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Scientific Investigations Report 2010–5204

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

Cover. Elizabeth River above West Branch at Hillside, New Jersey. (Photograph by Brian Painter, U.S. Geological Survey)

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KEN SALAZAR, Secretary

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

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Conversion factors, datums, and water-quality abbreviations

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
liter per second (L/s)	15.85	gallon per minute (gal/min)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

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

Water-quality abbreviations:

EDL	Estimated detection limit
GFF	Glass fiber filter
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzo-p-difurans
POC	Particulate organic carbon
SS	Suspended sediment
TOPS	Trace organic platform sampler
TEQ	Toxic equivalency
µg	microgram
ng	nanogram
ng/g	nanograms per gram
pg	picogram
pg/g	picograms per gram
mg/yr	milligrams per year
Mgal/yr	million gallons per year

Organic Compounds and Cadmium in the Tributaries to the Elizabeth River in New Jersey, October 2008 to November 2008: Phase II of the New Jersey Toxics Reduction Workplan for New York–New Jersey Harbor

By Jennifer L. Bonin

Abstract

Samples of surface water and suspended sediment were collected from the two branches that make up the Elizabeth River in New Jersey—the West Branch and the Main Stem—from October to November 2008 to determine the concentrations of selected chlorinated organic and inorganic constituents. The sampling and analyses were conducted as part of Phase II of the New York–New Jersey Harbor Estuary Plan–Contaminant Assessment and Reduction Program (CARP), which is overseen by the New Jersey Department of Environmental Protection. Phase II of the New Jersey Workplan was conducted by the U.S. Geological Survey to define upstream tributary and point sources of contaminants in those rivers sampled during Phase I work, with special emphasis on the Passaic and Elizabeth Rivers. This portion of the Phase II study was conducted on the two branches of the Elizabeth River, which were previously sampled during July and August of 2003 at low-flow conditions. Samples were collected during 2008 from the West Branch and Main Stem of the Elizabeth River just upstream from their confluence at Hillside, N.J.

Both tributaries were sampled once during low-flow discharge conditions and once during high-flow discharge conditions using the protocols and analytical methods that were used in the initial part of Phase II of the Workplan. Grab samples of streamwater also were collected at each site and were analyzed for cadmium, suspended sediment, and particulate organic carbon. The measured concentrations, along with available historical suspended-sediment and stream-discharge data were used to estimate average annual loads of suspended sediment and organic compounds in the two branches of the Elizabeth River. Total suspended-sediment loads for 1975 to 2000 were estimated using rating curves developed from historical U.S. Geological Survey suspended-sediment and discharge data, where available.

Concentrations of suspended-sediment-bound polychlorinated biphenyls (PCBs) in the Main Stem and the West Branch of the Elizabeth River during low-flow conditions were 534 ng/g (nanograms per gram) and 1,120 ng/g, respectively, representing loads of 27 g/yr (grams per year) and 416 g/yr, respectively. These loads were estimated using contaminant concentrations during low flow, and the assumed 25-year average discharge, and 25-year average suspended-sediment concentration. Concentrations of suspended-sediment-bound PCBs in the Main Stem and the West Branch of the Elizabeth River during high-flow conditions were 3,530 ng/g and 623 ng/g, respectively, representing loads of 176 g/yr and 231 g/yr, respectively. These loads were estimated using contaminant concentrations during high-flow conditions, the assumed 25-year average discharge, and 25-year average suspended-sediment concentration. Concentrations of suspended-sediment-bound polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-difuran compounds (PCDD/PCDFs) during low-flow conditions were 2,880 pg/g (picograms per gram) and 5,910 pg/g in the Main Stem and West Branch, respectively, representing average annual loads of 0.14 g/yr and 2.2 g/yr, respectively. Concentrations of suspended-sediment-bound PCDD/PCDFs during high-flow conditions were 40,900 pg/g and 12,400 pg/g in the Main Stem and West Branch, respectively, representing average annual loads of 2.05 g/yr and 4.6 g/yr, respectively. Total toxic equivalency (TEQ) loads (sum of PCDD/PCDF and PCB TEQs) were 3.1 mg/yr (milligrams per year) (as 2, 3, 7, 8-TCDD) in the Main Stem and 28 mg/yr in the West Branch during low-flow conditions. Total TEQ loads (sum of PCDD/PCDFs and PCBs) were 27 mg/yr (as 2, 3, 7, 8-TCDD) in the Main Stem and 32 mg/yr in the West Branch during high-flow conditions. All of these load estimates, however, are directly related to the assumed annual discharge for the two branches. Long-term measurement of stream discharge and suspended-sediment concentrations would be needed to verify these

loads. On the basis of the loads calculated from the concentrations measured in this study, it appears that the West Branch is the principal source of PCBs, PCDD/PCDFs, and total TEQ to the Elizabeth River during low-flow and high-flow conditions. Additional sources of these constituents may be present between the confluence of the two branches that make up the Elizabeth River and the head-of-tide.

Introduction

The New Jersey Department of Environmental Protection (NJDEP), as part of its Toxics Reduction Workplan for the New York–New Jersey Harbor (NJTRWP, the New Jersey component of the New York–New Jersey Harbor Estuary Program Contaminant Assessment and Reduction Program (CARP)) conducted an extensive Phase I sampling program in cooperation with other agencies to determine the concentrations and loads in the tributaries, estuaries, and kills associated with Newark and Raritan Bays during 2000-04 (New Jersey Department of Environmental Protection, 2001; New York–New Jersey Harbor Estuary Program, 1996) (fig. 1). The role of the U.S. Geological Survey (USGS) in that program was to determine concentrations and mass loads of organic compounds and trace elements that originate above the heads-of-tide in the Passaic, Raritan, Rahway, Elizabeth, and Hackensack Rivers, the main tributaries to Newark and Raritan Bay (Bonin and Wilson, 2006; Wilson and Bonin, 2007). The head-of-tide refers to the uppermost point of a river that is affected by tidal fluctuations. Other researchers concurrently measured concentrations of organic compounds in the lower estuarine/tidal parts of these rivers. These studies demonstrated that the Passaic River accounted for the major loads to Newark Bay and that high concentrations of selected organic and inorganic compounds were present at the head-of-tide of the Elizabeth River (Wilson and Bonin, 2007).

As a follow-up to Phase I, the NJDEP, in cooperation with other agencies, initiated a Phase II study. For Phase II, the USGS collected samples from tributaries to the Passaic River, the Saddle River, the Second and Third Rivers, and the Elizabeth River (the West Branch and Main Stem, upstream from their confluence (fig. 2)) during low-flow conditions with the goal of determining the concentrations of polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-difuran compunds (PCDD/PCDFs), and trace elements (mercury, cadmium, and lead) in water and suspended sediment from these tributaries. Those data were collected in part to identify the sources of these compounds, and these data, collected for the two branches of the Elizabeth River during high- and low-flow conditions, were used in this study to estimate loads of suspended sediment and organic and inorganic compounds delivered by these tributaries to the Elizabeth River. Comparisons of constituent concentrations and loads were made among the two sites on the tributaries and with the main stem of the Elizabeth River (after the two branches have converged), and compounds were identified that could serve as markers for sediment from each tributary. The various reports from previous studies done in this area for the CARP program can be found at: *http://www.state.nj.us/dep/dsr/njtrwp*.

Purpose and Scope

The purpose of this report is to present concentrations and estimates of loads of suspended sediment, particulate organic carbon, PCBs, PCDD/PCDFs, and cadmium in samples from the tributaries to the Elizabeth River during low- and high-flow discharge conditions. The data from the samples collected on the two branches that make up the Elizabeth River were evaluated to determine whether distinct chemical signatures could be identified for each tributary in an effort to help determine possible sources of contaminants to the Elizabeth River head-of-tide. Also presented are comparisons of these constituent data to data previously collected for the two tributaries that make up the Elizabeth River, and to the suspended-sediment chemistry data previously collected for the head-of-tide sampling site on the Elizabeth River. Samples were collected at the two tributaries to the Elizabeth River, once during low-flow conditions and once during elevated discharge/high-flow conditions from October 2008 to November 2008. Field characteristics and normalized concentrations of constituents are presented in tables. Flow-duration curves showing discharge and suspended-sediment load in relation to percent exceedance are presented in illustrations.

Description of Study Area

The study area consists of the Main Stem and West Branch of the Elizabeth River, which flows into the Arthur Kill (fig. 1; table 1). The Elizabeth River drains a small, highly urbanized basin of less than 100 mi^2, and consequently has small discharges (less than 100 ft^3/s). Flow in this river is affected by inputs from sewers and other outfalls, several small dams, and wetland areas, all of which affect the hydrologic response of this river.

Land use in this river basin, as determined from the NJDEP Geographic Information Systems Database for the part of the basin upstream from the sampling sites, provides useful insight into the characteristics of this river basin. The entire basin is classified as urban. The high degree of urbanization is reflected in the large number of waste-treatment plants and other facilities that are permitted to release effluent into the surface-water system in each basin (Bonin and Wilson, 2006).

Methods

Sampling and analytical methods used in this study are consistent with those used in the Phase I work of the NJDEP

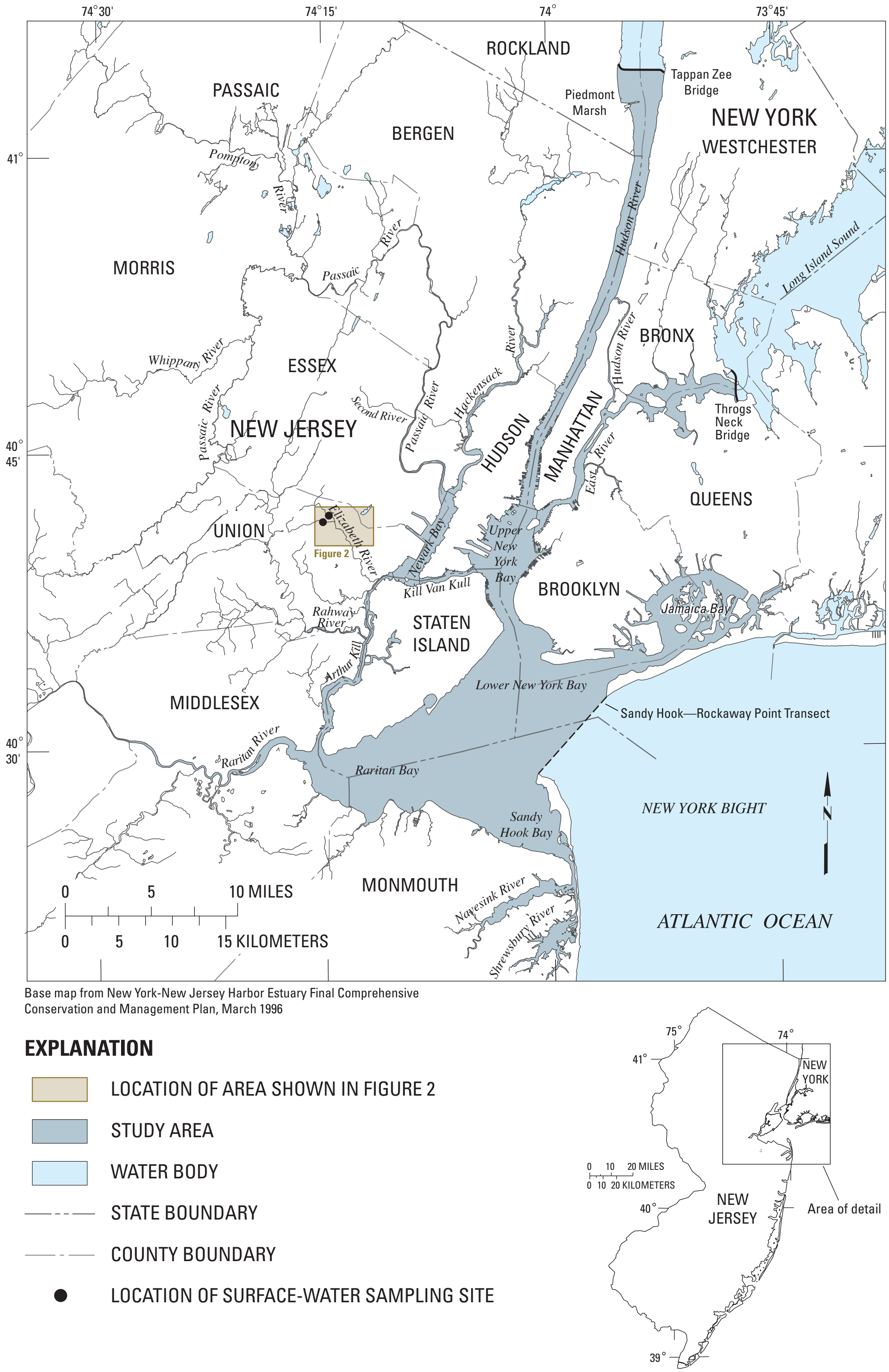

Figure 1. Location of study area and surface-water sampling sites in New Jersey.

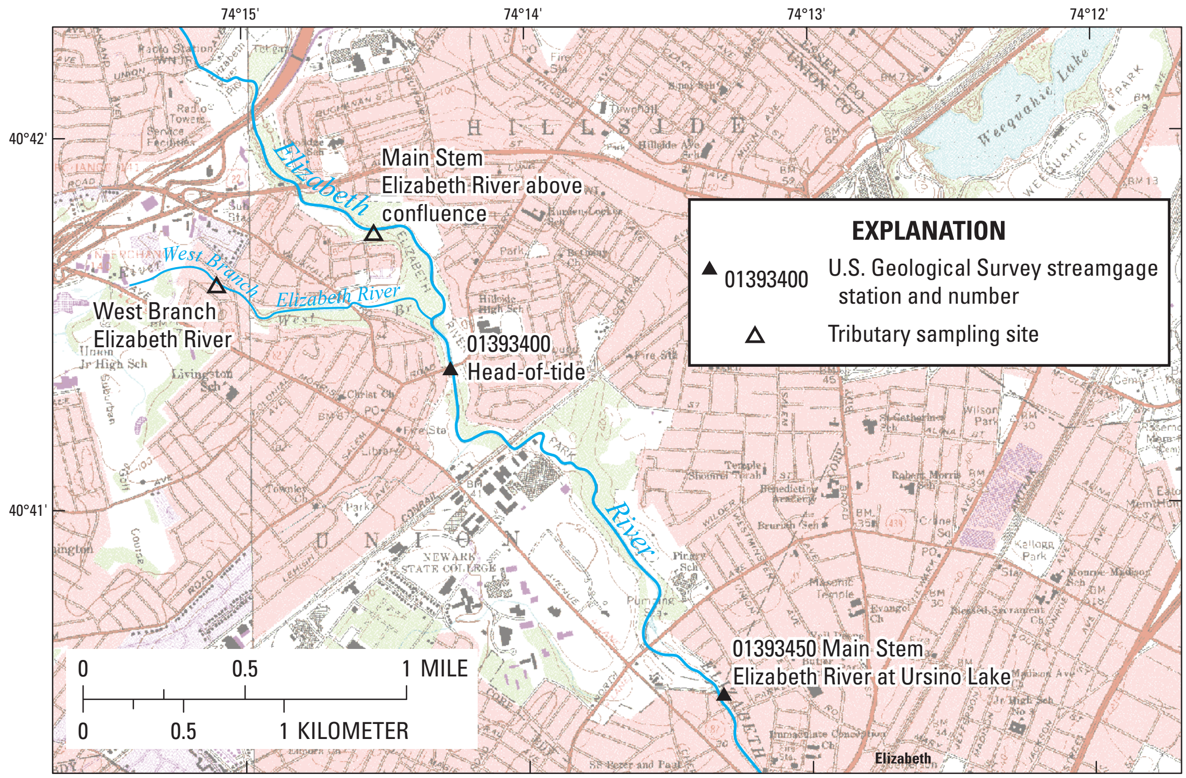

Figure 2. Location of sampling sites on the West Branch and Main Stem of the Elizabeth River, Elizabeth, New Jersey. (See figure 1 for location of this figure.)

Workplan. Detailed descriptions of the sampling and analytical methods used in Phase I can be found in Bonin and Wilson (2006) and Wilson and Bonin (2007). Phase I sampling was performed during high-flow and low-flow conditions at the head-of-tide in each tributary.

In the initial part of the Phase II work, the tributaries were sampled during low-flow conditions using the large-volume sampling methods developed for Phase I. In this study, both tributaries of the Elizabeth River were sampled once during low-flow and once during high-flow conditions, using large-volume sampling methods. Large-volume (>50 L) samples were collected over 4 to 6 hours at selected sites where tributaries converge to form the main branches of the Elizabeth River (fig. 2). These samples are considered to be representative of the streams during low-flow and high-flow conditions as they were collected during times of steady low discharge or throughout the rising limb and halfway through the falling limb of the hydrograph during a high-flow event. Sampling was conducted under similar conditions in the Phase I work, although flow-weighted composite samples also were collected during high-flow events in Phase I. In contrast, sampling during high-flow events on the two tributaries to the Elizabeth River was done for the length of the time the river level was rising and remained elevated, which due to the nature of these flashy, urban rivers resulted in high-flow-event samples being collected over a 2- to 4-hour period.

Filtration was used to collect suspended sediment for analysis of organic compounds. This study focused on the constituents of interest in the particulate phase for two reasons. Firstly, the dissolved concentrations were deemed to be adequately characterized in previous studies. Secondly, most of the organic compounds are bound to, and transported by, suspended sediment (Wilson and Bonin, 2007). The samples were analyzed using U.S. Environmental Protection Agency (USEPA) Method 1668A for PCBs (U.S. Environmental Protection Agency, 1999) and Method 1613B for PCDD/PCDFs (U.S. Environmental Protection Agency, 1994). Grab samples of river water also were collected and analyzed for concentrations of dissolved and whole water cadmium (Cd), along with suspended sediment and particulate organic carbon (POC). Cadmium was measured using inductively coupled plasma-mass spectrometry (ICP-MS) (Garbarino and Struzeski, 1998; Garbarino and others, 2006). Details of the analytical program used in this study can be found in the Phase I reports by Bonin and Wilson (2006) and Wilson and Bonin (2007), and in NJDEP documentation (New Jersey Department of Environmental Protection, 2001).

Table 1. Description of sampling sites and characteristics of Elizabeth River sites in New Jersey, 2008.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; Mgal, million gallons; n/a, not applicable]

	Main Stem Elizabeth River Phase II base flow	Main Stem Elizabeth River	Main Stem Elizabeth River	West Branch Elizabeth River Phase II base flow	West Branch Elizabeth River	West Branch Elizabeth River
Date sampled	[1]7/31/03	10/22/08	10/25/08	[1]8/7/03	11/7/08	11/13/08
Survey number	2003-IICA	2008-IIICA	2008-IIICB	2003-IICA	2008-IIICA	2008-IIICB
Sample identification	2USG1003SA	3USG001SA	3USG002SA	2USG1006SA	3USG003SA	3USG004SA
Condition/type	Low Flow	Low Flow	High Flow	Low Flow	Low Flow	High Flow
Latitude of site	40° 41’ 44”	40° 41’ 44”	40° 41’ 44”	40° 41’ 34”	40° 41’ 34”	40° 41’ 34”
Longitude of site	74° 14’ 32”	74° 14’ 32”	74° 14’ 32”	74° 15’ 05”	74° 15’ 05”	74° 15’ 05”
USGS station name	Elizabeth River above West Branch at Hillside, NJ	Elizabeth River above West Branch at Hillside, NJ	Elizabeth River above West Branch at Hillside, NJ	West Branch Elizabeth River above Sayre Rd at Union, NJ	West Branch Elizabeth River above Sayre Rd at Union, NJ	West Branch Elizabeth River above Sayre Rd at Union, NJ
USGS station number	01393300	01393300	01393300	01393345	01393345	01393345
USGS streamgage station name	Elizabeth River at Ursino Lake	Elizabeth River at Ursino Lake	Elizabeth River at Ursino Lake	Elizabeth River at Ursino Lake	Elizabeth River at Ursino Lake	Elizabeth River at Ursino Lake
USGS streamgage station number	01393450	01393450	01393450	01393450	01393450	01393450
Location of sampling site in relation to existing station	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream
Location of sampling site in relation to USGS head-of-tide sampling station[2]	Upstream	Upstream	Upstream	Upstream	Upstream	Upstream

Table 1. Description of sampling sites and characteristics of Elizabeth River sites in New Jersey, 2008.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; Mgal, million gallons; n/a, not applicable]

	Main Stem Elizabeth River Phase II base flow	Main Stem Elizabeth River	Main Stem Elizabeth River	West Branch Elizabeth River Phase II base flow	West Branch Elizabeth River	West Branch Elizabeth River
Time sampling initiated	1300	940	1900	1315	1205	1400
Time sampling ended	1715	1440	2100	1715	1730	1745
Mean daily discharge at USGS streamgage station (on day of sampling), in ft^3/s	9.3	6.3	38	24	9.7	46
Mean discharge at USGS streamgage station (at time of sampling), in ft^3/s	[3]9.3	[3]6.39	[3]13.03	[3]20	[3]8.91	[3]188.11
Estimated percentage of the mean annual discharge of the Elizabeth River[4]	12	12	12	88	88	88
Estimated discharge, in ft^3/s	[5]12	[6]0.77	[6]1.56	[5]17.6	[6]7.84	[6]165.54
Total volume of discharge during sampling, in Mgal	[5]1.127	0.86	0.09	[5]2.276	1.11	15.07
Peak instanteous discharge at USGS streamgage station on day of sampling, in ft^3/s, storm samples only	n/a	n/a	329	n/a	n/a	216

[1]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

[2]The USGS head-of-tide sampling station is the sampling station used in the New Jersey Toxics Reduction Workplan, Phase I.

[3]This value is the discharge at the Elizabeth River at Ursino Lake station during the time of sampling. It represents the sum of the discharges in the East and West Branches and the main stem of the Elizabeth River.

[4]Estimated percentages based on work done by Wilson and Bonin, 2008, in first part of Phase II study.

[5]Discharge estimated in field at time of sampling.

[6]Discharge estimated based on value at Elizabeth River at Ursino Lake, weighted by tributary's contribution (Wilson and Bonin, 2007).

Sampling Sites

Descriptions of the Elizabeth River sampling sites are presented in table 1, and specific sampling sites are shown in figure 2 along with the associated USGS streamgage stations referred to in this report. The West Branch and the Main Stem of the Elizabeth River were sampled 1,460 ft and 3,000 ft, upstream from their confluence at Hillside, N.J. (fig. 2). The confluence is approximately 1,200 ft upstream from the Phase I head-of-tide sampling site on the Elizabeth River at Hillside, which, in turn, is approximately 1.5 river miles upstream from the USGS streamgage station at Ursino Lake, N.J. The East Branch of the Elizabeth River is encased in a storm drain and could not be sampled (Wilson and Bonin, 2008).

Sampling and Analysis

Sampling was conducted on both branches of the Elizabeth River with a Trace Organic Platform Sampler (TOPS) equipped with a 50-ft length of pre-cleaned 3/8-inch-diameter Teflon tubing that was run into the center of flow of each stream. The tubing was held by a cement block that kept the intake approximately 6 inches above the streambed and approximately 3 ft out from the weight. One dedicated TOPS sampler was used for all of the sampling and was cleaned between uses by pumping hot, soapy water through the sampler, followed by a rinse with deionized (DI) water, methanol, and a final DI water rinse. The tubing was cleaned between sites by washing with hot soapy water for a minimum of 1 hour, followed by two rinses with DI water, a 1-hour soak in a 10-percent solution of hydrochloric acid, and a final rinse with DI water.

The TOPS contained a 0.5-micron (nominal) glass-fiber canister filter and a 1-micron, pre-baked glass-fiber flat filter (fig. 3). These filters were identical to those used in the Phase I and II sampling. In the TOPS, water is pumped through the canister filter at a rate of 1 to 2 L/min. The filtered water stream is split with one line going to waste and the second passing through a 1-micron flat filter at a rate not exceeding 200 mL/min. A schematic diagram of the TOPS, as configured for this study, is shown in figure 3. A target volume of 300 to 500 L per sample was processed through the filters which resulted in the capture of at least 0.5 g of sediment on the canister filter (if it is assumed that the streamwater contained 1 to 2 mg/L of suspended sediment). The one canister filter and several flat filters that were used at each site were combined in the laboratory for extraction and analysis. Water that was processed through the filters was collected, and the volume was measured using a Class A glass, graduated cylinder. The volumes of water processed for each sample and the suspended sediment and carbon content of the processed water are listed in table 2.

Samples for analysis of Cd were collected directly from a tee in the inlet line located immediately in front of the TOPS. Samples were collected by attaching a piece of pre-cleaned silicon pump tubing to the tee and placing the tubing through the rotary head of a small peristaltic pump. This line removed

Table 2. Field characteristics of samples collected from Elizabeth River sites in New Jersey, 2008.

[SS, suspended sediment; mg/L, milligrams per liter; POC, particulate organic carbon, mgC/L, milligrams of carbon per liter]

	Main Stem Elizabeth River	Main Stem Elizabeth River	West Branch Elizabeth River	West Branch Elizabeth River
Date sampled	10/22/08	10/25/08	11/7/08	11/13/08
Condition/type	Low Flow	High Flow	Low Flow	High Flow
Survey number	2008-IIICA	2008-IIICB	2008-IIICA	2008-IIICB
Total volume of water through filters sent for analysis, in liters (measured)	1,086	257.93	1,086	695.04
Mean SS concentration[1], in mg/L (measured)	2.38	[2]6.00	2.45	11.91
Corrected mass of SS, in grams (calculated)	2.32	6.04	2.39	7.45
Mean POC concentration[1], in mgC/L (measured)	0.543	[2]1.846	0.695	2.452
Corrected mass of carbon, in grams (calculated)	0.530	5.071	0.680	1.534

[1]Mean concentrations of suspended sediment and particulate organic carbon concentrations are geometric means of the grab sample concentrations.

[2]These concentrations are based on only one sample as a result of instrument failure.

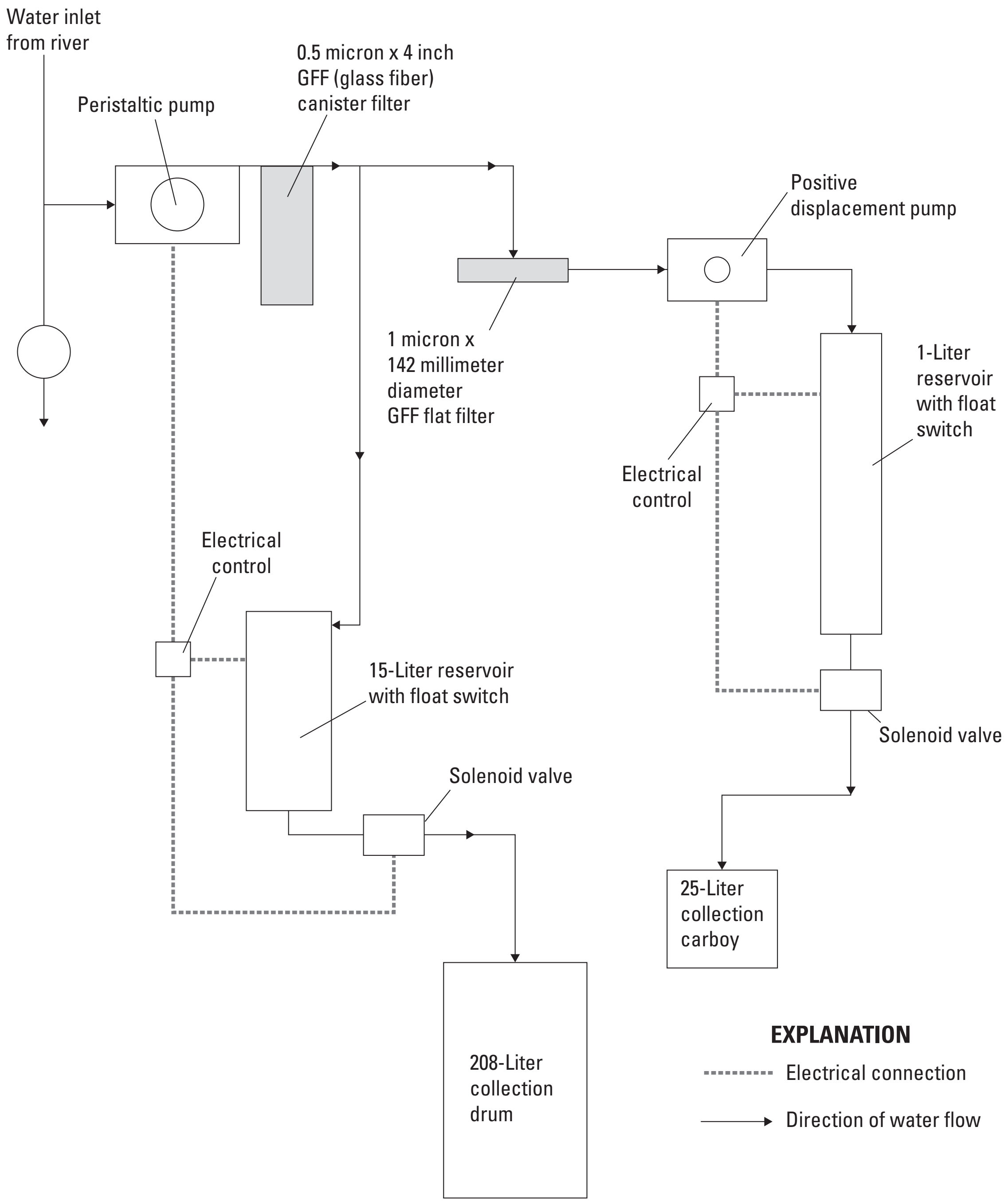

Figure 3. Schematic diagram of a modified Trace Organic Platform Sampler (TOPS). (From Bonin and Wilson, 2006)

water from the inlet to the TOPS. The line then was pumped for at least 5 minutes before a sample was collected. Filtered samples were collected by attaching a 0.45-micron polyether sulfone capsule filter (Gelman) to the pump tubing and filling sample bottles directly from the filter outlet. Unfiltered samples were collected by removing the filter and filling the sample bottle directly from the tubing outlet. All tubing, bottles, and filters were pre-cleaned using USGS metal sampling preparation protocol (Wilde, 2004).

Samples were stored on ice during transport to the USGS New Jersey Water Science Center (NJWSC) laboratory in West Trenton, N.J., where the filters were stored frozen until being sent for analysis. Concentrations of PCBs and dioxin/furans in the particulate phase were determined by Test America Laboratories, Knoxville, Tenn., using Phase I analytical methods (New Jersey Department of Environmental Protection, 2001; Bonin and Wilson, 2006). Concentrations of the individual PCB congeners were measured using USEPA Method 1668A–modified (U.S. Environmental Protection Agency, 1999), and dioxins and difurans were measured following USEPA Method 1613B (U.S. Environmental Protection Agency, 1994). Both of these methods are isotope dilution methods that use high-resolution mass spectrometry to identify and quantify the individual congeners. Concentrations of total Cd were measured by the USGS National Water Quality Laboratory, Denver, Colorado, using inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry (Garbarino and Struzeski, 1998). Concentrations of dissolved Cd were measured by the USGS National Water Quality Laboratory using collision/reaction cell inductively coupled plasma-mass spectrometry (Garbarino and others, 2006).

In addition to the samples collected for organic and inorganic analysis, four pairs of grab samples were collected at each site for analysis of suspended sediment and POC. These samples were collected directly from the sampling line at approximately equally spaced intervals throughout the TOPS sampling. The concentration of suspended sediment in these samples was measured at the USGS Kentucky Water Science Center Suspended Sediment Laboratory in Louisville, Kentucky (Sholar and Shreve, 1998). Particulate organic carbon was separated by filtering 60 mL of river water through 25-millimeter-diameter 1-micron pore-size glass fiber filters. Filtering was performed upon return from the field in the USGS NJWSC laboratory. The filter was frozen and sent for analysis of POC at the USGS National Water Quality Laboratory. POC was analyzed using USEPA Method 440.0 (Zimmerman and others, 1997).

The mass of suspended sediment and carbon trapped on the TOPS filter was calculated by multiplying the volume of water filtered by the mean concentrations of suspended sediment (or POC) in the four grab samples (Bonin and Wilson, 2006). Early trials in the Phase I sampling demonstrated that the canister filters allowed approximately 10 percent (by weight) of particles to pass through the filters (consistent with the manufacturer's specifications). Therefore, it was assumed that 10 percent of the calculated mass of suspended sediment broke through the canister filter and went either to waste or to the flat filters. Because most of the water that passed through the filter was ultimately sent to the waste line, no further numerical adjustment could be made to the calculated trapped mass of sediment. Therefore, to calculate the mass of suspended sediment (and carbon) trapped on the filters sent for analysis, the geometric mean of the suspended-sediment (and POC) concentrations in the grab samples that were collected, multiplied by the volume of water filtered, was multiplied by a filter capture efficiency factor of 0.9 (Wilson and Bonin, 2007). This is the same correction that was applied to the calculations executed during Phase I and II of the program. Then, the normalized concentrations of sediment-bound chemicals were calculated by dividing the mass of each individual (or total) chemical species recovered from the filter by the adjusted mass of the captured sediment. The volume of water processed through the filters, the concentrations of suspended sediment and carbon, and the calculated masses of suspended sediment that were recovered on the filters are presented in table 2.

CARP and USGS identifiers were assigned to each sample collected using the same convention used for the Phase I and initial round of the Phase II sampling, except that the first digit of the sample was changed to "3" (for example, 3USGXXXSA) (table 1). The raw and normalized analytical results for PCBs and PCDD/PCDFs, as reported by the laboratory in units of nanograms or picograms per sample, are available from the NJDEP.

Reporting of Analytical Results

The raw data for suspended-sediment-bound PCBs were blank-corrected in the same manner used in the NJTRWP Phase I sampling program. The samples collected from the Elizabeth River (West Branch and Main Stem) were analyzed for suspended-sediment-bound PCBs and PCDD/PCDFs. Some PCB and PCDD/PCDF congeners were reported as "not detected" in the raw data set and were dealt with by substituting one-half the value of the sample-specific detection limit for each individual congener as reported by the contract laboratory. Non-detected congeners were dealt with in this same manner in Phase I and the initial part of Phase II. Blank elimination consisted of removing reported masses of individual congeners that were less than or equal to 3 times the largest of the corresponding masses in the associated method blanks for PCBs and less than or equal to 5 times the largest of the corresponding masses in the method blanks for dioxins/furans (Wilson and Bonin, 2007). Field and equipment blanks for PCBs and PCDD/PCDFs were not collected in this study due to budget constraints. However, field and equipment blanks collected in both Phase I and the initial part of Phase II did not show any significant contamination that would affect the data reporting. Raw trace-element data were reported by the analytical laboratory, corrected for method blanks by subtraction.

Occurrence of Organic Compounds and Cadmium in Suspended Sediment

Summaries of the PCB, PCDD/PCDF, and cadmium concentrations in samples are presented in tables 3 and 4. The concentrations of the PCBs on a homolog basis are presented in tables 5 and 6, and the concentrations and TEQs of the coplanar PCBs are listed in table 7. Concentrations and TEQs of the dioxin and furan congeners are listed in table 8.

Polychlorinated Biphenyls and Dioxin-Furans

Concentrations of total suspended-sediment-bound PCBs in samples collected during low-flow conditions were 534 ng/g (2,340 ng/g carbon) in the Main Stem of the Elizabeth River and 1,120 ng/g (3,950 ng/g carbon) in the West Branch of the Elizabeth River. During high-flow conditions, concentrations of suspended-sediment-bound PCBs were 3,530 ng/g (11,400 ng/g carbon) in the Main Stem and 623 ng/g (3,030 ng/g carbon) in the West Branch (table 3). In a sample from the Main Stem of the Elizabeth River, the suspended-sediment-bound PCB concentration during the high-flow event was more than 6 times higher than the low-flow particulate PCB concentration. In contrast, the suspended-sediment-bound PCB concentration during the high-flow event in the West Branch of the Elizabeth River was roughly half of the particulate PCB concentration in the sample collected during low flow. The concentration of suspended-sediment-bound PCB was roughly 2 times higher in the sample from the West Branch of the Elizabeth River than in the sample from the Main Stem during low-flow conditions but 5.6 times lower in the West Branch of the Elizabeth River than in the Main Stem during high-flow conditions (table 3).

The concentration of suspended-sediment-bound PCBs in the sample from the Main Stem of the Elizabeth River collected during low-flow conditions was roughly 66 percent of the suspended sediment-bound concentration in the sample from the Main Stem of the Elizabeth River, which was measured previously and occurred during low-flow conditions on July 31, 2003. The average concentration of suspended-sediment-bound PCBs calculated using values from the two samples collected on the Main Stem of the Elizabeth River during this study was roughly 45 times higher than the average of all samples previously collected at the head-of-tide site, Elizabeth River at Hillside. The concentration of suspended-sediment-bound PCBs in the West Branch of the Elizabeth River during low-flow conditions was roughly 36 percent of the suspended-sediment-bound PCB concentration in the West Branch of the Elizabeth River, which was previously measured and also occurred during low-flow conditions on August 7, 2003. The average suspended-sediment-bound PCB concentration calculated for the two samples collected on the West Branch of the Elizabeth River during this study was roughly 19 times higher than the average of all samples collected previously at the head-of-tide site, Elizabeth River at Hillside (table 3).

Concentrations of total suspended-sediment-bound PCDD/PCDFs during low-flow conditions were 2,880 pg/g for the Main Stem of the Elizabeth River and 5,910 pg/g for the West Branch of the Elizabeth River. During high-flow conditions, concentrations of suspended-sediment-bound PCDD/PCDFs were 40,900 pg/g for the Main Stem and 12,400 pg/g for the West Branch. For the Main Stem of the Elizabeth River, the suspended-sediment-bound PCDD/PCDF concentration during the high-flow event was more than 14 times higher than the low-flow particulate PCDD/PCDF concentration. The suspended-sediment-bound PCDD/PCDF concentration during the high-flow event in the West Branch of the Elizabeth River was more than 2 times greater than the low-flow particulate PCDD/PCDF concentration (table 3). The suspended-sediment-bound PCDD/PCDF concentration was roughly 2 times higher for the West Branch of the Elizabeth River than for the Main Stem during low-flow conditions but 3.3 times lower for the West Branch of the Elizabeth River than for the Main Stem during high-flow conditions (table 3).

The suspended-sediment-bound PCDD/PCDF concentration for the Main Stem of the Elizabeth River during low-flow conditions was roughly 39 percent of the suspended-sediment-bound concentration for the Main Stem of the Elizabeth River, which was measured previously and occurred during low-flow conditions on July 31, 2003. The average suspended-sediment-bound PCDD/PCDF concentration calculated for the two samples collected from the Main Stem of the Elizabeth River during this study was about 75 percent of the average of all samples collected previously at the head-of-tide site, Elizabeth River at Hillside. The suspended-sediment-bound PCDD/PCDF concentration in the sample from the West Branch of the Elizabeth River during low-flow conditions was about 60 percent of the suspended sediment-bound concentration in the sample from the West Branch of the Elizabeth River, which was measured previously and occurred during low-flow conditions on August 7, 2003. The average suspended-sediment-bound PCDD/PCDF concentration calculated from the two samples collected on the West Branch of the Elizabeth River during this study was about 32 percent of the average of all samples collected previously at the head-of-tide site, Elizabeth River at Hillside (table 3).

As in the samples collected at the head-of-tide site for the NJTWRP Phase I study, and the samples collected from the Elizabeth River tributary for the first part of the Phase II study, the suite of dioxin and furan congeners was dominated (by weight) by the PCDDs. The concentration of 2,3,7,8-TCDD was less than the estimated detection limit (EDL) in each of these samples, except for the high-flow sample collected from the West Branch of the Elizabeth River. However, two other congeners (1,2,3,7,8-PeCDD and 2,3,7,8-TCDF) have high toxic equivalence factors (TEF) and, as a result, are of particular interest. 1,2,3,7,8-PeCdd was present in high-flow and low-flow samples from both the Main Stem and West Branch of the Elizabeth River. 2,3,7,8-TCDF was present in

Table 3. Concentrations of total organic compounds in samples of suspended sediment from Elizabeth River sites in New Jersey, 2008.

[PCBs, polychlorinated biphenyls; ng/g nanograms per gram; ng/gC, nanograms per gram of carbon; PCDD/PCDFs, polychlorinated dibenzo-p-dioxins and difurans; TCDD, tetracholorinated dibenzo-p-dioxin; pg/g, picograms per gram; TEQ, toxic equivalency; <, less than; na, not applicable]

	Main Stem Elizabeth River (Phase II base flow)	Main Stem Elizabeth River	Main Stem Elizabeth River	Main Stem Elizabeth River (Average)	West Branch Elizabeth River (Phase II base flow)	West Branch Elizabeth River	West Branch Elizabeth River	West Branch Elizabeth River (Average)	Elizabeth River at Hillside[1] (Average of all samples)
Date	[2]7/31/2003	10/22/08	10/25/2008	10/22/08; 10/25/08	[1]8/7/03	11/7/08	11/13/08	11/7/08; 11/13/08	na
Hydrologic event type	Low Flow	Low Flow	High Flow	Average	Low Flow	Low Flow	High Flow	Average	Average
Sample identifier	EBEL073103	3USG001SA	3USG002SA	na	WBEL080703	3USG003SA	3USG004SA	na	na
Liters of river water passed through filters	634.5	1,086	257.93	na	289.7	1,086	695.04	na	na
Mass of suspended sediment collected (grams)	1.03	2.32	1.39	na	1.10	2.39	7.45	na	na
Total sediment-bound PCBs (ng/g)	806	534	3,530	2,030	3,110	1,120	623	871	44.9
Total sediment-bound PCBs (ng/gC)	4,610	2,340	11,400	6,870	8,970	3,950	3,030	3,490	1,100
Total sediment-bound PCDD/PCDFs (pg/g)	7,270	2,880	40,900	21,900	9,880	5,910	12,400	9,160	28,900
Total sediment-bound PCDD (pg/g)	6,680	2,630	38,000	20,300	8,860	5,290	11,400	8,340	26,400
Total sediment-bound PCDF (pg/g)	590	253	2,860	1,550	1,020	622	1,020	821	2,500
Sediment-bound 2,3,7,8-TCDD (pg/g)	<8.0	4.3	7.2	6	<10	4.2	4.6	4.4	7.3
TEQ from PCDD/PCDFs (pg/g)	22	52	156	104	20	37	50	43	135
TEQ from PCBs (pg/g)	19	9.7	383	196	71	38	35	37	na
Total TEQ as 2,3,7,8-TCDD (pg/g)	41	62	539	301	91	75	85	80	na

[1]This average represents the average of two base flow and two storm events collected at the Elizabeth River head-of-tide station for the Phase I study. See Wilson and Bonin, 2007.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

Table 4. Concentrations of cadmium in samples of water and suspended sediment from Elizabeth River sites in New Jersey, 2008.

[mg/L, milligrams per liter; Cd, cadmium; ng/L, nanograms per liter; ng/g nanograms per gram; <, less than; na, not applicable]

	Main Stem Elizabeth River	Main Stem Elizabeth River	Main Stem Elizabeth River	Main Stem Elizabeth River	West Branch Elizabeth River	West Branch Elizabeth River	West Branch Elizabeth River	West Branch Elizabeth River	Elizabeth River at Hillside[1]
Sample identifier	2USG1003SA	3USG001SA	3USG002SA	Average	2USG1006SA	3USG003SA	3USG004SA	Average	na
Condition/type	Low Flow	Low Flow	High Flow	Average	Low Flow	Low Flow	High Flow	Average	na
Date sampled	[2]7/31/03	10/22/08	10/25/08	10/22/2008; 10/25/2008	[2]8/7/03	11/7/08	11/13/08	na	na
Suspended sediment (mg/L)	1.8	2.38	6.00	4.19	4.22	2.45	11.91	7.18	na
Particulate organic carbon (mg/L)	0.33	0.543	1.846	1.19	1.440	0.695	2.452	1.574	na
Total Cd (ng/L)	133	100	na	na	41	<60	[3]53	<57	190
Dissolved Cd (ng/L)	107	78	na	na	27	[3]13	38	26	118
Suspended sediment Cd (ng/L)	26	22	na	na	14	<47	15	<31	72
Suspended sediment Cd (ng/g)	14,400	9,380	na	na	3,310	<19,200	1,260	<10,230	12,500

[1]This average represents the average of samples collected during two base-flow and two storm events at the Elizabeth River head-of-tide site for the Phase I study. See Wilson and Bonin, 2007.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

[3]Estimated value as result was below the reporting level.

Table 5. Concentrations of polychlorinated biphenyl homologs in samples of suspended sediment from Elizabeth River sites in New Jersey, 2008.

[ng/g, nanograms per gram]

	Main Stem Elizabeth River						West Branch Elizabeth River						Elizabeth River @ Hillside[1]	
Sample identifier	EBEL073103[2]		3USG001SA		3USG002SA		WBEL080703[2]		3USG003SA		3USG004SA		Overall average	
Condition/type	Low flow in suspended sediment		Low flow in suspended sediment		High flow in suspended sediment		Low flow in suspended sediment		Low flow in suspended sediment		High flow in suspended sediment		in suspended sediment	
Homolog group	**ng/g**	**Percent**	**ng/g**	**Percent**	**ng/g**	**Percent**	**ng/g**	**Percent**	**ng/g**	**Percent**	**ng/g**	**Percent**	**ng/g**	**Percent**
Mono + di	5.8	0.72	1.5	0.28	27	0.77	5.8	0.19	4.9	0.44	10	1.6	35	1.4
Tri	36	4.5	4.0	0.75	101	2.9	55	1.8	9.4	0.84	17	2.7	170	6.9
Tetra	83	10	14	2.6	253	7.2	380	12	115	10	74	12	300	12.4
Penta	200	25	56	10.5	558	16	860	28	128	11	87	14	420	16.5
Hexa	252	31	250	46.7	1,310	37	1,090	35	495	44	263	42	770	30.7
Hepta	175	22	171	32.0	1,030	29	570	18	307	27	139	22	600	24.3
Octa	47	5.8	35	6.5	230	6.5	120	3.87	60	5.3	28	4.5	150	6.2
Nona	6.0	0.74	2.7	0.50	17	0.49	8.4	0.27	3.6	0.32	3.4	0.55	25	1.0
Deca	2.0	0.25	0.70	0.13	5.2	0.15	1.60	0.05	0.70	0.06	1.3	0.21	11	0.44
Total PCBs	**806**	**100**	**535**	**100**	**3,530**	**100**	**3,100**	**100**	**1,120**	**100**	**623**	**100**	**2,480**	**100**

[1]This average represents the average of samples collected during two base flow and two storm events at the Elizabeth River head-of-tide site for the Phase I study. See Wilson and Bonin, 2007.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

only the high-flow samples from both branches. Concentrations of 1,2,3,7,8-PeCDD were 22 pg/g and 23 pg/g for the Main Stem of the Elizabeth River during low-flow and high-flow conditions, respectively, and concentrations were 6.9 and 9.5 pg/g for the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively. Concentrations of 2,3,7,8-TCDF were 28 pg/g in the high-flow sample from the Main Stem of the Elizabeth River and 5.7 pg/g in the high-flow sample from the West Branch of the Elizabeth River (table 8). The EDLs for 2,3,7,8-TCDD were 8.6 pg/g and 14 pg/g in samples from the Main Stem of the Elizabeth River during low-flow and during high-flow conditions, respectively, and 8.4 pg/g and 2.7 pg/g in samples from the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively.

TEQs from PCDD/PCDFs were calculated using the TEFs from VanLeeuwen (1997) and expressed in picograms per gram as 2,3,7,8-TCDD. Although a more current list of TEFs was made available in 2006 by the World Health Organization, the older list was used for the purposes of comparisons to earlier data. The TEQs from PCDD/PCDFs were 52 pg/g and 156 pg/g for samples from the Main Stem of the Elizabeth River during low-flow and high-flow conditions, respectively, and 37 pg/g and 50 pg/g for samples from the West Branch of the Elizabeth River during low-flow and during high-flow conditions, respectively. The TEQs from PCDD/PCDFs during low-flow conditions calculated in a previous study were 22 pg/g for the Main Stem and 20 pg/g for the West Branch of the Elizabeth River (Wilson and Bonin, 2008). The average TEQ from PCDD/PCDFs for the sample from the head-of-tide site on the Elizabeth River at Hillside was 135 pg/g (table 3).

As in earlier studies, the coplanar PCBs contribute significantly to the total TEQs for both branches of the Elizabeth River. This is especially true for the high-flow sample collected on the Main Stem of the Elizabeth River. TEQs for the coplanar PCBs in the samples (table 3) were 9.7 pg/g and 383 pg/g for the Main Stem of the Elizabeth River during low-flow and high-flow conditions, respectively, and 38 pg/g and 35 pg/g for the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively. The TEQs from PCDD/PCDFs measured previously in the summer of 2008 at these sites during low-flow conditions were 19 pg/g for the Main Stem and 71 pg/g for the West Branch of the Elizabeth River (Wilson and Bonin, 2008). Summing the TEQs from the PCDD/PCDFs and PCBs results in total toxic equivalencies of 62 pg/g during low-flow conditions and 539 pg/g during high-flow conditions in the Main Stem of the Elizabeth River and 75 pg/g during low-flow conditions and 85 pg/g during high-flow conditions in the West Branch of the Elizabeth River (table 3). This finding shows that TEQs in the Main Stem of the Elizabeth River during high-flow conditions were more than 8 times greater than during low-flow conditions and at least 6 times greater than the TEQs in the West Branch of the Elizabeth River during any flow condition.

Table 6. Ratio of the average concentration of polychlorinated biphenyl homologs in high-flow samples to that in low-flow samples collected from Elizabeth River sites in New Jersey, 2008.

[Values for polychlorinated biphenyl (PCB) homolog groups and total PCBs are unitless ratios of weight percent in the high-flow sample to weight percent in the low-flow sample.]

Homolog group	Elizabeth River at Hillside[1]	Main Stem Elizabeth River	West Branch Elizabeth River
	Ratio of average high flow to low flow in suspended sediment (percent)	Ratio of average high flow to low flow in suspended sediment (percent)	Ratio of average high flow to low flow in suspended sediment (percent)
Mono + di	0.7	2.7	3.7
Tri	0.6	3.8	3.3
Tetra	0.7	2.7	1.2
Penta	1.3	1.5	1.2
Hexa	1.2	0.79	0.96
Hepta	1.0	0.91	0.82
Octa	1.0	1.0	0.84
Nona	1.2	0.99	1.7
Deca	1.7	1.1	3.4
Total PCBs	**0.8**	**6.60**	**0.55**

[1]Ratio of average for Elizabeth River samples on May 22, 2001, and June 4, 2003, to Elizabeth River samples on June 29, 2000, and Apr. 25, 2001. See Wilson and Bonin, 2007.

Table 7. Concentrations and toxic equivalent quotients for selected polychlorinated biphenyls in samples of suspended sediment from Elizabeth River sites in New Jersey, 2008.

[TEF, toxic equivalence factor; CON, concentration; TEQ, toxic equivalency; NA, not available, PCBs, polychlorinated biphenyls; TCDD, tetrachlorinated dibenzo-p-dioxin; all values in picograms per gram]

		Main Stem Elizabeth River		Main Stem Elizabeth River		Main Stem Elizabeth River		West Branch Elizabeth River		West Branch Elizabeth River		West Branch Elizabeth River		Elizabeth River Head-of-tide	
	Sample identifier	EBEL073103[1]		3USG001SA		3USG002SA		WBEL080703[1]		3USG003SA		3USG004SA		Phase I average[2]	
	Condition/type	Low flow		Low flow		High flow		Low flow		Low flow		High flow			
PCB number	TEF	CON	TEQ[3]	CON	TEQ[3]	CON	TEQ[3]	CON	TEQ[3]	CON	TEQ[3]	CON	TEQ[3]	CON	TEQ[3]
11	NA	1,120	NA	224	NA	1,420	NA	1,250	NA	3,590	NA	6,460	NA	2,800	NA
77	0.0001	1,080	0.11	179	0.02	3,290	0.33	1,860	0.19	330	0.03	674	0.07	4,600	0.46
81	0.0001	[4]72.5	[4].00	86	0.01	1,440	0.14	[4]86	[4].00	84	0.01	268	0.03	160	0.016
105	0.0001	8,300	0.83	1,410	0.14	20,800	2.1	29,400	2.9	2,130	0.21	5,200	0.52	15,000	1.5
114	0.0005	516	0.26	94	0.05	1,120	0.56	2,200	1.1	126	0.06	200	0.10	1,100	0.55
118	0.0001	23,200	2.32	5,390	0.54	62,100	6.2	88,800	8.9	7,740	0.77	10,300	1.0	32,000	3.2
123	0.0001	364	0.04	50	0.01	791	0.08	1,210	0.12	84	0.01	179	0.02	700	0.07
126	0.1	108	10.80	32	3.2	3,340	334	372	37.2	270	27	268	26.8	440	44
156/157	0.0005	4,470	2.24	2,950	1.5	21,900	11	18,200	9.1	4,180	2.1	3,300	1.7	9,200	4.6
167	0.00001	1,960	0.02	1,380	0.01	8,560	0.09	7,040	0.07	2,020	0.02	1,500	0.02	4,200	0.042
169	0.01	[4]95.4	[4].00	140	1.4	1,250	13	321	3.2	315	3.2	275	2.8	350	3.5
170	0.0001	17,400	1.74	22,500	2.3	129,000	13	60,100	6.0	38,200	3.8	16,500	1.7	49,000	4.9
180	0.00001	48,900	0.49	47,400	0.47	299,000	3.0	153,000	1.5	75,700	0.76	34,400	0.34	140,000	1.4
189	0.0001	695	0.07	832	0.08	4,640	0.46	2,300	0.23	1,290	0.13	828	0.08	1,900	0.19
Total TEQ from PCBs	**NA**	**NA**	**19**	**NA**	**9.7**	**NA**	**383**	**NA**	**71**	**NA**	**38**	**NA**	**35**	**259,000**	**64**

[1]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

[2]Average values for head-of-tide low-flow samples collected from the Elizabeth River at Hillside, N.J., during Phase I. See Wilson and Bonin, 2007.

[3]Values of TEQ are in units of picograms per gram as 2,3,7,8-TCDD.

[4]Congener not detected. Value reported is estimated detection level (EDL). The concentration of non-detected congeners was set to 0 when calculating TEQ.

A goal of this study was to determine whether a distinct chemical signature exists that can be used to identify suspended sediment from either branch of the Elizabeth River. The data do not appear to show distinct chemical signatures for either tributary as the relative concentrations (percent of total contributed by each congener group) for PCB homologs in the suspended sediment (table 5) were found to be generally the same. There are, however, a few characteristics in the PCB composition that may be useful in identifying the sources of sediment to the downstream reaches. The most notable differences observed were that the suspended sediment in the West Branch contained a slightly higher percentage of the tetra-chlorinated homologs and a slightly lower percentage of the hepta- and octa-chlorinated homologs than in the Main Stem, but these differences are minor.

When compared with the average concentrations measured previously at the head-of-tide sampling site (table 5), the samples from the Main Stem and West Branch collected in 2008 contained higher percentages of hexa-chlorinated homologs and lower percentages of tri- and nona-chlorinated homologs. In other words, there appears to be a shift toward the middle chlorination level homologs in the suspended sediment collected upstream from the head-of-tide site.

When comparing the average ratios of the homolog groups in high-flow and low-flow samples between the two branches and the head-of-tide site (table 6), the differences appear to be minor. However, suspended sediment from both branches appears to be enriched in the lower level (mono- to tetra-) chlorinated compounds when compared to the values from the suspended-sediment samples from the head-of-tide site. The average ratio of the high-flow samples to low-flow samples from the West Branch of the Elizabeth River seems to indicate that the West Branch may be enriched in the higher level (nona- and deca-) chlorinated homolog groups compared to the head-of-tide site and to the Main Stem. Of the coplanar congeners that were measurable in the samples collected in this study (table 7), all coplanar PCBs were present in higher concentrations in the West Branch than in the Main Stem at low flow, with the exception of PCB 81, which was detected at similar concentrations in both branches at low flow. At high flow, however, all coplanar PCBs were detected in higher concentrations in the Main Stem than in the West Branch, with the exception of PCB 11, which was detected at a higher concentration in the West Branch than in the Main Stem at high flow. However, the relative percentages of these congeners were approximately the same in the samples from the two branches.

A few PCB congeners were found to be unique to the West Branch. Of the entire suite of congeners that was measured in low-flow and high-flow samples, PCBs 36, 54, 67, 79, 93/100, 94, 96, 104, and 152 were present only in the samples from the West Branch, whereas no congener was unique to samples from the Main Stem. Therefore, these congeners could be used to identify and quantify sediment loads originating from the West Branch of the Elizabeth River.

PCB 11 was shown in previous studies to be a potentially useful marker of PCB sources and has been attributed to the production of pigments and associated waste in streams (Litton and others, 2002). PCB 11 was found to be present in samples collected during low-flow and high-flow conditions on both branches of the Elizabeth River. At low-flow and at high-flow conditions, the suspended-sediment-bound concentrations of PCB 11 were much higher for the West Branch of the Elizabeth River (3,590 pg/g and 6,460 pg/g, respectively) than for the Main Stem (224 pg/g and 1,420 pg/g, respectively) (table 7). The values for the Main Stem are less than the average low-flow value at the head-of-tide site (2,800 pg/g; table 7), but the values on the West Branch during low-flow and during high-flow conditions are greater than the average low-flow value for the head-of-tide site. Thus, PCB 11 may be useful in indicating the amount of mixing of tributary sediment as the waters converge to flow downstream to the head-of-tide site. Further investigation of the sources of PCB 11 could facilitate the identification of the sources of PCBs in the two branches.

Cadmium

The trace element cadmium was measured in grab samples that were collected approximately midway through the sampling period at both the Main Stem and West Branch of the Elizabeth River sites. Two samples were collected at both the Main Stem and West Branch of the Elizabeth River site—one unfiltered sample was analyzed for total (whole-water) cadmium, and a second, filtered sample was analyzed for dissolved cadmium. The concentration of cadmium associated with the suspended sediment was assumed to be the difference between the two measured concentrations divided by the concentration of suspended sediment in each sample. For example, the calculation for particulate cadmium concentration is

$$\frac{\text{Total Cd (ng/L)} - \text{Dissolved Cd (ng/L)}}{\text{Suspended sediment (g/L)}} = \text{Particulate Cd (ng/g)}$$

The measured concentrations of total (whole-water) and dissolved cadmium, and the calculated concentrations of cadmium in the suspended sediment, are listed in table 4. Total Cd was 100 ng/L in the low-flow sample collected from the Main Stem of the Elizabeth River. A sample for total Cd could not be collected on the Main Stem of the Elizabeth River during the sample collection at high flow. Total Cd concentrations were less than 60 ng/L (non-detectable) and an estimated 53 ng/L (below the reporting level) for the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively. Dissolved Cd concentrations were 78 ng/L on the Main Stem of the Elizabeth River during low-flow conditions and an estimated 13 ng/L (below the reporting level) and 38 ng/L on the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively. Both total and dissolved Cd concentrations measured during this study were

Table 8. Concentrations and toxic equivalent quotients for polychlorinated dibenzo-p-dioxins and difuran congeners in samples of suspended sediment from Elizabeth River, New Jersey, 2008.

[TEF, toxic equivalence factor; CDD, chlorinated dibenzo-p-dioxins; CDF, chlorinated dibenzo-p-furans; T, tetra; Pe, penta; Hx, hexa; Hp, hepta; O, octa; CON, concentration; TEQ, toxic equivalency; all values in picograms per gram; <, less than; BE, blank eliminated]

		Main Stem Elizabeth River		Main Stem Elizabeth River		Main Stem Elizabeth River		West Branch Elizabeth River		West Branch Elizabeth River		West Branch Elizabeth River		Elizabeth River head-of-tide[1]	
Sample identifier		EBEL073103[2]		3USG001SA		3USG002SA		WBEL080703[2]		3USG003SA		3USG004SA		Average	
Condition/type		Low flow		Low flow		High flow		Low flow		Low flow		High flow			
Organic compound	**TEF[3]**	**CON**	**TEQ**	**CON**	**TEQ**	**CON**	**TEQ**	**CON**	**TEQ**	**CON**	**TEQ**	**CON**	**TEQ**	**CON**	**TEQ**
2,3,7,8-TCDD	1	[4]<8.0	0.00	4.3	4.3	7.2	7.2	[4]<9.8	0.00	4.2	4.2	4.6	4.6	5.1	5.1
1,2,3,7,8-PeCDD	1	8.9	8.85	22	22	23	23	[4]<6.5	.00	6.9	6.9	9.5	9.5	24	24
1,2,3,7,8,9-HxCDD	0.1	BE	.00	22	2.2	104	10	BE	.00	18.8	1.9	29	2.9	93	9.3
1,2,3,4,7,8-HxCDD	0.1	13	1.3	22	2.2	40	4.0	11	1.1	6.9	0.69	14	1.4	32	3.2
1,2,3,6,7,8-HxCDD	0.1	BE	0	22	2.2	113	11	BE	.00	21	2.1	33	3.3	84	8.4
1,2,3,4,6,7,8-HpCDD	0.01	550	5.5	136	1.4	4,290	43	813	8	426	4.3	854	8.5	1,700	17
OCDD	0.0001	6,110	0.61	2,400	0.24	33,500	3.4	8,040	.80	4,800	0.48	10,500	1.1	19,500	2.0
2,3,7,8-TCDF	0.1	37	3.7	4.3	0.43	28	2.8	25	2.5	4.8	0.48	5.7	0.57	77	7.7
1,2,3,7,8-PeCDF	0.05	11	0.53	22	1.1	16	0.80	10	.50	3.1	0.15	8.0	0.40	20	.99
2,3,4,7,8-PeCDF	0.5	BE	.00	22	11	34	17	BE	.00	9.5	4.7	11	5.4	49	24
1,2,3,4,7,8-HxCDF	0.1	BE	.00	7.2	0.72	91	9.1	38	3.8	31	3.1	48	4.8	110	11
2,3,4,6,7,8-HxCDF	0.1	BE	.00	22	2.2	41	4.1	BE	.00	14	1.4	17	1.7	45	4.5
1,2,3,6,7,8-HxCDF	0.1	BE	.00	4.8	0.48	61	6.1	BE	.00	19	1.9	19	1.9	170	17
1,2,3,7,8,9-HxCDF	0.1	[4]<4.6	.00	22	2.2	36	3.6	[4]<5.8	.00	21	2.1	6.7	0.7	2.1	.21
1,2,3,4,6,7,8-HpCDF	0.01	180	1.8	49	0.49	984	9.8	304	3.1	214	2.1	299	3.0	610	6.1
1,2,3,4,7,8,9-HpCDF	0.01	BE	.00	22	0.22	43	0.43	BE	.00	15	0.15	20	0.20	41	.41
OCDF	0.0001	362	0.04	79	0.01	1520	0.15	643	.06	290	0.03	580	0.06	1,150	.12
Total CDD		**6,680**	**16**	**2,630**	**34**	**38,000**	**102**	**8,860**	**10**	**5,290**	**21**	**11,400**	**31**	**21,400**	**69**
Total CDF		**590**	**6.1**	**253**	**18**	**2,860**	**54**	**1,020**	**9.9**	**622**	**16**	**1,020**	**19**	**2,270**	**72**
Total		**7,270**	**22**	**2,880**	**52**	**40,900**	**156**	**9,880**	**20**	**5,910**	**37**	**12,400**	**50**	**23,700**	**141**

[1]Average values for head-of-tide low-flow samples collected from the Elizabeth River at Hillside, N.J., during Phase I. See Wilson and Bonin, 2007.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

[3]TEF values from van Leeuwen, 1997.

[4]Value is the reported estimated detection level; actual concentration would be less than this value. TEQ set to 0.0 for non-detected congeners.

similar to total and dissolved concentrations measured in the earlier studies of these tributaries. Average total and dissolved Cd concentrations measured previously for the head-of-tide site on the Elizabeth River at Hillside were much higher than any of the concentrations measured in this study or previously for these tributaries (table 4).

The concentration of total trace elements is related to the amount of suspended material that is captured in a sample, especially in systems where the suspended sediment has a high content of trace elements (Wilson and Bonin, 2007). For the most part, the concentrations of suspended-sediment-bound cadmium in these rivers were similar to the cadmium concentrations measured earlier for these tributaries (Wilson and Bonin, 2008), and only a weak correlation was observed between the concentration of suspended sediment or POC and these cadmium concentrations. Further sampling would be needed to determine whether whole-water or total cadmium concentrations in these tributaries are a function of the amount of suspended sediment captured.

Tributary Loads

The loads of suspended sediment and constituents were calculated for each tributary using the available USGS discharge data and the constituent concentrations in the samples collected during this study.

Suspended-Sediment and Carbon Loads

River discharge and suspended sediment are key pieces of information needed to construct suspended-sediment rating curves, which show the relations between daily discharge and daily suspended-sediment load. Because the two branches of the Elizabeth River have not been routinely monitored or sampled by the USGS for discharge or suspended sediment, the suspended sediment to discharge relation based on the 25 years of data from the Elizabeth River at Ursino Lake, N.J., was substituted for these rivers. The head-of-tide site is in close proximity and has comparable land area and land cover to that in the branches of the Elizabeth River (Wilson and Bonin, 2008). According to the discharge measured in each branch at the time that it was sampled (under low-flow conditions), approximately 88 percent of the combined discharge was supplied by the West Branch, and 12 percent was supplied by the Main Stem (upstream from the confluence) (Wilson and Bonin, 2008). Loads in the tributaries were estimated using relations developed previously for the Elizabeth River head-of-tide site; the load calculations were, in turn, based on the discharge proportioned between the two branches.

The suspended-sediment loads then were multiplied by the concentration of the total suspended-sediment-bound PCB, PCDD/PCDF, or Cd at high-flow and low-flow conditions, as demonstrated previously (Wilson and Bonin, 2007), to obtain respective constituent loads. The constituent loads for the high-flow and low-flow samples were also averaged to obtain an estimated average annual constituent load for each branch of the Elizabeth River, as required by the CARP and done in previous studies (Wilson and Bonin, 2007). The estimated average annual discharge in each branch was multiplied by the associated total dissolved cadmium concentration to obtain the yearly average dissolved loads for cadmium.

The average annual suspended-sediment loads, calculated using sediment-discharge relations based on data for water years[1] 1975 to 2001 (where discharge data were available; see table 9) are presented for the two branches of the Elizabeth River and for the head-of-tide site on the Elizabeth River at Hillside, N.J., in table 10 (Wilson and Bonin, 2008; Wilson and Bonin, 2007). The head-of-tide site on the Elizabeth River at Hillside has a mean annual discharge of 6,220 Mgal/yr (million gallons per year), an estimated sediment load of 0.42 million kilograms of suspended sediment per year, and 14,400 kg of POC per year. These values are based on discharge data collected over 27 years and on data from suspended-sediment grab samples collected over 16 years (Bonin and Wilson, 2007). The Main Stem of the Elizabeth River is estimated to contribute 12 percent of the discharge and loads to the head-of-tide site, which translates to an average annual discharge of 746 Mgal/yr, 0.05 million kilograms of suspended sediment per year, and 1,730 kg of POC per year. The West Branch of the Elizabeth River is estimated to contribute 88 percent of the discharge and loads to the head-of-tide site, which translates to an mean annual discharge of 5,474 Mgal/yr, 0.37 million kilograms of suspended sediment per year, and 12,700 kg of POC per year (table 10).

Constituent Loads

The discharge and suspended-sediment loads calculated during this study under low-flow and high-flow conditions indicate that, of the two branches of the Elizabeth River, the West Branch clearly contributes a larger load of PCBs and PCDD/PCDFs to the Elizabeth River head-of-tide site than the Main Stem. During low-flow conditions, the West Branch contributes 416 g/yr of suspended-sediment-bound PCBs and 2.2 g/yr of suspended-sediment-bound PCDD/PCDFs, whereas the Main Stem contributes 27 g/yr of suspended-sediment-bound PCBs and 0.14 g/yr of suspended-sediment-bound PCDD/PCDFs. During high-flow conditions the West Branch contributes 231 g/yr of suspended-sediment-bound PCBs and 4.6 g/yr of suspended-sediment-bound PCDD/PCDFs, whereas the Main Stem contributes 176 g/yr of suspended-sediment-bound PCBs and 2.05 g/yr of suspended-sediment-bound

[1]The water year in North America is referred to as the twelve-month period beginning October 1 in one year and ending September 30 of the following year. The water year is designated by the calendar year in which it ends. (Natural Resources Conservation Services National Water and Climate Center, accessed September 10, 2010)

Table 9. Rating curves for suspended sediment and particulate organic carbon in the West Branch and Main Stem of the Elizabeth River in New Jersey.

[kg/d, kilograms per day; Mgal/d, millions gallons per day; ln, natural logarithm; r^2, correlation coefficient]

Period of discharge data used	Length of discharge record, in years	Period of water-quality data used	Suspended sediment rating curve (SS = suspended-sediment load in kg/d; Q = mean daily discharge, in Mgal/d)	Particulate organic carbon rating curve (POC = Particulate organic carbon load in kg/d; Q = mean daily discharge, in Mgal/d)
10/1/75–9/30/02	27	10/25/78–8/1/94	[1]ln (SS) = 1.557 * ln (Q) + 1.848 r^2 = 0.70	[1]ln (POC) = 1.218 * ln (Q) – 0.015 r^2 = 0.56

[1]These equations were developed for the New Jersey Toxics Reduction Workplan, Phase II study for low-flow conditions on these two tributaries. See Wilson and Bonin, 2008.

PCDD/PCDFs. The low-flow samples collected in previous studies during 2003 and the subsequent loads calculated from those samples support this assessment that the West Branch is the larger contributor of suspended-sediment loads of PCBs and PCDD/PCDFs when compared to the Main Stem (table 10).

The total toxicity load (as measured by TEQ load) of the West Branch of the Elizabeth River is also much higher than that of the Main Stem at low-flow conditions, approximately 9 times higher. The TEQ load during high-flow conditions is nearly equal (table 10). The TEQ is 28 mg/yr and 32 mg/yr in the West Branch of the Elizabeth River during low-flow and high-flow conditions, respectively, and 3.1 mg/yr and 27 mg/yr in the Main Stem of the Elizabeth River during low-flow and high-flow conditions, respectively. TEQ loads from PCBs and PCDD/PCDFs are larger in the West Branch of the Elizabeth River than in the Main Stem of the Elizabeth River during low-flow conditions. Total TEQ loads of the PCDD/PCDFs are larger in the West Branch than the Main Stem during high-flow conditions. In contrast, the TEQ load from PCBs in the Main Stem (19 mg/yr) is larger than the TEQ load from PCBs in the West Branch (13 mg/yr) during high-flow conditions.

The estimated loads of PCBs and PCDD/PCDFs for each branch were calculated by averaging the two load values (one for low-flow and one for high-flow conditions) for each branch, as was done in the previous study per the requirements of the CARP program (New Jersey Department of Environmental Protection, 2001); estimated loads of PCBs and PCDD/PCDFs are presented in table 10. The average estimated loads for Elizabeth River at Hillside, N.J., are also presented in table 10 for comparison to the present study (Wilson and Bonin, 2007).

The loads also were estimated using a different method based on the period of record of discharge for the Elizabeth River at Ursino Lake, N.J., site; the resulting suspended-sediment rating curve was calculated on the basis of the 25-year historical discharge rating curve developed previously for the Elizabeth River (table 9) (Wilson and Bonin, 2007). Discharge and suspended sediment were plotted in relation to percent exceedance for both branches of the Elizabeth River, on the basis of the assumed proportion of discharge used by Wilson and Bonin (2008). The low-flow events and the high-flow events were plotted on flow-duration graphs for the two branches of the Elizabeth River (figs. 4 and 5). A threshold point was assumed on each plot below which the low-flow concentration for PCBs and PCDD/PCDFs was applied and above which the high-flow concentration for PCBs and PCDD/PCDFs was applied. Each discharge point used to calculate the 25-year average flow was used to estimate a suspended-sediment daily load value using that day's mean discharge from the rating curve developed previously. The value of the mean daily discharge, either above or below the assumed threshold, would dictate which contaminant concentration would be used in the calculation, either low-flow PCB or PCDD/PCDF concentration, or high-flow PCB or PCDD/PCDF concentration. The daily loads were summed for each of the available 25 years of discharge data, and a 25-year load average was estimated for each branch of the Elizabeth River. These estimated loads are presented in table 10 and can be compared to the loads that were estimated previously by averaging the low-flow and high-flow loads for the head-of-tide site (Wilson and Bonin, 2007).

The loads estimated as average loads for one sample collected during low flow and one sample collected during high flow on the Elizabeth River can be compared to the loads estimated using the 25-year flow-weighted average method. For the Main Stem of the Elizabeth River, the loads of PCBs and PCDD/PCDFs and the TEQ loads estimated using the 25-year flow-weighted average method were about one-half the loads estimated by averaging the load values from low-flow and high-flow events. For the West Branch of the Elizabeth River, the loads of PCBs and PCDD/PCDFs and the TEQ loads estimated using the 25-year flow-weighted average method are comparable to and slightly smaller (with the exception of the PCDD/PCDF loads that were slightly larger) than the loads calculated by averaging the values from the low-flow and high-flow events (table 10).

The loads for cadmium are presented in table 11 and indicate that the West Branch is a larger contributor of dissolved and suspended-sediment-bound cadmium to the Elizabeth

Table 10. Estimated loads of suspended sediment, particulate organic carbon, and organic compounds in samples from the Elizabeth River, New Jersey, 2008.

[Mgal/yr, million gallons per year; kg/yr, kilograms per year; g/yr, grams per year; mg/yr, milligrams per year; NA, not available; TEQ, toxic equivalence; PCB, polychlorinated biphenyl; PCDD/PCDF, polychlorinated dibenzo-p-dioxins and difurans]

	Main Stem Elizabeth River (above confluence)					West Branch Elizabeth River					Elizabeth River at head-of-tide[1]
River condition	Low flow	Low flow	High flow	Average	25-year flow-weighted average	Low flow	Low flow	High flow	Average	25-year flow-weighted average	Average
Study/date sampled	7/31/03[2]	10/22/08	10/25/08	10/22/08 and 10/25/08	10/22/08 and 10/25/08	8/7/03[2]	11/7/08	11/13/08	11/7/08 and 11/13/08	11/7/08 and 11/13/08	NA
Dates of available discharge data	NA	NA	NA	NA	1/1/75–9/30/02	NA	NA	NA	NA	1/1/75–9/30/02	10/1/75–9/30/02
Mean annual discharge (Mgal/yr)	746 [3](12 percent)	746 [3](12 percent)	746 [3](12 percent)	746 [3](12 percent)	NA	5,474 [3](88 percent)	5,474 [3](88 percent)	5,474 [3](88 percent)	5,474 [3](88 percent)	NA	6,220
Suspended-sediment load (millions of kg/yr)	0.05 [3](12 percent)	0.05 [3](12 percent)	0.05 [3](12 percent)	0.05 [3](12 percent)	NA	0.37 [3](88 percent)	0.37 [3](88 percent)	0.37 [3](88 percent)	0.37 [3](88 percent)	NA	0.42
Particulate organic carbon load (kg/yr)	1,730 [3](12 percent)	1,730 [3](12 percent)	1,730 [3](12 percent)	1,730 [3](12 percent)	NA	12,700 [3](88 percent)	12,700 [3](88 percent)	12,700 [3](88 percent)	12,700 [3](88 percent)	NA	14,400
Suspended-sediment-bound PCB load (g/yr)	40	27	176	102	48	1,150	416	231	323	210	1,000
Suspended-sediment-bound PCDD/PCDF load (g/yr)	0.36	0.14	2.05	1.09	0.55	3.7	2.2	4.6	3.4	3.8	12
TEQ load from PCDD/PCDF (mg/yr)	1.1	2.6	7.8	5.2	2.2	7.4	13.7	18.5	16.1	15.8	56
TEQ load from PCBs (mg/yr)	0.95	0.49	19	9.8	5.2	26	14.1	13.0	13.7	11.3	28
Total TEQ load (mg/yr)	2.1	3.1	27	15	7.4	34	28	32	30	27	84

[1]Load estimates calculated using samples collected from the Elizabeth River at Hillside, N.J., during Phase I. See Wilson and Bonin, 2007.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

[3]Reported value represents the estimated percentage of the mean annual discharge in the main stem Elizabeth River.

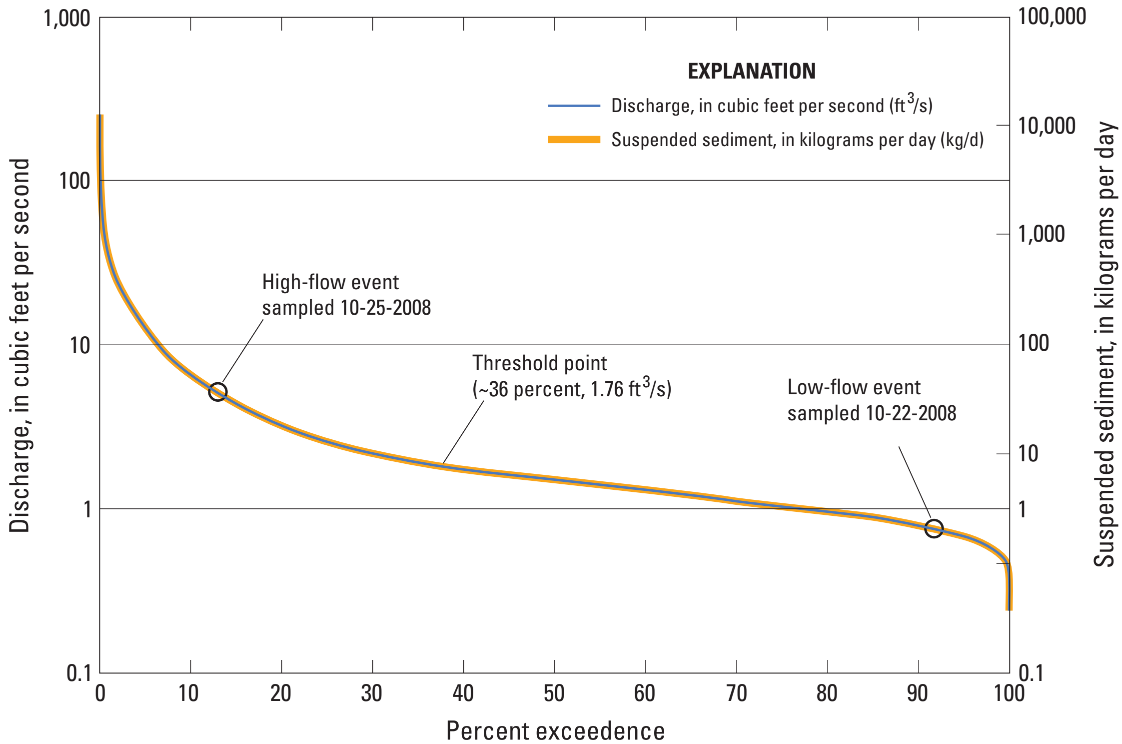

Figure 4. Flow-duration curve and suspended-sediment loads at station 01393300, Elizabeth River above West Branch at Hillside, N.J. (Main Stem of the Elizabeth River).

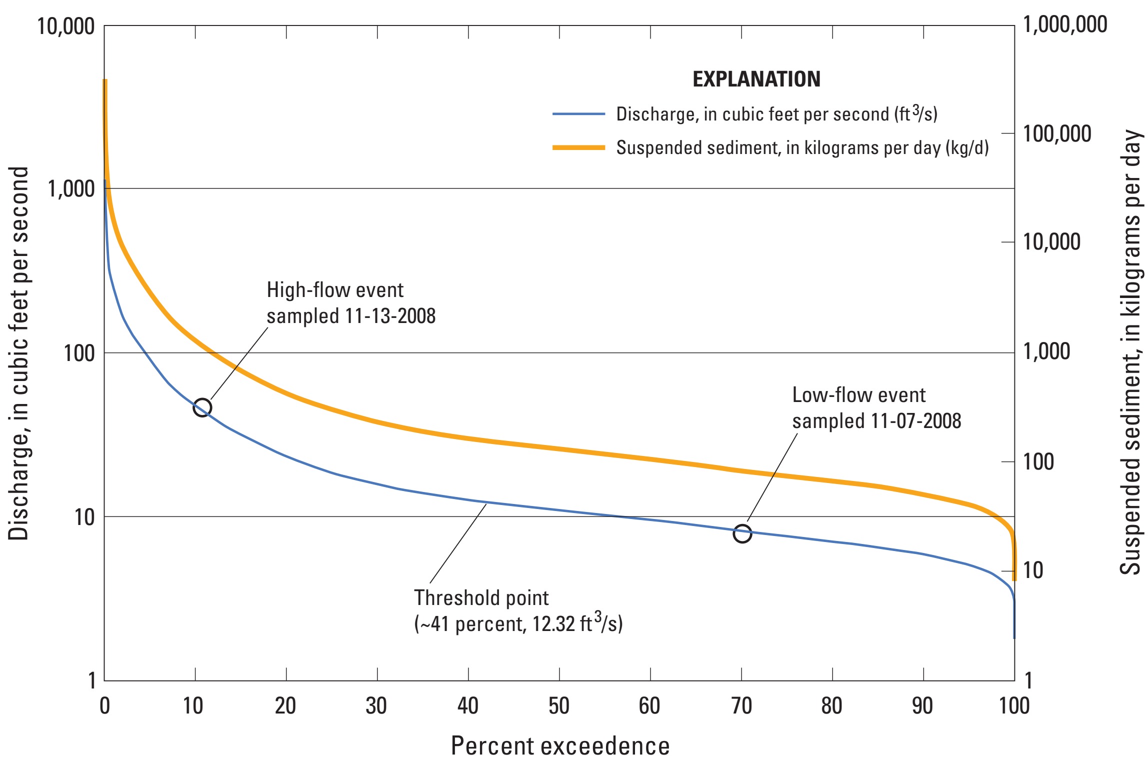

Figure 5. Flow-duration curve and suspended-sediment loads at station 01393345, West Branch of the Elizabeth River above Sayre Rd at Union, N.J.

Table 11. Estimated loads of cadmium in samples from the Elizabeth River in New Jersey, 2008.

[NA, not available; na, not applicable; <, less than; kg/yr, kilograms per year]

	Main Stem Elizabeth River (upstream from confluence)			West Branch Elizabeth River			
Dates of available discharge data	NA	NA	NA	NA	NA	NA	NA
River condition	Low flow	High flow	Low flow	Low flow	High flow	Low flow	Average
Date sampled	10/22/08	10/25/08	7/31/03[1]	11/7/08	11/13/08	8/7/03[1]	11/7/08 and 11/13/08
Dissolved cadmium load (kg/yr)	0.22	na	0.3	0.27	0.79	.56	0.52
Suspended sediment cadmium load (kg/yr)	0.47	na	0.72	<7.1	0.47	1.2	<3.79

[1]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

Table 12. Constituent loads expressed as percentage of the average annual suspended-sediment load for the tributaries to, and the heads-of-tide of, the Elizabeth River, New Jersey, 2008.

[Values are in percent. POC, particulate organic carbon; TEQ, toxic equivalence; PCDD/PCDFs, polychlorinated dibenzo-p-dioxins and difurans; PCBs, polychlorinated biphenyls]

	Main Stem Elizabeth River (upstream from confluence)				West Branch Elizabeth River			
Discharge	[1]12	[1]12	[1]12	[1]12	[1]88	[1]88	[1]88	[1]88
Suspended sediment	[1]12	[1]12	[1]12	[1]12	[1]88	[1]88	[1]88	[1]88
POC	[1]12	[1]12	[1]12	[1]12	[1]88	[1]88	[1]88	[1]88
River condition	Low Flow	Average	Low Flow	High Flow	Low Flow	Average	Low Flow	High Flow
Date sampled	7/31/03[2]	10/22/08 and 10/25/08	10/22/08	10/25/08	8/7/03[2]	11/7/08 and 11/13/08	11/7/08	11/13/08
Suspended sediment-bound PCBs	4	10	3	18	115	32	42	23
Suspended sediment PCDD/PCDFs	3	9	1	17	31	28	18	38
TEQ from PCDD/PCDFs	2	9	5	14	13	29	24	33
TEQ from PCBs	3	35	2	68	93	49	50	46
Total TEQ	3	18	4	32	40	35	33	38

[1]Loads based on estimated discharge.

[2]These samples were collected during base flow for the New Jersey Toxics Reduction Workplan, Phase II study. See Wilson and Bonin, 2008.

River than is the Main Stem during low-flow conditions, though comparisons can be made only for samples collected during low flow because collection of a sample from the Main Stem during the high-flow event for cadmium analysis was not feasible. The loads for dissolved cadmium in samples collected from the West Branch during low-flow and high-flow conditions are 0.27 kg/yr and 0.79 kg/yr, respectively, and 0.22 kg/yr for the Main Stem during low-flow conditions. The loads for suspended-sediment-bound cadmium in samples collected from the West Branch during low-flow and high-flow conditions are less than 7.1 kg/yr and 0.47 kg/yr, respectively, and 0.47 kg/yr for the Main Stem during low-flow conditions.

The differences between the summed contaminant loads for the tributaries and for those estimated for the head-of-tide site, and the differences between the loads calculated for low flow in this study and those calculated for low flow in the previous study, reflect the effects of (1) the uncertainty caused by the limited number of samples available to characterize the variation in the tributary loads; (2) the error in the estimation procedures, including the rating curves and assumed estimated discharge percentages for each branch; (3) the processes that could alter the concentrations of suspended-sediment-bound contaminant species downstream from the confluence, including the presence of unknown sources in this area; (4) the possible differences due to sampling at different “low-flow” points along the flow regime curve; and (5) the possible variation due to sampling at different times of the year and a few years later.

The lack of historic discharge and suspended-sediment data makes it difficult to reliably estimate the loads for the West Branch and Main Stem of the Elizabeth River, the two tributaries that eventually combine and flow past the Elizabeth River head-of-tide site (tables 10 and 11). A noteworthy result is that the combined low-flow load of suspended-sediment-bound PCBs estimated for the two branches (443 g/yr; combining 27 g/yr for the Main Stem and 416 g/yr for the West Branch; table 10) is slightly more than one-third the total low-flow load estimated for the Elizabeth River at the head-of-tide (1,190 g/yr) calculated previously (Wilson and Bonin, 2008). The combined average load of suspended-sediment-bound PCBs estimated for the two branches (425 g/yr; combining 102 g/yr for the Main Stem and 323 g/yr for the West Branch, table 10) is slightly less than one-half the total average load estimated for the Elizabeth River at the head-of-tide (1,000 g/yr) calculated previously (Wilson and Bonin, 2008). This difference could be the result of analytical uncertainty, but more likely, it is the result of the assumed contribution of discharge and suspended sediment assigned to each tributary. Alternatively, the concentrations measured during this study may not accurately represent the range of values in the tributaries; the values for discharge or suspended-sediment load may have been greatly underestimated, or suspended-sediment-bound PCBs may have come into the system somewhere between the confluence and the head-of-tide sampling site at Hillside, N.J. Because the proportion of the discharge attributed to each branch was assumed, the proportion supplied by each branch and the enrichment factors for the loads are considered to be only rough estimates (table 12). A more complete discharge/suspended-sediment record is needed to improve the estimates of loads. However, on the basis of the available concentration data and resulting load calculations, the West Branch of the Elizabeth River appears to be the more important contributor of PCBs, PCDD/PCDFs, total toxicity (as measured by the TEQ loads), and cadmium during low-flow and high-flow conditions.

Summary and Conclusions

The U.S. Geological Survey conducted a study to characterize and determine the concentrations and loads of organic compounds and cadmium in the West Branch and Main Stem of the Elizabeth River during low-flow and high-flow conditions as part of the New Jersey Department of Environmental Protection (NJDEP) Toxics Reduction Workplan for the New York–New Jersey Harbor Estuary Program. Samples of suspended sediment were collected from the two main tributaries to the freshwater Elizabeth River (the West Branch and the Main Stem) from October 2008 to November 2008, then analyzed for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-difuran compounds (PCDD/PCDFs), and cadmium. This sampling was conducted on the basis of results obtained in the Phase II NJTRWP CARP study that was conducted at the two main tributaries to the Elizabeth River during low-flow conditions. The sampling and analytical methods used in this current study are identical to those used in the Phase I and Phase II NJTRWP work.

Organic chemicals and inorganic trace elements were found in measurable concentrations in suspended sediment from each of the branches of the Elizabeth River sampled during high-flow and low-flow conditions. The characteristics of the PCB and other constituent chemistries and the estimated loads of constituents and sediment were evaluated to determine whether the West Branch of the Elizabeth River was, in fact, the main source of PCB and PCDD/PCDF contamination upstream from the head-of-tide on the Elizabeth River.

As a result of the elevated concentrations of PCBs and PCDD/PCDFs measured previously in the West Branch of the Elizabeth River, the sampling described in this report was undertaken in the two branches upstream from the head-of-tide site with the goal of determining (1) the contribution of suspended sediment and contaminants from both branches (upstream from the confluence) during high-flow conditions to test the earlier theory that West Branch is the major contributor of contaminants to the Elizabeth River, (2) whether the samples collected on both branches during low-flow conditions would closely match data from the previous study carried out during low-flow conditions, and (3) whether distinctive characteristics exist in the contaminant chemistry that could serve as a marker for identifying the suspended sediment from each tributary.

To help illustrate and better understand the various findings of this study, the following numbered conclusions are also presented in a tabular format for comparative purposes. The table in this section presents comparisons of the West Branch to the Main Stem for both low- and high-flow sampling events.

As previously mentioned, long-term discharge data were not available for either of these branches, so the percentages that were estimated from previous studies, where discharge was crudely measured and flow proportioned between the two branches, were used.

1. It was estimated that the West Branch may supply 80 to 90 percent of the low-flow discharge downstream from the confluence. A greater contribution by the West Branch is consistent with the flows observed at the time the tributaries were sampled during low-flow conditions. Both branches of the Elizabeth River were sampled during high-flow conditions that were within 10 to 15 percent exceedance of the Elizabeth River at Hillside flow-duration curve. However, the estimated high-flow discharge of the West Branch of the Elizabeth River was greater than the estimated high-flow discharge of the Main Stem.

It is not known whether the estimated discharge proportions developed in a previous study hold true at elevated discharges. For the purposes of this study, it was assumed that the previously developed proportional discharges for each branch were reasonable for all flow conditions.

2. The concentrations of suspended sediment in the low-flow samples collected from each branch were comparable; however, the concentration of suspended sediment in the high-flow sample collected from the West Branch was almost twice that of the Main Stem.

3. During low flow, the POC concentration in the West Branch was approximately 1.3 times higher than the POC concentration in the Main Stem. Similarly, during high flow, the POC concentration in the West Branch was 1.33 times higher than that in the Main Stem.

4. The concentration of suspended-sediment-bound PCBs in the West Branch was 2.1 times higher than that in the Main Stem during low flow. During high-flow conditions, the concentration of suspended-sediment-bound PCBs in the West Branch was 0.18 times lower than that in the Main Stem. (During high-flow conditions, the concentration of suspended-sediment-bound PCBs in the Main Stem was 5.66 times higher than that in the West Branch.)

5. The concentration of suspended-sediment-bound PCDD/PCDFs in the West Branch was 2 times higher than that in the Main Stem during low flow. During high-flow conditions, the concentration of suspended-sediment-bound PCDD/PCDFs in the West Branch was 0.3 times lower than that in the Main Stem. (During high-flow conditions, the concentration of suspended-sediment-bound PCDD/PCDFs in the Main Stem was 3.3 times higher than that in the West Branch.)

In terms of PCB and PCDD/PCDF concentrations, the West Branch of the Elizabeth River had higher values than the Main Stem of the Elizabeth River but only during low-flow conditions. The reverse occurred during high flows when the Main Stem had higher PCB and PCDD/PCDF concentrations than the West Branch of the Elizabeth River.

6. During low flow, the TEQ value calculated for the PCDD/PCDFs in the West Branch was 0.71 times lower than that calculated for the Main Stem. During high flow, the TEQ value calculated for the PCDD/PCDFs in the West Branch was 0.32 times lower than that calculated for the Main Stem. (During low flow, the TEQ value calculated for the PCDD/PCDFs in the Main Stem was 1.4 times higher than that calculated for the West Branch. During high flow, the TEQ value calculated for the PCDD/PCDFs in the Main Stem was 3.1 times higher than that calculated for the West Branch.)

7. During low flow, the TEQ value calculated for the PCBs in the West Branch was 3.9 times higher than that calculated for the Main Stem. During high flow, the TEQ value calculated for the PCBs in samples from the West Branch was 0.09 times lower than that calculated for the Main Stem. (During high flow, the TEQ value calculated for the PCBs in samples from the Main Stem was roughly 11 times higher than that calculated for the West Branch.)

8. In terms of total toxicity, as calculated for the various PCDD/PCDFs and PCBs that have TEF values, at low flow the West Branch had a slightly higher (1.2 times) toxicity than the Main Stem, but during high flow, the West Branch had a much lower (0.16 times) total toxicity than the Main Stem. (During high flow, the Main Stem had a much higher total toxicity than the West Branch by 6.3 times.)

The relative concentrations for PCB homologs in the suspended sediment were generally the same for both tributaries, though a shift toward middle chlorination level homologs distinguished the tributary data from the data collected previously at the head-of-tide site. Generally, PCBs were present in higher concentrations in samples from the West Branch than in samples from the Main Stem during low flow and in higher concentrations in samples from the Main Stem than in samples from the West Branch during high-flow conditions.

9. A few (nine) unique PCB congeners were present only in the samples from the West Branch, although no PCB congener was unique to the Main Stem.

10. PCB 11 was shown to be present in both tributaries during both high-flow and low-flow conditions, though at a much higher concentration in a sample from the West Branch. The concentration of PCB 11 in the West Branch was 16 times higher and 4.55 times higher than the concentration of PCB 11 in the Main Stem during low-flow and high-flow conditions, respectively.

11. The concentrations of total and dissolved cadmium were lower in the West Branch than in the Main Stem during low-flow conditions. No comparisons can be made for samples collected during high flow because a cadmium sample was unattainable from the Main Stem during high flow.

This result is similar to the results found previously with respect to cadmium concentrations in samples collected during low-flow conditions.

12. The loads that were calculated using either the average of the low-flow and high-flow samples or a 25-year flow and sediment-weighted average indicate that the West Branch is the likely major contributor of PCBs, PCDD/PCDFs, toxicity (measured by TEQ), and cadmium to the head-of-tide site downstream on the Elizabeth River.

However, the loads estimated in this study indicate that the sum of the average loads in the Main Stem and West Branch of the Elizabeth River are not enough to account for the total average loads estimated for the head-of-tide site. Although this may indicate the presence of other sources of PCBs and PCDD/PCDFs between the head-of-tide and the point at which the tributaries converge, additional work would be needed to verify this. On the basis of these results (and assumptions made regarding discharge), however, the West Branch is the likely major contributor of PCBs, PCDD/PCDFs, and toxicity (measured by TEQ) to the head-of-tide of the Elizabeth River.

Summary of conclusions presented for the Main Stem and West Branch of the Elizabeth River, New Jersey, 2008.

[POC, particulate organic carbon; SS, suspended sediment; PCB, polychlorinated biphenyl; PCDD/PCDF, polychlorinated dibenzo-p-dioxins and difurans; TEQs, toxic equivalencies; N/A, not available]

Conclusion	Constituent	Relation of West Branch of the Elizabeth River to the Main Stem of the Elizabeth River	
		Low Flow	High Flow
1	Discharge contributed by each branch:	80 to 90 percent of total flow	Greater[1]
2	Suspended-sediment concentration:	Comparable	Approximately 2 times higher
3	POC concentration:	1.3 times higher	1.33 times higher
4	SS-bound PCB concentration:	2.1 times higher	0.18 times lower
5	SS-bound PCDD/PCDF concentration:	2 times higher	0.30 times lower
6	TEQs for PCDD/PCDFs:	0.71 times lower	0.32 times lower
7	TEQs for PCBs:	3.9 times higher	0.09 times lower
8	Total toxicity:	1.2 times higher	0.16 times lower
9	Unique PCB congeners:	9 unique congeners as compared to no unique congeners	9 unique congeners as compared to no unique congeners
10	PCB 11:	16 times higher	4.55 times higher
11	Concentration of total and dissolved cadmium:	Lower	N/A
12	Loads of SS-bound PCBs, PCDD/PCDFs, total TEQs, and cadmium:	Higher	Higher

[1]The exact or estimated percentage of flow contributed by the West Branch of the Elizabeth River as compared to the Main Stem of the Elizabeth River during high flow conditions cannot be quantified as discharge measurements were not made. A visual determination was made and comparisons based thereupon.

As discussed previously, the concentrations of total PCDD/PCDFs in the West Branch are double the concentrations in the Main Stem during low flow; however, the total PCDD/PCDF concentrations are much greater in the Main Stem than in the West Branch during high flow. This finding that the major contributor of PCDD/PCDFs changes depending on the flow condition precludes the use of PCDD/PCDF concentrations in identifying the tributary source to the head-of-tide site. Similarly, the suite of measurable PCDD/PCDFs and their relative concentrations are essentially identical in the two branches and at the head-of-tide, which limits their usefulness for distinguishing the tributaries as sources.

The uncertainty associated with calculations made using these data indicates the need to sample rivers during high-flow conditions, as well as during low-flow conditions. These data also indicate that quantifying the amount of sediment carried in a river system is a crucial part of calculating loads of contaminants. Caution is needed in using these data because a limited number of samples were used to make calculations and form conclusions. Assumptions as to the estimated proportional discharge coming from each branch may cause some of the load calculations to be inaccurate so that further studies to quantify the volumes of water and sediment coming from each branch are warranted. Sampling at different flow conditions would lead to a more representative view of the concentrations of suspended sediment and contaminants along the flow-duration curve. Future studies could include the use of a flow-duration curve and suspended-sediment rating curves for the other rivers to arrive at more accurate loads of sediment and contaminants to Newark Bay that are not skewed by weighting high-flow samples too heavily in load calculations.

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