	0.240	0.274E

Site name	Manganese, water, unfiltered, recoverable (micrograms per liter)	Mercury, water, filtered (micrograms per liter)	Mercury, water, unfiltered, recoverable (micrograms per liter)	Nickel, water, filtered (micrograms per liter)	Nickel, water, unfiltered, recoverable (micrograms per liter)	Vanadium, water, filtered (micrograms per liter)	Vanadium, water, unfiltered (micrograms per liter)	Zinc, water, filtered (micrograms per liter)	Zinc, water, unfiltered, recoverable (micrograms per liter)
E1C	108	<0.010	0.018	0.634	1.97	0.450	2.15	1.98	16.1
E1B	7.40	<0.010	<0.010	0.805	0.833	1.87	2.18	5.41	5.9
E1O	8.65	<0.010	<0.010	0.915	0.880	1.89	2.00	5.91	5.74
E2C	49.5	na	na	1.74	1.84	0.279	0.615	5.72	7.11
E2B	4.63	na	na	0.654	0.738	1.60	1.72	8.08	8.15
E2O	8.37	na	na	2.11	1.99	1.58	1.81	12.3	10.6
E2C	90.6	<0.010	0.021	1.51	2.69	0.374	2.12	4.75	17.9
E2B	4.00	0.006E	0.009E	0.954	0.959	2.31	2.46	10.2	11.3
E2O	3.82	<0.010	0.005E	1.11	1.11	1.77	1.95	8.49	8.89

Appendix 2. Major and trace elements in soils and sediments from Estates 1 and 2, Gloucester County, New Jersey, June–October, 2008.

[mg/kg, milligrams per kilogram; OC, organic carbon; gl., glauconitic]

Site number	Sample site and sample name	Sample composition	Sample depth (inches)	Date of sample collection	Sample start time	Total carbon (percent)	Organic carbon (OC) (percent)	Total aluminum (Al) (mg/kg)	Total antimony (Sb) (mg/kg)	Total arsenic (As) (mg/kg)
394224075120101	Estates 1 bankside core R-1	OC-rich silt	0–15	20081001	1125	8.54	8.43	38,200	0.79	16.1
394224075120101	Estates 1 bankside core R-1	clay, silt	15–20	20081001	1126	4.47	4.45	33,600	0.63	7.5
394224075120101	Estates 1 bankside core R-1	clay, lignite	36–40	20081001	1127	1.05	1.04	14,400	0.24	4.0
394224075120101	Estates 1 bankside core R-1	clay, sand	40–43	20081001	1128	2.04	2.04	16,700	0.26	3.0
394349075124001	Estates 2 detention basin core TC-1	gl. clay	0–6	20080620	1135	4.51	4.48	56,600	1.20	23.5
394347075123901	Estates 2 detention basin core TC-2	gl. clay	38–47	20080710	1130	0.62	0.62	48,600	0.72	35.7
394347075123901	Estates 2 detention basin core TC-2R	gl. clay	38–47	20080710	1131	0.57	0.56	49,800	0.83	45.4
394348075124101	Estates 2 bankside augur TC-B	loamy sand	19–22	20080710	1330	0.83	0.83	20,800	0.43	12.0

Sample site and sample name	Sample depth (inches)	Total barium (Ba) (mg/kg)	Total calcium (Ca) (mg/kg)	Total cadmium (Cd) (mg/kg)	Total chromium (Cr) (mg/kg)	Total copper (Cu) (mg/kg)	Total iron (Fe) (mg/kg)	Total potassium (K) (mg/kg)	Total magnesium (Mg) (mg/kg)
Estates 1 bankside core R-1	0–15	281	5,630	0.71	50.7	18.7	33,000	8,310	2,010
Estates 1 bankside core R-1	15–20	204	3,910	0.88	60.4	16.1	17,600	7,950	1,770
Estates 1 bankside core R-1	36–40	114	1,530	0.25	38.7	6.5	15,400	5,380	1,170
Estates 1 bankside core R-1	40–43	136	2,260	0.33	30.0	7.6	13,900	4,900	926
Estates 2 detention basin core TC-1	0–6	348	4,390	0.67	208	18.3	63,200	24,500	9,670
Estates 2 detention basin core TC-2	38–47	107	3,800	3.80	191	5.3	126,000	52,100	18,200
Estates 2 detention basin core TC-2R	38–47	102	3,790	3.40	207	5.5	139,000	52,600	19,200
Estates 2 bankside augur TC-B	19–22	148	792	0.12	66	6.6	33,100	11,800	4,000

Appendix 2. Major and trace elements in soils and sediments from Estates 1 and 2, Gloucester County, New Jersey, June–October, 2008.—Continued

[mg/kg, milligrams per kilogram; OC, organic carbon; gl., glauconitic]

Sample site and sample name	Sample depth (inches)	Total manganese (Mn) (mg/kg)	Total sodium (Na) (mg/kg)	Total nickel (Ni) (mg/kg)	Total phosphorus (P) (mg/kg)	Total lead (Pb) (mg/kg)	Total vanadium (V) (mg/kg)	Total zinc (Zn) (mg/kg)	Carbonate carbon (percent)
Estates 1 bankside core R-1	0–15	569	1,070	18.2	1,410	39.9	47.2	108	0.11
Estates 1 bankside core R-1	15–20	102	781	13.1	664	57.4	49.2	117	0.02
Estates 1 bankside core R-1	36–40	76.5	374	4.6	161	12.6	27.2	44.5	0
Estates 1 bankside core R-1	40–43	120	486	6.2	176	15.4	26.9	49.7	0
Estates 2 detention basin core TC-1	0–6	181	2,080	27.0	2,040	24.1	106	146	0.03
Estates 2 detention basin core TC-2	38–47	61.5	415	24.6	703	5.75	92.4	146	0
Estates 2 detention basin core TC-2R	38–47	64	388	25.9	725	6.05	98.9	137	0
Estates 2 bankside augur TC-B	19–22	137	569	7.1	753	9.96	40	48.6	0

For additional information, write to:

Director

U.S. Geological Survey

New Jersey Water Science Center

810 Bear Tavern Road, Suite 206

West Trenton, NJ 08628

or visit our Web site at:

<http://nj.usgs.gov/>

Document prepared by the West Trenton Publishing Service Center

