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Data Compilation for Assessing Sediment and Toxic Chemical Loads from the Green River to the Lower Duwamish Waterway, Washington

Data Series 880

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

Cover: Photograph of U.S. Geological Survey personnel collecting water quality samples from the Duwamish River, Washington, with a D-96 sampler. (Photograph taken by Kathy Conn, U.S. Geological Survey, April 29, 2013.)

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Suggested citation:
Conn, K.E., and Black, R.W., 2014, Data compilation for assessing sediment and toxic chemical loads from the Green River to the lower Duwamish Waterway, Washington: U.S. Geological Survey Data Series 880, 46 p., http://dx.doi.org/10.3133/ds880.

ISSN 2327-638X (online)

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02831	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
micrometer (µm)	0.003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
milliliter (mL)	0.03382	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
	Flow rate	
milliliter per minute (mL/min)	0.0002642	gallon per minute (gpm)
liter per second (L/sec)	0.2642	gallon per minute (gpm)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton	1,000	kilograms

Conversion Factors, Datum, and Abbreviations and Acronyms

Conversion Factors

Mass concentration unit	Equals
gram per kilogram (g/kg)	part per thousand
milligram per kilogram (mg/kg)	part per million (ppm)
microgram per kilogram (µg/kg)	part per billion (ppb, 10^9)
nanogram per kilogram (ng/kg)	part per trillion (ppt, 10^{12})
Liquid concentration unit	**Equals**
gram per liter (g/L)	part per thousand
milligram per liter (mg/L)	part per million (ppm)
nanogram per liter (ng/L)	part per trillion (ppt, 10^{12})
picogram per liter (pg/L)	part per quadrillion (ppt, 10^{15})

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

$$°F=(1.8×°C)+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Turbidity is given in Nephelometric Turbidity Units (NTU).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datum

Gage height is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929).

Abbreviations and Acronyms

ADCP	acoustic Doppler current profiler
ARI	Analytical Resources, Inc.
AXYS	AXYS Analytical Services, Ltd.
BCM	Bed Composition Model
cPAHs	carcinogenic polycyclic aromatic hydrocarbons
CVO	U.S. Geological Survey Cascades Volcano Observatory Sediment Laboratory
DL	detection limit
Ecology	Washington State Department of Ecology
EDI	equal-discharge increment
EMPC	estimated maximum possible concentration
EPA	U.S. Environmental Protection Agency
HPAH	high molecular-weight polycyclic aromatic hydrocarbons

Conversion Factors, Datum, and Abbreviations and Acronyms

Abbreviations and Acronyms

HRMS	high-resolution mass spectrometry
LDW	Lower Duwamish Waterway
LPAH	low molecular-weight polycyclic aromatic hydrocarbons
LRMS	low-resolution mass spectrometry
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PSD	particle-size distribution
PSRM	Puget Sound Reference Material
RKM	river kilometer
RL	reporting limit
SSC	suspended-sediment concentration
STM	Sediment Transport Model
TEQ	toxic equivalent
TOC	total organic carbon
USGS	U.S. Geological Survey
VOCs	volatile organic compounds

Data Compilation for Assessing Sediment and Toxic Chemical Loads from the Green River to the Lower Duwamish Waterway, Washington

By Kathleen E. Conn and Robert W. Black

Abstract

Between February and June 2013, the U.S. Geological Survey collected representative samples of whole water, suspended sediment, and (or) bed sediment from a single strategically located site on the Duwamish River, Washington, during seven periods of different flow conditions. Samples were analyzed by Washington-State-accredited laboratories for a large suite of compounds, including polycyclic aromatic hydrocarbons and other semivolatile compounds, polychlorinated biphenyl Aroclors and the 209 congeners, metals, dioxins/furans, volatile organic compounds, pesticides, butyltins, hexavalent chromium, and total organic carbon. Chemical concentrations associated with bulk bed sediment (<2 mm) and fine bed sediment (<62.5 µm) fractions were compared to chemical concentrations associated with suspended sediment. Bulk bed sediment concentrations generally were lower than fine bed sediment and suspended-sediment concentrations. Concurrent with the chemistry sampling, additional parameters were measured, including instantaneous river discharge, suspended-sediment concentration, sediment particle-size distribution, and general water-quality parameters. From these data, estimates of instantaneous sediment and chemical loads from the Green River to the Lower Duwamish Waterway were calculated.

Introduction

The Lower Duwamish Waterway (LDW) is the final 8-km reach of the Green/Duwamish River as it enters Elliott Bay, Puget Sound in Seattle, Washington (fig. 1) and is the site of intense current and historical anthropogenic influence that has resulted in contaminated sediments. Land uses include numerous residential, industrial, and commercial activities such as airplane parts manufacturing, boat manufacturing, concrete manufacturing, food processing, and marinas. In 2001–02, the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) required remedial investigations and feasibility studies on the 8-km-long, 1.8 km^2 LDW under the Federal Superfund law and Washington's Model Toxics Control Act because of concern about human health risks from exposure to contaminated sediments. The main contaminants of concern for human health include polychlorinated biphenyls (PCBs), dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and arsenic. Additionally, approximately 47 compounds (including individual metals, polycyclic aromatic hydrocarbons [PAHs], phthalates, and other volatile and semivolatile organic compounds) have numeric criteria in Ecology's Sediment Management Standards for protection of the benthic community. Five locations with highly contaminated sediment were identified for early cleanup, and those cleanup activities are completed or near completion (with a target completion date of 2015). The EPA's proposed cleanup plan for the remaining areas was released in early 2013 and includes using combinations of dredging, capping, natural recovery, enhanced natural recovery, and treatment.

To support the implementation of a cleanup plan of contaminated sediments in the LDW, Ecology is leading source control activities to identify sources of sediment recontamination adjacent to and upstream of the LDW. The three major sources of sediment to the LDW were identified as re-suspended bed sediment within the LDW, lateral sources from land adjacent to the LDW, and upstream sources that are transported by the Green River to the Duwamish River/LDW. The river changes names from the Green River to the Duwamish River at the Black River confluence at river kilometer (RKM) 18. The Sediment Transport Model (STM) developed for the LDW predicts that every year more than 185,000 metric tons of sediment enters the LDW, and that greater than 99 percent of that originates from upstream sources, while approximately 0.5 percent originates from lateral sources and 0.2 percent originates from bed sediment within the LDW (Lower Duwamish Waterway Group, 2008). Additionally, the STM predicts that approximately 90 percent of the total bed area in the LDW receives 10 cm of new sediment within 10 years or less. Therefore, the sediment and contaminant transport and loading dynamics from the Green River to the LDW will determine, in large part, the sediment recovery potential of remediated areas in the LDW.

2013 NAIP (National Agricultural Imagery Program) 1 meter imagery,
USDA's Farm Service Agency,
Washington State Plane South, NAD83

Figure 1. Location of U.S. Geological Survey (USGS) sampling station relative to the Lower Duwamish Waterway, Seattle, Washington.

Limited field data are available regarding sediment and contaminant transport and loading dynamics from the Green River to the LDW. The STM estimated suspended- and bed-sediment loading into the LDW from upstream sources using grain size information and a flow-rating curve for the Green River based on discharge data from 1960–80 and 1996–98. That physical model was then coupled with contaminant-concentration data to create a Bed Composition Model (BCM). The discharge data used was from a USGS streamgaging station located in Auburn, Washington, more than 40 RKM upstream of the LDW. It was acknowledged that flows at that station were approximately 10 percent less than actual flows into the LDW because of additional inputs between the station and the LDW. This resulted in estimated sediment loads that may have underestimated actual values by 20–25 percent (Lower Duwamish Waterway Group, 2008). The upstream contaminant data was extrapolated from five historical data sets from King County, Washington, Ecology, and the U.S. Army Corps of Engineers. Only one of those data sets (Gries and Sloan, 2009) measured contaminants in suspended sediment (the other studies measured surface sediment or whole water). However, the sample size of the Gries and Sloan data set was relatively small (n=7), and none of the samples were collected during the rising limb of high flow periods. It is hypothesized that a disproportionately large amount of chemical loading from upstream sources to the LDW may occur during the rising limb of storm periods, especially following a period of dry weather. The upstream data that were used in the BCM primarily originated from surface bed-sediment data, and it was acknowledged that those values were estimates of actual contaminant concentrations because the suspended-sediment fraction was not fully represented. Additionally, suspended-sediment-associated chemical loadings are expected to be affected by a number of factors, including antecedent precipitation, streamflow, seasonality, suspended-sediment concentration, sediment organic carbon content, and particle-size distribution. Better estimates of annual sediment loading and toxic chemical loading from suspended sediment in the Green River to the LDW are needed based on concurrent, representative measurements of streamflow, suspended-sediment concentration, and suspended-sediment chemistry collected over a range of conditions at a location close to the LDW upper boundary. These results will improve our understanding of the potential for recontamination of recently remediated sediment within the LDW.

The Duwamish/Green River basin is nearly flat and its tidal influence extends year-round more than 19 km upstream from the river mouth and during low-flow conditions at least 27 km upstream. The upstream boundary of the LDW, as determined by the Lower Duwamish Superfund Site (Lower Duwamish Waterway Group, 2012), is at RKM 8, therefore, is in estuarine conditions with very strong tidal influences. The sole location of operation for this study was USGS water quality station: Duwamish River at Golf Course at Tukwila, Washington; USGS Site 12113390 (figs. 1 and 2). This sampling area had a private bridge that facilitated access to the river. This sampling station is located at approximately RKM 16.7, which is tidally influenced but non-estuarine. The selection of this sampling station minimized the potential for collection of suspended sediment that could have originated from the LDW and been re-suspended and transported upstream during high tides. Development along the river between the upper boundary of the LDW (RKM 8) and the sampling station (RKM 16.7) includes the golf course, a small commercial complex, and residential properties. The contaminant contributions to the river from this reach, which were not captured in this study, primarily consist of stormwater outfalls.

Purpose and Scope

This report presents data from sampling of whole water, suspended sediment, and bed sediment at a station on the Duwamish River upstream of the LDW between February and June 2013. Whole-water, suspended-sediment, and bed-sediment samples were analyzed for PAHs, PCBs, dioxins/furans, metals, other semivolatile organic compounds, volatile organic compounds (VOCs), pesticides, butyltins, hexavalent chromium, total organic carbon (TOC), and particle-size distribution (PSD, for sediment samples only). Field measurements were made of temperature, pH, specific conductance, dissolved oxygen, and turbidity. The chemical results, coupled with measurements of instantaneous streamflow and suspended-sediment concentration (SSC), provide preliminary estimates of instantaneous sediment and chemical loads associated with upstream sources in the Green River to the LDW.

Methods

Field Sampling and Processing

Between February and June 2013, seven bridge-based sampling periods were conducted over a range of precipitation and flow conditions targeting high flows. Additionally, six boat-based sampling periods were conducted during low-flow conditions. Real-time stage and discharge measurements from upstream USGS gaging stations were used to inform sampling. To minimize tidal backwater effects (that could transport sediment upstream), samples were collected during a 6-hour window surrounding low tide. During each bridge-based sampling period, five tasks occurred to measure instantaneous discharge, general water quality, water chemistry, suspended-sediment physical parameters, and suspended-sediment chemistry. Additionally, bed-sediment chemistry was measured during each boat-based sampling period. A summary of these tasks is contained in table 1.

Figure 2. Selected sampling station, Duwamish River at Golf Course at Tukwila, Washington (12113390), located at river kilometer 16.7.

Table 1. Field tasks, parameters collected, collection methods, references, and laboratories completing each task, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[Task numbers correspond to the task numbers discussed in the text. **Abbreviations:** NTU, Nephelometric Turbidity Unit; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; USGS, U.S. Geological Survey; VOC, volatile organic compound; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µm, micrometer; µS/cm, microsiemens per centimeter at 25 °C; mm, millimeter; –, none]

Task No.	Field tasks	Parameter collected	Collection method	Published collection methods	Laboratory	Notes
1	Instantaneous discharge	River discharge (ft^3/s)	Acoustic Doppler current profiler	Mueller and Wagner (2009)	USGS-Tacoma, Washington	–
2	General water quality (field parameters)	Water temperature (°C), pH, dissolved oxygen (mg/L), specific conductance (µS/cm), turbidity (NTU)	YSI, Inc., multiparameter sonde	U.S. Geological Survey (variously dated)	USGS-Tacoma, Washington	–
3a	Water chemistry	Dioxins/Furans, PAHs, PCB Aroclors, 209 PCB congeners, metals, other semivolatile compounds, pesticides, butyltins, hexavalent chromium, total organic carbon. See appendix A for analyte list.	Depth- and width-integrated sample using Teflon® samplers. Sample transferred to Teflon® churn in on-site mobile laboratory for complete homogenization prior to sample processing.	Wilde and others (2004). Davis and the Federal Interagency Sedimentation Project (2005). U.S. Geological Survey (variously dated). National Field Manual for the Collection of Water-Quality Data. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9.	Analytical Resources, Inc., Tukwila, Washington and AXYS Analytical, Ltd., Sidney, BC, Canada	–
3b	Water chemistry (VOCs)	Volatile organic compounds (µg/L). See appendix A for analyte list.	USGS hand-held VOC sampler designed to minimize chemical loss; sample collected at 60 percent of depth in thalweg.	Shelton (1997)	Analytical Resources, Inc., Tukwila, Washington	–
4	Suspended-sediment physical parameters	Characterization of abundance and size distribution of suspended sediment.	Depth- and width-integrated sample. A stand alone sample collected using USGS suspended-sediment sampling protocol immediately after water chemistry sample.	Edwards and Glysson (1999); Radtke (2005)	USGS Cascades Volcano Observatory Sediment Laboratory (CVO), Vancouver, Washington	These samples did not receive any chemical analyses. Results were used with the suspended-sediment chemistry sampling results (see Task No. 5) to estimate suspended sediment-bound chemicals.

Table 1. Field tasks, parameters collected, collection methods, references, and laboratories completing each task, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

[Task numbers correspond to the task numbers discussed in the text. **Abbreviations:** NTU, Nephelometric Turbidity Unit; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; USGS, U.S. Geological Survey; VOC, volatile organic compound; °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µm, micrometer; µS/cm, microsiemens per centimeter at 25 °C; mm, millimeter; –, none]

Task No.	Field tasks	Parameter collected	Collection method	Published collection methods	Laboratory	Notes
5	Suspended-sediment chemistry	Dioxins/Furans, PAHs, PCB Aroclors, 209 PCB congeners, metals, other semivolatile compounds, volatile organic compounds, pesticides, butyltins, hexavalent chromium, total organic carbon. See appendix analyte list.	Concurrent with water chemistry sampling, 1,000–2,000 liters of sediment-laden water pumped from the thalweg at 60 percent depth through Teflon® tube into Teflon® lined buckets. Suspended sediment collected by flow-through centrifuge for chemical analysis.	Sample collection method developed as part of this project. Sediment handling methods: Shelton and Capel (1994)	Analytical Resources, Inc., Tukwila, Washington and AXYS Analytical, Ltd., Sidney, BC, Canada	An additional 5–10 liters of water was pumped to assess particle size distribution and suspended-sediment concentration. This additional sample was not analyzed for chemistry, but was compared to the results from task 4.
6	Bed-sediment chemistry	Dioxins/Furans, PAHs, PCB Aroclors, 209 PCB congeners, metals, other semivolatile compounds, volatile organic compounds, pesticides, butyltins, hexavalent chromium, total organic carbon, grain size. See appendix for analyte list.	Top 10 cm of sediment collected from up to 10 depositional areas containing fine-grained particles located 1,000 meters up- and downstream of water chemistry sampling. Sediment samples collected and composited with Teflon® and glass sampling equipment. All samples sieved to 2 mm. Metals samples sieved with nylon sieve. Organic samples sieved with stainles steel sieve.	Radtke (2005); Shelton and Capel (1994); Washington State Department of Ecology (2008).	Analytical Resources, Inc., Tukwila, Washington and AXYS Analytical, Ltd., Sidney, BC, Canada	A subset of samples were also sieved to less than 62.5 µm and both size fractions were submitted for chemistry analysis.

- **Task 1** (*instantaneous discharge*): River discharge was measured using an acoustic Doppler current profiler (ADCP) following standard USGS protocols (Mueller and others, 2009).
- **Task 2** (*general water quality*): Water-quality parameters (water temperature, pH, dissolved oxygen, specific conductance, and turbidity) were measured using a multiparameter sonde. During the first two sampling periods, water quality parameters were measured at each of the five cross-section stations (see tasks 3 and 4), and it was found that the cross-section was well-mixed. During the remaining sampling periods, the sonde was co-located with the pump intake (see task 5).
- **Task 3** (*water chemistry*): Based on the discharge measurements, the river cross-section was divided into five equal discharge increments (EDIs) for water chemistry analysis and suspended-sediment physical parameter analysis (see task 4) using standard USGS protocols (U.S. Geological Survey, variously dated). This sampling technique collects a flow-weighted, depth-integrated sample that is representative of the entire river cross-section at that sampling site. Briefly, a sampler is lowered at a consistent transit rate from the surface to the bottom and back to the surface of the water column at each of the five stations. The process was repeated until necessary sample volume was obtained. Water samples were collected from each cross section station in 3-L Teflon® bags using an approved D-96 sampler (Davis and Federal Interagency Sedimentation Project, 2005). The water samples were composited in a 14-L Teflon® churn and immediately processed in an on-site mobile laboratory. In the mobile laboratory, the composited water sample was churned according to USGS protocols (U.S. Geological Survey, variously dated) to ensure sample homogenization prior to bottle filling.
  Volatile organic compounds were collected separately using a USGS designed and tested hand-held sampler to avoid losses resulting from sample pouring, transferring, and churning (Shelton, 1997). The sampler, containing up to four 40 mL glass vials, was lowered to a mid-point in the vertical water column at a single station in the centroid of flow. Water filled the bottle slowly from the bottom to avoid turbulence and head space that could result in analyte losses. All bottled samples were stored on ice and transported within 6 hours to Analytical Resources, Inc. (ARI) in Tukwila, Washington. Samples for high-resolution mass spectrometry (HRMS) analysis were then shipped from ARI to AXYS Analytical Services, Ltd. (AXYS), while the remaining analyses were done by ARI.
- **Task 4** (*suspended-sediment physical parameters*): After completion of the water chemistry sampling, a second cross section of depth- and width-integrated sampling was completed to characterize the abundance and size distribution of suspended sediment using standard USGS protocols (Edwards and Glysson, 1999; Radke, 2005). Using the same EDI sampler as was used in task 3, water was collected in multiple 3-L polyethylene bags. The volume of water collected depended on current sediment conditions and ranged between 5 and 15 L (one to three bags per station). The samples were transported to the USGS Cascades Volcano Observatory (CVO) in Vancouver, Washington for analysis of SSC and PSD.
- **Task 5** (*suspended-sediment chemistry*): Concurrent with tasks 3 and 4, river water was pumped from a point source through Teflon® tubing into sequential buckets lined with Teflon® bags for suspended-sediment chemistry analysis. Various pumps were tested throughout the project, including a peristaltic pump and two types of submersible pumps. The pump intake was located approximately 0.6 times the depth in the thalweg. On sampling days when large floating debris was present, the pump intake was located mid-channel out of the debris path. The volume of water collected depended on the current sediment conditions, and ranged between 1,000 and 2,000 L. During low-flow/low-turbidity sampling periods, when more than 1,000 L of water was needed for sufficient suspended-sediment sample, a second station visit occurred at low tide on the day before or after to collect additional water to composite with the first 1,000 L. The sample-filled Teflon® bags were sealed for transport.
  At the Washington Water Science Center Field Services Unit located in Tacoma, Washington, the water and sediment from the Teflon® bags were pumped into parallel continuous flow-through centrifuges to concentrate the suspended sediment. Water samples were pumped from the bags into the centrifuges using Teflon® tubing, C-FLEX tubing, and a peristaltic pump at a flow rate of 200–300 mL/min to maximize sediment recovery. Pre-centrifuged water in buckets was kept at 4 °C until centrifugation, which typically required 24–48 hours. Concentrated sediment and the overlying water from the centrifuge bowl (approximately 300 mL per bowl) was composited in a glass jar and stored quiescently at 4 °C. After as many as 72 hours of settling, sediment was still suspended in the overlying water. The overlying water was carefully removed by pipette and filtered through pre-weighed 0.3 µm nominal pore size glass fiber filters. Two to six filters were required per sampling period to filter the overlying water. The filters and sediment samples were shipped on ice to ARI.

- **Task 6** (*bed-sediment chemistry*): A bed-sediment sample was collected during six low-flow, low tide conditions when depositional areas were exposed along the river bank. Samples were collected according to modified Ecology and USGS protocols (Shelton and Capel, 1994; Radke, 2005; Washington State Department of Ecology, 2008) for analysis of the same suite of chemical parameters as the suspended-sediment samples (see table 1) and PSD. Briefly, sub-samples (0–10 cm depth) from as much as 10 locations marked by geographic information systems within 1,000 m upstream (during the first two periods) or 1,000 m downstream (during the remaining four periods) of the bridge were composited into a single sample during each period. Locations were selected to focus on areas with a high deposition of fine material. Immediately after sample collection, the composited sample was homogenized using a Teflon® spatula in an on-site mobile laboratory. The sediment was wet sieved with a Teflon® spatula through a 2 mm diameter sieve prior to jar filling. Samples for metals analysis were processed through a plastic sieve, and samples for organic analyses were processed through a stainless steel sieve. During the final three sampling periods, the composited slurry was also wet sieved with a Teflon® spatula through a 62.5 µm diameter sieve and collected into separate jars for analysis to compare chemistry results from the bulk bed sediment (<2 mm) to results from the fine bed sediment (<62.5 µm). Overlying water from the wet sieving procedure (<300 mL) was decanted from the jars and discarded prior to chemical analysis. A summary of sampling dates and completed tasks is given in table 2.

Analytical Methods

Samples of water (task 3), suspended sediment (task 5), and bed sediment (task 6) were analyzed for a suite of chemical and physical parameters using EPA-approved and (or) USGS-approved methods by ARI, AXYS, and CVO. Table 3 lists parameter group, method, and analyzing laboratory. A complete list of analytes for each media is contained in the appendix tables. During low-turbidity sampling periods, even with consecutive days of water collection, there was insufficient suspended-sediment concentrated from the centrifuge to analyze for all parameters. In those cases, only prioritized analyses were conducted for dioxins/furans, PCB congeners, metals, PAHs, and TOC. The 0.3 µm filters from the centrifuge decant water were composited with an aliquot of suspended sediment and extracted together for dioxins/furans and PCB congeners only. The dry weight of the filter was subtracted from the total sample weight to determine a concentration per dry sediment. The remaining chemical analytes were analyzed in a separate sediment sample (with no filter).

Quality Assurance and Quality Control

USGS quality assurance procedures for surface-water measurements and water-quality sampling and analysis were followed (Wagner and others, 2007; U.S. Geological Survey, variously dated). These procedures included proper equipment selection, cleaning procedures, and sampling protocols for low level organic compounds, VOCs, and metals. Sampling equipment for chemical analyses was made of Teflon® that had been pre-cleaned with phosphate-free soap, rinsed three times with tap water, soaked in 5 percent hydrochloric acid, rinsed with deionized water, rinsed with high purity methanol, and air dried. Field sampling techniques included various measures to avoid sample contamination, including the "clean hands, dirty hands" technique and processing of water samples in a clean mobile laboratory. Hydrologists and hydrologic technicians on this project had been trained at the USGS National Training Center in the collection of water-quality samples, including samples for trace organic and low level mercury analyses.

Included in each of the seven sampling periods was a trip blank for VOCs ("trip blank") in which a sample of deionized water filled in a VOC vial at the laboratory conducting the analysis was transported in the cooler to and from the site during field sampling. Other quality control samples for chemistry analysis, listed by date in table 2, included:

- One field equipment blank sample of water ("field blank"), in which organic-free blank water was transported in its original container in the mobile laboratory to the field site where it was poured into the pre-cleaned Teflon® churn, churned, and filled into sample bottles in the mobile laboratory.

- One field replicate of water ("field replicate"), in which a second sample was collected at each EDI station immediately following the first sample and composited in a second pre-cleaned Teflon® churn.

- One centrifuge equipment blank sample of suspended sediment ("equipment blank"), in which an environmental sediment sample that had been burned in a muffle furnace at 450 °C for 6 hours, was mixed with organic-free blank water to form a slurry. The slurry was pumped and processed through all of the field and lab equipment for suspended-sediment sampling (that is, Teledyne Isco pump, Teflon® tubing, Teflon® bag, Teflon® tubing, centrifuge bowl, and glass jar).

- One centrifuge source sediment sample ("source blank"), in which the environmental sediment sample that had been burned in a muffle furnace at 450 °C for 6 hours, was directly placed into a sample jar for analysis.

- One field split of bed sediment ("field split"), in which the sieved, homogenized material was split into two sample jars for analysis.

Table 2. Field tasks and sampling dates at Duwamish River at Golf Course at Tukwila, Washington, 2013.

[A trip blank for volatile organic compounds was included with each water chemistry sample. **Abbreviations:** X, task was completed on that date; –, task not completed on that date; TOC, total organic carbon; PSRM, Puget Sound Reference Material; <, less than; mm, millimeter; µm, micrometer]

Task No.	Field tasks	Sampling date						
		02-07-2013	03-13-2013	04-05-2013	04-08-2013	04-29-2013	05-13-2013	06-19-2013
1	Instantaneous discharge	X	X	X	X	X	X	X
2	General water quality (field parameters)	X	X	X	X	X	X	–
3a	Water chemistry	X	X	X	X	X (plus field replicate)	X, metals, TOC only (plus field blank)	X, metals, TOC only
3b	Water chemistry (volatile organic compounds)	X	X	X	X	X (plus field replicate)	X (field blank only)	–
4	Suspended-sediment physical parameters	X	X	X	X	–	X	X
5	Suspended-sediment chemistry	X	X, composited with 03-14-13	X, composited with 04-04-13 (plus equipment blank and source blank)	X, composited with 04-07-13	–	X	–

Task No.	Field tasks	Sampling date					
		02-26-2013	03-29-2013	04-26-2013	05-09-2013	05-31-2013	06-21-2013
6	Bed-sediment chemistry	X	X	X (plus field split and PSRM)	X (plus <62.5 µm sample)	X (plus <62.5 µm sample)	X (plus <62.5 µm sample)

- One Puget Sound Reference Material (PSRM), which is a regionally-relevant sediment standard reference material for dioxins/furans, PCB congeners, and PCB Aroclors, was analyzed for dioxins/furans, PCB congeners, PCB Aroclors and total organic carbon by the corresponding laboratories. Laboratory results were compared to the average concentration of the standard as determined during previous round robin laboratory testing.

Both analytical laboratories conducted laboratory blank, replicate, and matrix spike analyses according to their quality-assurance and quality-control plan (that is, with every batch of approximately 20 samples). If values exceeded control limits then corrective actions were taken such as re-runs and re-extractions. Additional details regarding the field and laboratory methods are available in Black and Conn (2013).

Table 3. Analytical parameter groups, methods, and analyzing laboratory for samples collected at Duwamish River at Golf Course, at Tukwila, Washington, 2013.

[**Abbreviations:** ARI, Analytical Resources, Inc., Tukwila, Wash.; AXYS, AXYS Analytical, Ltd., Sidney, British Columbia, Canada; CVO, U.S. Geological Survey Cascades Volcano Observatory; EPA, U.S. Environmental Protection Agency; PSEP, Puget Sound Estuary Program; SIM, selected ion monitoring; SM, standard methods]

Analytical parameter	EPA method / reference	Analyzing laboratory
Volatile organic compounds	EPA 8260A	ARI
Semivolatile compounds	EPA 8270D	ARI
Low-level polycyclic aromatic hydrocarbons	EPA 8270D SIM	ARI
Polychlorinated biphenyl Aroclors	EPA 8082A	ARI
209 polychlorinated biphenyl congeners	EPA 1668A	AXYS
Pesticides	EPA 8081B	ARI
Dioxins/furans	EPA 1613B	AXYS
Trace elements	EPA 200.8	ARI
Low-level mercury	EPA 7470A	ARI
Butyltins	Krone and others (1989)	ARI
Hexavalent chromium	EPA 7196 (SM 3500 CrD)	ARI
Total organic carbon	EPA 415.1 / Plumb (1981)	ARI
Total solids	SM 2540B	ARI
Suspended-sediment concentration	Guy (1977)	CVO
Particle-size distribution (suspended-sediment)	Guy (1977)	CVO
Particle-size distribution (bed-sediment)	Puget Sound Estuary Program (1986)	ARI

Data Reporting

Field notes and field parameters measured during each sampling period were reviewed by USGS project managers. An EPA Level 4 data package was produced by the two analytical laboratories for every sample analyzed in this project. Each package included detailed information regarding package completeness, instrument calibration and performance, and instrument output (that is, chromatograms) for confirmation of detections and non-detections. A narrative was provided with each package, documenting any deviations from protocol or problems encountered during analysis. All data packages were reviewed by the project manager at a level comparable to an EPA Level 2 validation, including assessment of precision (replicate analyses), accuracy (compound recovery), and blank contamination. The Level 2 validation identified some minor discrepancies, such as missed flags, which were reported to the laboratory and corrected in a revised data package. A representative subsample of data packages were reviewed by USGS analytical chemists with current organic and inorganic instrument expertise at a level comparable to an EPA Level 4 validation. This included recalculation of results from instrument responses to confirm the correct identification and quantitation of analytes, tentatively-identified compounds, and non-detected compounds. The Level 4 validation identified no major miscalculations by either lab. The Level 2 and Level 4 reviews identified a need to further censor the result qualifiers, which is described in detail in appendix A.

Numerous nearly synonymous terms are used by the laboratories for reporting analytical data based on criteria defined by the EPA or accreditation agencies. For simplicity, detection limit (DL) and reporting limit (RL) are the only two terms used in this report. The DL is defined as the lowest result that can be reliably distinguished from a blank based on historical method blank detections with a false positive rate of less than or equal to 1 percent. For compounds determined by HRMS, including the dioxins/furans and PCB congeners, the DL is defined as the concentration equivalent to three times the estimated chromatographic noise height, determined individually for every sample analysis run. The RL is defined as the lowest concentration that can be reliably achieved within specific limits of precision and accuracy during routine operating conditions. For HRMS compounds, the RL is determined by prorating the concentration of the lowest calibration limit for sample size and extract volume by using:

([lowest level calibration standard] × [extract volume])/ sample size.

Differences between various laboratory and agency protocols for coding analytical data to address measurement considerations and (or) abnormalities are common.

Adjustments to the laboratory-provided qualifiers from laboratories used in this study were made to be consistent with Ecology's Toxics Cleanup Program data reporting protocols (Washington State Department of Ecology, 2008) as outlined in the EPA Functional Guidelines (U.S. Environmental Protection Agency, 2008, 2009, 2010, 2011). Data that had been flagged or qualified by the laboratory or during the Level 2 or Level 4 review process with qualifiers other than U- and J-containing qualifiers were amended following the protocols described in appendix A.

The complete analytical results are stored in Ecology's publicly-available Environmental Information Management database, including two qualifier columns containing the original lab qualifiers and the USGS-amended qualifiers. The complete analytical results for all individual compounds with USGS-amended qualifiers are presented in the appendix tables. In the "Quality-Assurance Data" and various "Chemistry Data" sections, only detected compounds (after qualifier amendments) are presented, which includes estimated (J-qualified) data. Only results from the more sensitive of the two methods for PAHs are presented. The Aroclor results from both analyzing laboratories are presented for comparison. J-qualified data is included in the summed or calculated values. The following summed and calculated values are presented in the results.

Dioxins/Furans

- Summed homologues (that is, total tetra-dioxins).
- Total dioxins/furans as a summed concentration of the 17 congeners.
- Total dioxins/furans as a Toxic Equivalent (TEQ) according to the World Health Organization 2005 guidelines (Van den Berg and others, 2006). If a congener was not detected above the detection level, a value of one half of the detection level was used in the calculations.

Polycyclic Aromatic Hydrocarbons

- Total cPAHs as a summed concentration of benzo(a) anthracene, chrysene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenz(a,h)anthracene, and total benzofluoranthenes (sum of b-, j-, and k- isomers).
- Total cPAHs as a TEQ according to the potency equivalency factors adopted by the California Environmental Protection Agency (California Environmental Protection Agency, 2005). If a compound was not detected above the detection level, a value of one half of the detection level was used in the calculations.
- Total high molecular weight PAHs (HPAH) as a summed concentration of fluoranthene, pyrene, benz[a] anthracene, chrysene, benzofluoranthene, benzo[b] fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, dibenzo[a,h]anthracene, and benzo[g,h,i]perylene.
- Total low molecular weight PAHs (LPAH) as a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

Polychlorinated Biphenyls

- Summed homologues (that is, total monochloro biphenyls).
- Total PCBs as a sum of the 209 congeners.
- Aroclors. Polychlorinated biphenyl results for all environmental and quality assurance samples are reported as a combination of three Aroclors: 1242, 1254, and 1260. The Aroclor concentrations were calculated according to the following equations, in which concentrations of specific congeners are summed and multiplied by a quantification factor:
  - Aroclor 1242= (8, 18/30, 20/28, 31) × 3.0
  - Aroclor 1254= (83/99, 86/87/97/108/119/125) × 8.0
  - Aroclor 1260= (170, 180/193, 183/185) × 5.0
- Analytical Resources, Inc. also presented PCB detections using EPA Method SW8082 as Aroclors 1242, 1254, and 1260. Though this method is less sensitive than the method used by AXYS for PCB congeners, the detections are presented for inter-lab Aroclor comparison. Analytical Resources, Inc. did not report total PCBs.

Other than the TEQ calculations (in which a value of one-half of the detection level was used for undetected compounds), only detected concentrations (including J-qualified detections) were included in summed values. If all compounds in a summed calculation were undetected, the total value is represented by the single highest detection level (with a U or UJ qualifier). All sediment concentrations were reported by the laboratories as a dry weight concentration. Organic carbon-normalized concentrations were calculated by dividing the dry weight concentration by the fraction of TOC in the sample.

Instantaneous chemical loads were estimated using a method based on whole water chemical concentrations and a method based on suspended-sediment chemical concentrations. Instantaneous whole-water chemical loads in grams per hour were calculated using the following equation:

$$\text{Water Chemical Load (g/hr)} = C_W \text{ (g/L)} \times Q \text{ (L/hr)} \qquad (1)$$

where

C_W is chemical concentration in whole water in grams per liter;

Q is instantaneous river discharge in liters per hour;

Instantaneous suspended-sediment chemical loads (g/hr) were calculated using the following equation:

$$\text{Sediment Chemical Load (g/hr)} = C_S \text{ (g/kg} \times \text{kg/}10^6 \text{ mg)} \times Q \text{ (L/hr)} \times SSC \text{ (mg/L)} \qquad (2)$$

where

C_S is chemical concentration in suspended sediment in gram per kilogram;

Q is instantaneous river discharge in liters per hour; and

SSC is suspended sediment concentration in milligrams per liter.

Non-detects were assigned a zero value for instantaneous loading calculations.

Hydrology and Field Parameter Data

The seven bridge-based sampling periods for water and (or) suspended sediment occurred over a range of precipitation and streamflow conditions (table 4). The sampling dates are overlayed on the stream gage-height record from the closest continuous streamgage (USGS 12113350 Green River at Tukwila, WA, fig. 3), which is located 3.2 RKM upstream of the sampling bridge (fig. 2). Although sampling periods targeted periods of predicted rainfall, actual rainfall often was less than predicted. Of the seven periods, five were during periods defined in this study as “low precipitation” (72-hour antecedent rainfall ≤0.4 in.). The other two samples were collected during the rising limb (April 5, 2013) and the peak flow (April 8, 2013) of a storm that set a single-day precipitation record of 1.54 in. at nearby Seattle-Tacoma International Airport. In this report, 72-hour antecedent rainfall is defined as the sum of the provisional daily total for the sampling date and 2 previous days from the USGS 12113000 precipitation station, located upstream in the watershed.

Stream gage height at USGS 12113350 at the time of sampling (always during low-tide) ranged from 3.77 to 12.64 ft. Measured instantaneous discharge at the sampling site during the time of sample collection ranged from 816 to 4,955 ft^3/s. River water temperature increased steadily during the study from 6.29 °C in February to 11.17 °C in May, with the exception of the storm-peak water temperature, which dipped more than a degree cooler than 2 days prior (table 4). Specific conductance ranged from 55 µS/cm at 25 °C (µS/cm) during the storm peak to 96 µS/cm during a low-precipitation period. Turbidity ranged from 2.7 Nephelometric Turbidity Units (NTU) during a low-precipitation period to an average of 20 NTU during the storm-peak sampling (with high sediment pulses exceeding 80 NTU). Suspended-sediment concentration (SSC), measured using representative discharge-weighted, depth integrated methods, ranged from 6 mg/L during a low-precipitation period to 81 mg/L during the storm peak (table 4). The percentage of fines in the suspended sediment ranged from 44 percent during the storm peak to 84 percent during a low-precipitation period (table 4). There was sufficient suspended sediment only during the storm peak to analyze a full particle-size distribution (see results in section, “Comparison of Suspended-Sediment and Bed-Sediment Data”).

All six boat-based bed-sediment sampling periods (fig. 3) occurred when the 72-hour antecedent rainfall was less than 0.2 in. The stream gage height at USGS 12113350 (3.2 RKM upstream of the sampling bridge) at the time of sample collection ranged from 3.91 to 8.46 ft.

Table 4. General hydrology, water quality, and field conditions during bridge-based sampling at Duwamish River at Golf Course at Tukwila, Washington, 2013.

[72-hour antecedent precipitation is the sum of the provisional daily total for the sampling date and two previous days from the U.S. Geological Survey (USGS) 12113000 precipitation station. **Abbreviations:** ft, feet; ft^3/s, cubic feet per second; mg/L, milligrams per liter; NTU, Nephelometric Turbidity Unit; °C, degrees Celsius; µm, micrometers; µS/cm, microsiemens per centimeter; <. less than; na, not applicable; –, not analyzed]

Parameter name	Unit	Sampling date					
		02-07-2013	03-13-2013	03-14-2013	04-02-2013	04-03-2013	04-04-2013
72-hour antecedent precipitation	inch	0.21	0.22	0.24	0.00	0.00	0.13
Stream gage height at USGS 12113350 (provisional)	ft	7.87	5.21	6.60	7.34	7.67	7.81
Instantaneous discharge	ft^3/s	2,460	1,480	1,980	–	–	–
Water temperature	°C	6.29	7.93	7.74	8.35	8.32	–
pH	na	7.23	7.04	7.20	7.29	7.19	–
Specific conductance	µS/cm	70	96	71	60	59	–
Turbidity	NTU	5.1	2.7	5.0	4.8	4.7	–
Dissolved oxygen	mg/L	11.74	11.12	11.51	11.54	11.62	–
Suspended-sediment concentration	mg/L	12	7	–	–	–	–
Suspended-sediment percent fines (<62.5 µm)	percent	61	80	–	–	–	–
Sonde location (for general water quality parameters)	NA	Thalweg, water surface	Thalweg, water surface	Thalweg, water surface	Thalweg, water surface	Thalweg, water surface	–
Pump intake location (for sediment chemistry)	NA	Thalweg, 4 ft from bottom	Thalweg, 4 ft from bottom	Thalweg, 5 ft from bottom	–	–	Thalweg, 5.5 ft from bottom

Parameter name	Unit	Sampling date					
		04-05-2013	04-07-2013	04-08-2013	04-29-2013	05-13-2013	06-19-2013
72-hour antecedent precipitation	inch	0.90	2.0	1.3	0.09	0.40	0.04
Stream gage height at USGS 12113350 (provisional)	ft	8.14	11.86	12.64	7.92	8.50	3.77
Instantaneous discharge	ft^3/s	2,490	–	4,955	2,620	2,750	816
Water temperature	°C	9.01	7.89	7.68	9.18	11.17	–
pH	na	7.15	7.13	7.09	6.96	–	–
Specific conductance	µS/cm	61	55	58	66	65	–
Turbidity	NTU	5.8	15	20	4.3	4.6 (8.5 post-rain)	–
Dissolved oxygen	mg/L	11.03	11.30	11.45	12.34	10.90	–
Suspended-sediment concentration	mg/L	17	–	81	–	31	6
Suspended-sediment percent fines (<62.5 µm)	percent	61	–	44	–	61	84
Sonde location (for general water quality parameters)	na	Thalweg, at pump intake	Mid-channel, at pump intake	Mid-channel, at pump intake	Thalweg, 6 ft from bottom	Mid-channel, at pump intake	–
Pump intake location (for sediment chemistry)	na	Thalweg, 6 ft from bottom	Mid-channel, 6 ft from bottom	Mid-channel, 6 ft from bottom	–	Mid-channel, 6 ft from bottom	Thalweg, 2 ft from bottom

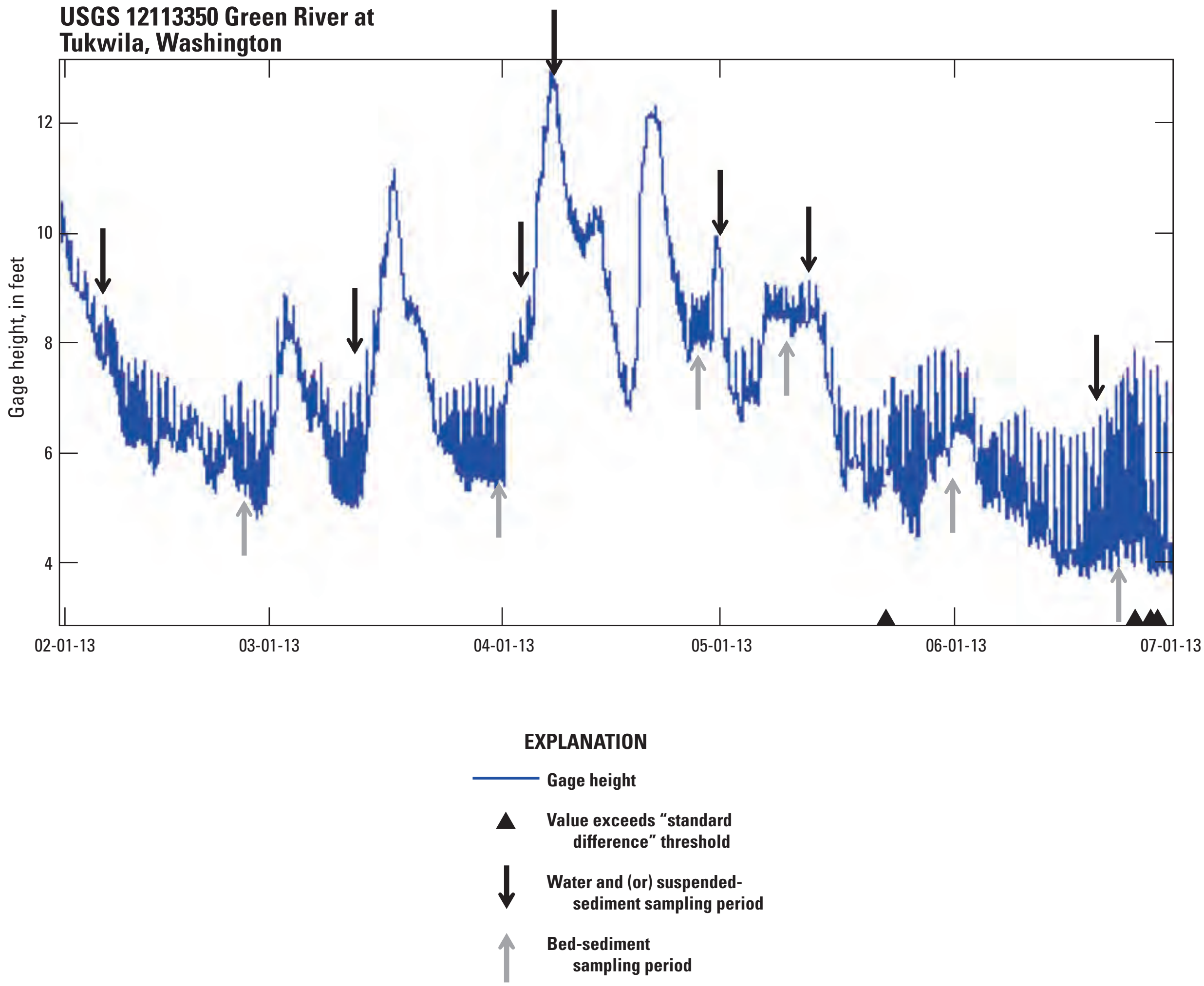

Figure 3. Gage height and suspended- (bridge based) and bed- (boat based) sediment collected at U.S. Geological Survey streamgage 12113350, Green River at Tukwila, Washington, February–July 2013. Sampling site is 3.2 river kilometers upstream of bridge.

Quality-Assurance Data

There were no detections of VOCs in the five trip blank water samples (see table A2). In the singe field equipment blank water sample, there were no detections of VOCs, metals, PAHs, or other semivolatile organic compounds, pesticides, butylins, hexavalent chromium, or TOCs (see table A2). Dioxins/furans and PCB congeners (table 5) were detected at low levels in the single water field blank sample (total dioxins/furans=1.05 picograms, expressed as a toxic equivalent, per liter [pg TEQ/L], J-qualified; total PCBs=160 pg/L, J-qualified). These concentrations were estimated (J-qualified) because they were less than the RL but greater than the DL. These concentrations were similar to the highest environmental sample concentrations, which were also low and estimated (total dioxins/furans=0.851 pg TEQ/L, J-qualified; total PCBs=184 pg/L, J-qualified; see section, "Water Chemistry Data"). These low estimated concentrations in the environmental samples and field blank sample were more than 10 times higher than the concentrations measured in the associated laboratory blank samples (based on comparison of individual congeners) and met all laboratory quality-assurance and quality-control criteria for quantified data (that is, retention times, ion ratios). Therefore, the results were not rejected during data review. Instead, this indicates a need for additional field blank sampling, including paired trip blanks and equipment blanks using blank water that has met quality assurance and quality control standards by the analyzing laboratory. The low concentrations in environmental water samples are reported with an appropriate footnote (see section "Water Chemistry Data").

Table 5. Quality assurance results for whole water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated. **Abbreviations:** HRMS, high-resolution mass spectrometry; LRMS, low-resolution mass spectrometry; mg/L, milligram per liter; pg/L, picogram per liter; pg TEQ/L, picograms toxic equivalent per liter; µg/L, microgram per liter; na, not applicable; –, no analysis done. See appendix for complete analyte results]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type						
			Field blank (05-13-2013)		Environmental sample (04-29-2013)		Field replicate (04-29-2013)		Relative percent difference between 04-29-2013 replicates
			Result	Q	Result	Q	Result	Q	
Total organic carbon	na	mg/L	1.5	U	2.59		1.73		40
Metals									
Arsenic	7440-38-2	mg/L	0.2	U	0.6		0.6		0
Barium	7440-39-3	mg/L	0.5	U	3.8		3.8		0
Copper	7440-50-8	mg/L	0.5	U	0.5	U	1		–
Lead	7439-92-1	mg/L	0.1	U	0.2		0.2		0
Nickel	7440-02-0	mg/L	0.5	U	0.5	U	0.6		–
Vanadium	7440-62-2	mg/L	0.2	U	1.3		1.4		-7
Dioxins and furans									
Total hexa-dioxins	34465-46-8	pg/L	2.00	J	0.512	UJ	0.496	UJ	–
Total hepta-dioxins	37871-00-4	pg/L	1.51	J	1.30	J	0.951	J	31
Total octa-dioxins	3268-87-9	pg/L	4.08	UJ	11.9	J	9.19	J	26
Total hexa-furans	55684-94-1	pg/L	0.655	J	0.512	UJ	0.496	UJ	–
Total hepta-furans	38998-75-3	pg/L	0.993	J	0.518	J	0.496	UJ	–
Total octa-furans	39001-02-0	pg/L	2.24	J	0.685	UJ	0.597	UJ	–
Total dioxins/furans	na	pg/L	7.40	J	13.7	J	10.1	J	30
Total dioxins/furans	na	pg TEQ/L	1.05	J	0.826	J	0.794	J	4
Polychlorinated biphenyl homologue (by high-resolution mass spectrometry [HRMS])									
Total monochloro biphenyls	27323-18-8	pg/L	6.36		7.81	J	7.49	J	4
Total dichloro biphenyls	25512-42-9	pg/L	6.07		16.1		13.9	J	15
Total trichloro biphenyls	25323-68-6	pg/L	48.8	J	17.0	J	10.7	J	46
Total tetrachloro biphenyls	26914-33-0	pg/L	66.1	J	10.6	J	14.0	J	-27
Total pentachloro biphenyls	25429-29-2	pg/L	25.1	J	17.8	J	28.2	J	-45
Total hexachloro biphenyls	26601-64-9	pg/L	7.87	J	9.99	J	13.8	J	-32
Total heptachloro biphenyls	28655-71-2	pg/L	1.90	UJ	0.851	J	1.22	J	-36
Total octachloro biphenyls	55722-26-4	pg/L	2.29	UJ	1.75	UJ	1.44	UJ	–
Total nonachloro biphenyls	53742-07-7	pg/L	2.59	UJ	2.30	UJ	1.95	UJ	–
Total decachloro biphenyls	2051-24-3	pg/L	1.85	UJ	1.55	UJ	1.13	UJ	–
Total polychlorinated biphenyl Aroclors (by HRMS)	1336-36-3	pg/L	160	J	80.1	J	89.2	J	-11
Polychlorinated biphenyl Aroclors (by by high-resolution mass spectrometry [HRMS])									
Aroclor 1242	53469-21-9	pg/L	82.9		16.6		15.7		5
Aroclor 1254	11097-69-1	pg/L	55.2		6.70	UJ	16.0	UJ	–
Aroclor 1260	11096-82-5	pg/L	1.90	UJ	1.45	UJ	2.74	UJ	–
Polychlorinated biphenyl Aroclors (by low-resolution mass spectrometry [LRMS])									
Aroclor 1242	53469-21-9	µg/L	0.01	U	0.01	U	0.01	U	–
Aroclor 1254	11097-69-1	µg/L	0.01	U	0.01	U	0.01	U	–
Aroclor 1260	11096-82-5	µg/L	0.01	U	0.01	U	0.01	U	–

The absolute relative percent difference between analyte concentrations in sequential field replicates of water samples collected on April 29, 2013 ranged from 0 to 46 percent (table 5).

The source blank used to conduct the suspended-sediment equipment blank (see section, "Quality Assurance and Quality Control" in the section "Methods" section) contained metals, TOC, hexavalent chromium, and low levels of dioxins/furans and PCBs (table 6). The percent increase in concentration from the source blank to the equipment blank (that is, the source blank after it had been processed through the field and laboratory equipment) was 16 percent or less for the metals. The percent TOC in the equipment blank was 0.279 percent as compared to 0.037 percent in the source blank. Hexavalent chromium was 1.18 mg/kg in the equipment blank as compared to 0.675 mg/kg in the source blank. Dioxins/furans and PCBs were undetected in the source blank and detected at very low concentration in the equipment blank (dioxins/furans=0.0281 ng TEQ/kg, J-qualified; total PCBs=17.0 ng/kg, J-qualified).

Bis(2-ethylhexyl)phthalate and PAHs were detected in the equipment blank, but not in the source blank, and appear to have been introduced during sample processing. Bis(2-ethylhexyl)phthalate was present at 36 µg/kg in the equipment blank as compared to less than 24 µg/kg in the source blank. PAHs were detected in the equipment blank from 0.73 µg/kg (benzo(g,h,i)perylene) to 3.07 µg/kg (pyrene). Total cPAHs in the equipment blank (0.13 µg TEQ/kg) were nearly 400 times smaller than the average cPAH concentrations in the environmental suspended-sediment samples (51.3 µg TEQ/kg). Overall, suspended-sediment equipment blank detections were at least 10 times to greater than 1,000 times less than average environmental concentrations (table 6). Therefore, the suspended-sediment sample collection and laboratory processing protocol was deemed appropriate for this project, and no suspended-sediment environmental data was qualified.

The relative percent difference between the parameter concentration in bed-sediment field split samples (table 7) was less than 35 percent, with the following exceptions: naphthalene (80 percent), 2-methylnaphthalene (62.5 percent), and 1-methylnaphthalene (50 percent). Although some homologue totals of dioxins/furans varied between the split samples, the total dioxins/furans (ng TEQ/kg) difference was 6 percent. Total PCBs varied by 57 percent, and PCB Aroclor 1260 varied by 98 percent, owing to large differences between samples in the hexa- through nona-homologues.

Acceptance criteria selected for the PSRM material followed that of the U.S. Army Corps of Engineers (http://www.nws.usace.army.mil/Missions/CivilWorks/Dredging/SRM.aspx), and was ±50 percent for individual dioxins/furans and PCB congeners and within the 95 percent confidence interval for PCB Aroclor 1260. The laboratory results for the PSRM for this project were within the acceptance criteria for all compounds, with the exception of 1,2,3,7,8,9-HXCDF and 2,3,4,6,7,8-HXCDF (table 8).

Other than the low-level dioxins/furans and PCB congener detections in the water field blank sample, which resulted in the qualified environmental water data below, the results from the field quality-assurance samples were deemed satisfactory and no additional qualifiers were applied to the environmental data.

Table 6. Quality assurance results for suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[See Quality Assurance and Quality Control section for complete description of "source blank" and "equipment blank". See appendix for complete analyte results. **Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); na, not applicable; U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; R, result rejected. **Average concentration of environmental suspended-sediment samples**: See table 9. **Abbreviations:** HPAH, high molecular-weight polycyclic aromatic hydrocarbons; LPAH, low molecular-weight polycyclic aromatic hydrocarbons; TEQ, toxic equivalent; mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; ng/kg, nanogram per kilogram; –, not analyzed]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type						
			Suspended sediment				Percent increase from "source blank" to "equipment blank"	Average concentration of environmental suspended-sediment samples	Ratio between average environmental concentration and "equipment blank"
			"source blank"		"equipment blank"				
			Result	Q	Result	Q		Result	
Total organic carbon	na	percent	0.037		0.279		654	4.77	17.1
Metals									
Arsenic	7440-38-2	mg/kg	1.3		1.4		8	–	–
Barium	7440-39-3	mg/kg	22.3		24.4		9	–	–
Chromium	7440-47-3	mg/kg	6.3		7.3		16	–	–
Copper	7440-50-8	mg/kg	11.3		12.4		10	–	–
Lead	7439-92-1	mg/kg	1.56		1.6		3	–	–
Nickel	7440-02-0	mg/kg	6.4		6.8		6	–	–
Vanadium	7440-62-2	mg/kg	20.4		23.2		14	–	–
Zinc	7440-66-6	mg/kg	16		17		6	–	–
Miscellaneous									
Chromium, hexavalent	18540-29-9	mg/kg	0.675		1.18		75	–	–
bis(2–ethylhexyl)phthalate	117-81-7	µg/kg	24	U	36		–	–	–
Polycyclic aromatic hydrocarbons									
Naphthalene	91-20-3	µg/kg	0.73	U	1.47		–	18.4	12.5
2–methylnaphthalene	91-57-6	µg/kg	0.5	U	0.83		–	36.8	44.3
Phenanthrene	85-01-8	µg/kg	0.5	U	2.98		–	60.6	20.3
Fluoranthene	206-44-0	µg/kg	0.5	U	2.93		–	75.0	25.6
Pyrene	129-00-0	µg/kg	0.5	U	3.07		–	77.1	25.1
Chrysene	218-01-9	µg/kg	0.5	U	1.01		–	57.6	57.0
Benzo(g,h,i)perylene	191-24-2	µg/kg	0.5	U	0.73		–	49.7	68.0
Total benzofluoranthenes	na	µg/kg	1	U	1.24		–	87.8	70.8
LPAH	na	µg/kg	0.73	U	4.45		–	97.8	22.0
HPAH	na	µg/kg	1	U	8.98		–	451	50.2
Total cPAHs	na	µg/kg	1	U	2.25		–	249	111
Total cPAHs (TEQ)	na	µg TEQ/kg	0.25	U	0.13		–	51.3	395
Dioxins/furans									
Total tetra-dioxins	41903-57-5	ng/kg	0.051	UJ	0.0151	UJ	–	0.275	–
Total penta-dioxins	36088-22-9	ng/kg	0.051	UJ	0.0151	UJ	–	0.583	–

Table 6. Quality assurance results for suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type: Suspended sediment: "source blank" Result	"source blank" Q	"equipment blank" Result	"equipment blank" Q	Percent increase from "source blank" to "equipment blank"	Average concentration of environmental suspended-sediment samples Result	Ratio between average environmental concentration and "equipment blank"
Dioxins/furans—Continued									
Total hexa-dioxins	34465-46-8	ng/kg	0.051	UJ	0.0151	UJ	–	7.63	–
Total hepta-dioxins	37871-00-4	ng/kg	0.051	UJ	0.057	J	–	64.5	1,131
Total octa-dioxins	3268-87-9	ng/kg	0.134	UJ	0.456	J	–	449	984
Total tetra-furans	55722-27-5	ng/kg	0.051	UJ	0.039	J	–	0.657	17
Total penta-furans	30402-15-4	ng/kg	0.051	UJ	0.0151	UJ	–	0.473	–
Total hexa-furans	55684-94-1	ng/kg	0.051	UJ	0.0151	UJ	–	2.19	–
Total hepta-furans	38998-75-3	ng/kg	0.051	UJ	0.021	UJ	–	15.3	–
Total octa-furans	39001-02-0	ng/kg	0.051	UJ	0.074	J	–	40.8	551
Total dioxins/furans	na	ng/kg	0.134	UJ	0.626	J	–	580	927
Total dioxins/furans	na	ng TEQ/kg	0.0806	UJ	0.0281	J	–	2.83	101
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])									
Total monochloro biphenyls	27323-18-8	ng/kg	0.051	R	0.393	J	–	10.0	25
Total dichloro biphenyls	25512-42-9	ng/kg	93.3	UJ	7.931		–	156	20
Total trichloro biphenyls	25323-68-6	ng/kg	1.74	UJ	2.44		–	294	120
Total tetrachloro biphenyls	26914-33-0	ng/kg	2.05	UJ	2.52	J	–	551	219
Total pentachloro biphenyls	25429-29-2	ng/kg	2.04	UJ	1.624	J	–	1,111	684
Total hexachloro biphenyls	26601-64-9	ng/kg	2.17	UJ	1.603		–	1,064	664
Total heptachloro biphenyls	28655-71-2	ng/kg	0.127	UJ	0.367	J	–	514	1,399
Total octachloro biphenyls	55722-26-4	ng/kg	0.159	UJ	0.04	J	–	199	4,964
Total nonachloro biphenyls	53742-07-7	ng/kg	0.233	UJ	0.049	UJ	–	60.2	–
Total decachloro biphenyls	2051-24-3	ng/kg	0.149	UJ	0.049	J	–	21.4	436
Total PCBs (by HRMS)	1336-36-3	ng/kg	93.3	UJ	17.0	J	–	3,980	235
Polychlorinated biphenyl (PCB) Aroclors (by high-resolution mass spectrometry [HRMS])									
Aroclor 1242	53469-21-9	ng/kg	2.4	UJ	15.0		–	507	34
Aroclor 1254	11097-69-1	ng/kg	1.84	UJ	6.50		–	1,680	259
Aroclor 1260	11096-82-5	ng/kg	0.127	UJ	0.995	J	–	1,138	1,144
Polychlorinated biphenyl (PCB) Aroclors (by low-resolution mass spectrometry [LRMS])									
Aroclor 1242	53469-21-9	µg/kg	3.8	U	3.9	U	–	–	–
Aroclor 1254	11097-69-1	µg/kg	3.8	U	3.9	U	–	–	–
Aroclor 1260	11096-82-5	µg/kg	3.8	U	3.9	U	–	–	–

Table 7. Quality assurance results for bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated. **Abbreviations:** cPAH, carcinogenic polycyclic aromatic hydrocarbon; HPAH, high molecular-weight polycyclic aromatic hydrocarbons; LPAH, low molecular-weight polycyclic aromatic hydrocarbons; mg/kg, milligram per kilogram; na, not applicable; ng/kg, nanogram per kilogram; TEQ, toxic equivalent; µg/kg, microgram per kilogram; –, no analysis done. See appendix for complete analyte results]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type				
			Field split (04-26-2013)		Environmental sample (04-26-2013)		Relative percent difference between 04-26-2013 splits
			Result	Q	Result	Q	
Total organic carbon	na	percent	1.49		1.41		-6
Grain size distribution							
Particle/grain size, Phi scale <-1	na	percent	0.1	U	0.1	U	–
Particle/grain size, Phi scale -1 to 0	na	percent	0.1		0.1		0
Particle/grain size, Phi scale 0 to 1	na	percent	0.8		0.7		-13
Particle/grain size, Phi scale 1 to 2	na	percent	9.4		9.3		-1
Particle/grain size, Phi scale 2 to 3	na	percent	43.6		42.4		-3
Particle/grain size, Phi scale 3 to 4	na	percent	28.7		29.1		1
Particle/grain size, Phi scale 4 to 5	na	percent	8.9		10		12
Particle/grain size, Phi scale 5 to 6	na	percent	3		2.2		-31
Particle/grain size, Phi scale 6 to 7	na	percent	1.8		1.9		5
Particle/grain size, Phi scale 7 to 8	na	percent	1.6		1.7		6
Particle/grain size, Phi scale 8 to 9	na	percent	0.9		1.1		20
Particle/grain size, Phi scale 9 to 10	na	percent	0.6		0.7		15
Particle/grain size, Phi scale >10	na	percent	0.8		0.8		0
Particle/grain size, fines (silt/clay)	na	percent	17.5		18.5		6
Metals							
Arsenic	7440-38-2	mg/kg	4.7		5		6
Barium	7440-39-3	mg/kg	78.1		76.5		-2
Chromium	7440-47-3	mg/kg	15.7		15.9		1
Copper	7440-50-8	mg/kg	18.6		18.6		0
Lead	7439-92-1	mg/kg	4.8		5.2		8
Mercury	7439-97-6	mg/kg	0.04		0.04		0
Nickel	7440-02-0	mg/kg	16.4		16.7		2
Vanadium	7440-62-2	mg/kg	38		37.1		-2
Zinc	7440-66-6	mg/kg	50		51		2
Miscellaneous							
Phenol	108-95-2	µg/kg	23		25		8
Benzyl alcohol	100-51-6	µg/kg	200		190		-5
bis(2-Ethylhexyl)phthalate	117-81-7	µg/kg	37		38		3
Polycyclic aromatic hydrocarbons							
Naphthalene	91-20-3	µg/kg	5.63		13.1		80
2-Methylnaphthalene	91-57-6	µg/kg	12.5		24		63
1-Methylnaphthalene	90-12-0	µg/kg	12.2		20.3		50
Acenaphthylene	208-96-8	µg/kg	0.66		0.7		6
Acenaphthene	83-32-9	µg/kg	0.81		0.78		-4
Fluorene	86-73-7	µg/kg	0.96		1.03		7
Phenanthrene	85-01-8	µg/kg	25.9		27.6		6
Anthracene	120-12-7	µg/kg	2.38		2.49		5
Fluoranthene	206-44-0	µg/kg	14.6		13.4		-9
Pyrene	129-00-0	µg/kg	14.4		14.5		1
Benzo(a)anthracene	56-55-3	µg/kg	7.13		6.6		-8
Chrysene	218-01-9	µg/kg	12		11.1		-8
Benzo(a)pyrene	50-32-8	µg/kg	5.93		5.45		-8

Table 7. Quality assurance results for bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type: Field split (04-26-2013) Result	Field split Q	Environmental sample (04-26-2013) Result	Environmental sample Q	Relative percent difference between 04-26-2013 splits
Polycyclic aromatic hydrocarbons—Continued							
Indeno(1,2,3-cd)pyrene	193-39-5	µg/kg	3.91		3.7		-6
Dibenz(a,h)anthracene	53-70-3	µg/kg	1.48		1.41		-5
Benzo(g,h,i)perylene	191-24-2	µg/kg	6.05		5.88		-3
Dibenzofuran	132-64-9	µg/kg	5.36		7.36		31
Total benzofluoranthenes	na	µg/kg	13		11.7		-11
LPAH	na	µg/kg	36.3		45.7		23
HPAH	na	µg/kg	78.5		73.7		-6
Total cPAHs	na	µg/kg	43.5		40.0		-8
Total cPAHs	na	µg TEQ/kg	8.60		7.90		-8
Dioxins/furans							
Total tetra-dioxins	41903-57-5	ng/kg	0.048	UJ	0.095	J	-
Total penta-dioxins	36088-22-9	ng/kg	0.169	J	0.15	UJ	-
Total hexa-dioxins	34465-46-8	ng/kg	0.458	J	1.32	J	97
Total hepta-dioxins	37871-00-4	ng/kg	11.4		8.8		-26
Total octa-dioxins	3268-87-9	ng/kg	85.4		65.7		-26
Total tetra-furans	55722-27-5	ng/kg	0.224		0.200		-11
Total penta-furans	30402-15-4	ng/kg	0.108	J	0.201	J	60
Total hexa-furans	55684-94-1	ng/kg	0.411	J	0.424	J	3
Total hepta-furans	38998-75-3	ng/kg	2.05		2.25		9
Total octa-furans	39001-02-0	ng/kg	5.58		3.96		-34
Total dioxins/furans	na	ng/kg	106		82.9		-24
Total dioxins/furans	na	ng TEQ/kg	0.589	J	0.556	J	6
Polychlorinated biphenyl homologues (PCB) (by high-resolution mass spectrometry [HRMS])							
Total monochloro biphenyls	27323-18-8	ng/kg	5.05		3.90		-26
Total dichloro biphenyls	25512-42-9	ng/kg	31.2		21.2		-38
Total trichloro biphenyls	25323-68-6	ng/kg	77.1		64.4		-18
Total tetrachloro biphenyls	26914-33-0	ng/kg	200		176		-13
Total pentachloro biphenyls	25429-29-2	ng/kg	506		528		4
Total hexachloro biphenyls	26601-64-9	ng/kg	635		1,240		65
Total heptachloro biphenyls	28655-71-2	ng/kg	454		1,280		95
Total octachloro biphenyls	55722-26-4	ng/kg	118		355		100
Total nonachloro biphenyls	53742-07-7	ng/kg	18.3		36.2		66
Total decachloro biphenyls	2051-24-3	ng/kg	6.70		6.06		-10
Total PCBs (by HRMS)	1336-36-3	ng/kg	2,050		3,710		57
Polychlorinated biphenyl (PCB) Aroclors (by high-resolution mass spectrometry [HRMS])							
Aroclor 1242	53469-21-9	ng/kg	138		111		-22
Aroclor 1254	11097-69-1	ng/kg	749		723		-3
Aroclor 1260	11096-82-5	ng/kg	909		2,670		98
Polychlorinated biphenyl (PCB) Aroclors (by low-resolution mass spectrometry [LRMS])							
Aroclor 1242	53469-21-9	µg/kg	4	U	3.8	U	–
Aroclor 1254	11097-69-1	µg/kg	4	U	3.8	U	–
Aroclor 1260	11096-82-5	µg/kg	4	U	3.8	U	–

Table 8. Quality assurance results for the Puget Sound Reference Material (PSRM), Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); UJ, not detected above detection limit; J, estimated. **PSRM action Low and High** is -50 percent and +50 percent, respectively (or 95 percent confidence interval for Aroclor 1260) of average interlaboratory round-robin results. **Abbreviations:** HRMS, high-resolution mass spectrometry; LRMS, low-resolution mass spectrometry; pg/g, picogram per gram; PSRM, Puget Sound Reference Material; µg/kg, microgram per kilogram; –, not determined. See http://www.nws.usace.army.mil/Missions/CivilWorks/Dredging/SRM.aspx for additional information]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type: PSRM current study laboratory result: Result	Q	PSRM average of round-robin result	PSRM action: Low	PSRM action: High
Dioxins/furans							
2,3,7,8-TCDD	1746-01-6	pg/g	0.976		1.05	0.525	1.57
1,2,3,7,8-PECDD	40321-76-4	pg/g	0.906	J	1.08	0.542	1.63
1,2,3,4,7,8-HXCDD	39227-28-6	pg/g	1.49		1.59	0.797	2.39
1,2,3,6,7,8-HXCDD	57653-85-7	pg/g	4.14		3.88	1.94	5.82
1,2,3,7,8,9-HXCDD	19408-74-3	pg/g	3.83		3.04	1.52	4.55
1,2,3,4,6,7,8-HPCDD	35822-46-9	pg/g	106		90.6	45.3	136
OCDD	3268-87-9	pg/g	908		811	406	1,217
2,3,7,8-TCDF	51207-31-9	pg/g	0.778		1.11	0.557	1.67
1,2,3,7,8-PECDF	57117-41-6	pg/g	0.93	J	1.23	0.613	1.84
2,3,4,7,8-PECDF	57117-31-4	pg/g	0.785	J	1.07	0.533	1.6
1,2,3,4,7,8-HXCDF	70648-26-9	pg/g	2.85		3.02	1.51	4.53
1,2,3,6,7,8-HXCDF	57117-44-9	pg/g	0.957	J	1.09	0.545	1.64
1,2,3,7,8,9-HXCDF	72918-21-9	pg/g	0.077	J	1.83	0.917	2.75
2,3,4,6,7,8-HXCDF	60851-34-5	pg/g	1.3		0.511	0.255	0.77
1,2,3,4,6,7,8-HPCDF	67562-39-4	pg/g	22.1		18.7	9.36	28.1
1,2,3,4,7,8,9-HPCDF	55673-89-7	pg/g	1.51		1.63	0.815	2.44
OCDF	39001-02-0	pg/g	53.6		58.4	29.2	87.6
Polychlorinated biphenyl (PCB) congeners (by high-resolution mass spectrometry [HRMS])							
PCB-001	2051-60-7	pg/g	27.2		23	12	35
PCB-002	2051-61-8	pg/g	10.9		–	–	–
PCB-003	2051-62-9	pg/g	24.8		25	13	38
PCB-004	13029-08-8	pg/g	126		114	57	171
PCB-005	16605-91-7	pg/g	5.62		–	–	–
PCB-006	25569-80-6	pg/g	178		169	85	254
PCB-007	33284-50-3	pg/g	18		17	8	25
PCB-008	34883-43-7	pg/g	373		366	183	548
PCB-009	34883-39-1	pg/g	19.3		20	10	29
PCB-010	33146-45-1	pg/g	4.5		–	–	–
PCB-011	2050-67-1	pg/g	74.2		74	37	110
PCB-012/013	na	pg/g	78.7		70	35	105
PCB-014	34883-41-5	pg/g	0.389	J	–	–	–
PCB-015	2050-68-2	pg/g	403		308	154	462
PCB-016	38444-78-9	pg/g	258		212	106	318
PCB-017	37680-66-3	pg/g	379		363	182	545
PCB-018/030	na	pg/g	637	J	615	307	922
PCB-019	38444-73-4	pg/g	77.5		68	34	102
PCB-020/028	na	pg/g	1,420		1,436	718	2,154
PCB-021/033	na	pg/g	545		–	–	–
PCB-022	38444-85-8	pg/g	406		385	192	577
PCB-023	55720-44-0	pg/g	1.03		–	–	–
PCB-024	55702-45-9	pg/g	6.73		–	–	–
PCB-025	55712-37-3	pg/g	259		245	122	367
PCB-026/029	na	pg/g	537		506	253	759
PCB-027	38444-76-7	pg/g	87.1		81	40	121

Table 8. Quality assurance results for the Puget Sound Reference Material (PSRM), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type: PSRM current study laboratory result		Sample date and type: PSRM average of round-robin result	Sample date and type: PSRM action	
			Result	Q		Low	High
Polychlorinated biphenyl (PCB) congeners (by high-resolution mass spectrometry [HRMS])—Continued							
PCB-031	16606-02-3	pg/g	1,140		1,132	566	1,697
PCB-032	38444-77-8	pg/g	244		237	118	355
PCB-034	37680-68-5	pg/g	9.08		–	–	–
PCB-035	37680-69-6	pg/g	27		26	13	39
PCB-036	38444-87-0	pg/g	0.713	UJ	–	–	–
PCB-037	38444-90-5	pg/g	437		355	178	533
PCB-038	53555-66-1	pg/g	2.43		–	–	–
PCB-039	38444-88-1	pg/g	12		–	–	–
PCB-040/041/071	na	pg/g	836		717	359	1,076
PCB-042	36559-22-5	pg/g	432		413	206	619
PCB-043	70362-46-8	pg/g	56.6		–	–	–
PCB-044/047/065	na	pg/g	2,040		2,026	1,013	3,039
PCB-045/051	na	pg/g	248		224	112	336
PCB-046	41464-47-5	pg/g	79.9		75	37	112
PCB-048	70362-47-9	pg/g	265		246	123	369
PCB-049/069	na	pg/g	1,600		1,550	775	2,325
PCB-050/053	na	pg/g	267		242	112	336
PCB-052	35693-99-3	pg/g	3,560		3,743	1,871	5,614
PCB-054	15968-05-5	pg/g	4.05		–	–	–
PCB-055	74338-24-2	pg/g	28		–	–	–
PCB-056	41464-43-1	pg/g	688		651	326	977
PCB-057	70424-67-8	pg/g	16.5		–	–	–
PCB-058	41464-49-7	pg/g	7.27		–	–	–
PCB-059/062/075	na	pg/g	158		142	71	213
PCB-060	33025-41-1	pg/g	283		253	126	379
PCB-061/070/074/076	na	pg/g	3,280		3,251	1,626	4,877
PCB-063	74472-34-7	pg/g	62.4		59	30	89
PCB-064	52663-58-8	pg/g	686		659	329	988
PCB-066	32598-10-0	pg/g	1,580		1,654	827	2,481
PCB-067	73575-53-8	pg/g	56.1		56	28	84
PCB-068	73575-52-7	pg/g	24.1		22	11	34
PCB-072	41464-42-0	pg/g	39.9		37	19	56
PCB-073	74338-23-1	pg/g	7.96		–	–	–
PCB-077	32598-13-3	pg/g	160		135	68	203
PCB-078	70362-49-1	pg/g	0.887	UJ	–	–	–
PCB-079	41464-48-6	pg/g	48.5		–	–	–
PCB-080	33284-52-5	pg/g	0.777	UJ	–	–	–
PCB-081	70362-50-4	pg/g	7.67	UJ	–	–	–
PCB-082	52663-62-4	pg/g	470		486	243	729
PCB-083/099	na	pg/g	2,710		2,548	1,274	3,821
PCB-084	52663-60-2	pg/g	1,340		1,327	664	1,991
PCB-085/116/117	na	pg/g	766		737	368	1,105
PCB-086/087/097/108/119/125	na	pg/g	3,290		3,337	1,668	5,005
PCB-088/091	na	pg/g	703		674	337	1,011
PCB-089	73575-57-2	pg/g	41.3		–	–	–
PCB-090/101/113	na	pg/g	6,840		6,957	3,478	10,435
PCB-092	52663-61-3	pg/g	1,170		1,180	590	1,770
PCB-093/095/098/100/102	na	pg/g	5,860		5,608	2,804	8,412
PCB-094	73575-55-0	pg/g	21.2		20	10	30

Table 8. Quality assurance results for the Puget Sound Reference Material (PSRM), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type				
			PSRM current study laboratory result		PSRM average of round-robin result	PSRM action	
			Result	Q		Low	High
Polychlorinated biphenyl (PCB) congeners (by high-resolution mass spectrometry [HRMS])—Continued							
PCB-096	73575-54-9	pg/g	29.8		29	14	43
PCB-103	60145-21-3	pg/g	60.4		57	28	85
PCB-104	56558-16-8	pg/g	0.693		–	–	–
PCB-105	32598-14-4	pg/g	1,530		–	–	–
PCB-106	70424-69-0	pg/g	1.72	UJ	–	–	–
PCB-107/124	na	pg/g	155		249	124	373
PCB-109	74472-35-8	pg/g	287		–	–	–
PCB-110/115	na	pg/g	6,230		6,488	3,244	9,733
PCB-111	39635-32-0	pg/g	3.22		–	–	–
PCB-112	74472-36-9	pg/g	0.668	UJ	–	–	–
PCB-114	74472-37-0	pg/g	68.4		68	34	102
PCB-118	31508-00-6	pg/g	4,160		4,021	2,011	6,032
PCB-120	68194-12-7	pg/g	21.2		19	9	28
PCB-121	56558-18-0	pg/g	1.31		–	–	–
PCB-122	76842-07-4	pg/g	46.9		44	22	66
PCB-123	65510-44-3	pg/g	66.1		54	27	81
PCB-126	57465-28-8	pg/g	19.2		–	–	–
PCB-127	39635-33-1	pg/g	10.8		–	–	–
PCB-128/166	na	pg/g	1,270		1,354	677	2,031
PCB-129/138/160/163	na	pg/g	13,100		14,189	7,094	21,283
PCB-130	52663-66-8	pg/g	552		591	296	887
PCB-131	61798-70-7	pg/g	102		116	58	174
PCB-132	38380-05-1	pg/g	4,090		4,569	2,284	6,853
PCB-133	35694-04-3	pg/g	163		179	90	269
PCB-134/143	na	pg/g	560		657	329	986
PCB-135/151/154	na	pg/g	5,520		6,326	3,163	9,488
PCB-136	38411-22-2	pg/g	1,890		2,141	1,071	3,212
PCB-137	35694-06-5	pg/g	218		223	112	335
PCB-139/140	na	pg/g	102		115	58	173
PCB-141	52712-04-6	pg/g	3,210		3,657	1,829	5,486
PCB-142	41411-61-4	pg/g	11.8	UJ	–	–	–
PCB-144	68194-14-9	pg/g	784		862	431	1,293
PCB-145	74472-40-5	pg/g	1.97		–	–	–
PCB-146	51908-16-8	pg/g	1,570	J	2,029	1,014	3,043
PCB-147/149	na	pg/g	11,800		14,314	7,157	21,471
PCB-148	74472-41-6	pg/g	12.7		–	–	–
PCB-150	68194-08-1	pg/g	14		–	–	–
PCB-152	68194-09-2	pg/g	4.61		–	–	–
PCB-153/168	na	pg/g	12,800		13,913	6,956	20,869
PCB-155	33979-03-2	pg/g	0.464		–	–	–
PCB-156/157	na	pg/g	860		891	446	1,337
PCB-158	74472-42-7	pg/g	1,190		1,257	628	1,885
PCB-159	39635-35-3	pg/g	295		239	119	358
PCB-161	74472-43-8	pg/g	8.4	UJ	–	–	–
PCB-162	39635-34-2	pg/g	21.8		–	–	–
PCB-164	74472-45-0	pg/g	967		1,068	534	1,602
PCB-165	74472-46-1	pg/g	9.55	UJ	–	–	–
PCB-167	52663-72-6	pg/g	383		367	184	551
PCB-169	32774-16-6	pg/g	21	UJ	–	–	–

Table 8. Quality assurance results for the Puget Sound Reference Material (PSRM), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type				
			PSRM current study laboratory result		PSRM average of round-robin result	PSRM action	
			Result	Q		Low	High
Polychlorinated biphenyl (PCB) congeners (by high-resolution mass spectrometry [HRMS])							
PCB-170	35065-30-6	pg/g	5,340		5,251	2,626	7,877
PCB-171/173	na	pg/g	2,090		1,794	897	2,691
PCB-172	52663-74-8	pg/g	671	J	903	452	1,355
PCB-174	38411-25-5	pg/g	7,360		6,604	3,302	9,906
PCB-175	40186-70-7	pg/g	281		249	125	374
PCB-176	52663-65-7	pg/g	870		806	403	1,209
PCB-177	52663-70-4	pg/g	4,310		3,630	1,815	5,445
PCB-178	52663-67-9	pg/g	1,390		1,237	619	1,856
PCB-179	52663-64-6	pg/g	2,830		2,719	1,359	4,078
PCB-180/193	na	pg/g	12,600		12,396	6,198	18,594
PCB-181	74472-47-2	pg/g	23.5		–	–	–
PCB-182	60145-23-5	pg/g	18.5	J	–	–	–
PCB-183/185	na	pg/g	5,160		4,184	2,092	6,277
PCB-184	74472-48-3	pg/g	1.25	UJ	–	–	–
PCB-186	74472-49-4	pg/g	0.255	UJ	–	–	–
PCB-187	52663-68-0	pg/g	8,540		7,316	3,658	10,974
PCB-188	74487-85-7	pg/g	3.72		–	–	–
PCB-189	39635-31-9	pg/g	199		185	93	278
PCB-190	41411-64-7	pg/g	1,440		1,077	539	1,616
PCB-191	74472-50-7	pg/g	273		217	108	325
PCB-192	74472-51-8	pg/g	0.318	UJ	–	–	–
PCB-194	35694-08-7	pg/g	2,720		2,624	1,312	3,936
PCB-195	52663-78-2	pg/g	983		1,169	585	1,754
PCB-196	42740-50-1	pg/g	1,530		1,579	789	2,368
PCB-197/200	na	pg/g	336	J	496	248	744
PCB-198/199	na	pg/g	3,150		3,260	1,630	4,890
PCB-201	40186-71-8	pg/g	368		373	187	560
PCB-202	2136-99-4	pg/g	500		487	243	730
PCB-203	52663-76-0	pg/g	1,880		1,829	914	2,743
PCB-204	74472-52-9	pg/g	0.335	J	–	–	–
PCB-205	74472-53-0	pg/g	147		143	71	214
PCB-206	40186-72-9	pg/g	609		575	288	863
PCB-207	52663-79-3	pg/g	84		91	46	137
PCB-208	52663-77-1	pg/g	138		124	62	186
PCB-209	2051-24-3	pg/g	97.2		97	48	145
Polychlorinaed biphenyl (PCB) Aroclors							
Aroclor 1260 (by HRMS)	11096-82-5	µg/kg	116		108	41	180
Aroclor 1260 (by LRMS)	11096-82-5	µg/kg	100		108	41	180

Water-Chemistry Data

Total organic carbon, metals, dioxins/furans, and PCB cogeners were detected in water samples (table 9).The following compound groups were analyzed for, but were not detected: PAHs, other semivolatile organic compounds, pesticides, VOCs, hexavalent chromium, and butyltins. In four of the seven water samples collected, TOC was greater than the RL of 1.5 mg/L at concentrations ranging from 1.86 mg/L during a low-precipitation period to 2.78 mg/L during the storm peak. Of the dioxin/furan congeners, only the hepta- and octa-congeners were detected. All environmental detections of total dioxins/furans and total PCBs (table 9) were estimated because they were less than the RL (J-qualified). These levels were similar to concentrations in the one field blank sample (table 5, see section, "Quality-Assurance Data" for additional details).

Eight metals were detected in water samples: arsenic, barium, chromium, copper, lead, nickel, vanadium, and zinc (fig. 4, table 9). Mercury was not detected greater than the detection level of 20 ng/L. Nickel was detected only during the rising limb and storm peak and chromium and zinc were detected only during the storm peak. Concentrations of the remaining five detected metals during the storm peak were 2–3.5 times greater than the average concentration of the five low-precipitation periods.

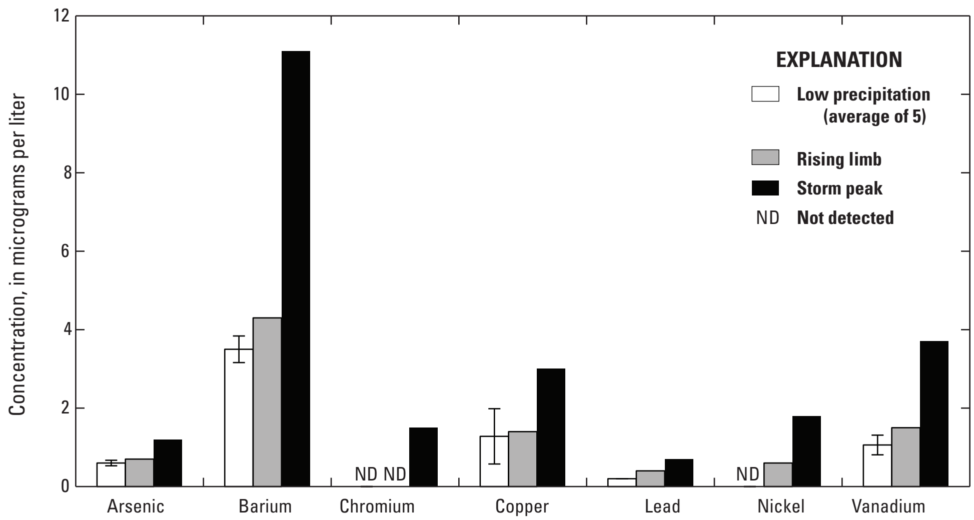

Figure 4. Concentrations of metals in whole-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013. The low-precipitation concentration represents the average of five samples with 72-hour antecedent rainfall less than or equal to 0.40 inch. Error bars represent ±1 standard deviation.

Table 9. Concentrations of detected compounds in whole water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; **Abbreviations:** mg/L, milligram per liter; µg/L, microgram per liter; pg/L, picogram per liter; na, not applicable; pg TEQ/L, picograms toxic equivalent per liter; –, not analyzed]

Parameter name	Chemical Abstracts Service number	Unit	Sample date and type													
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		04-29-2013		05-13-2013		06-19-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Total organic carbon	na	mg/L	2.29		1.86		1.5	U	2.78		2.59		1.5	U	1.5	U
Metals																
Arsenic	7440-38-2	µg/L	0.6		0.6		0.7		1.2		0.6		0.5		0.7	
Barium	7440-39-3	µg/L	3.3		3.1		4.3		11.1		3.8		3.9		3.4	
Chromium	7440-47-3	µg/L	0.5	U	0.5	U	0.5	U	1.5		0.5	U	0.5	U	0.5	U
Copper	7440-50-8	µg/L	2.3		1		1.4		3		1.7		0.8		0.6	
Lead	7439-92-1	µg/L	0.2		0.2		0.4		0.7		0.2		0.2		0.1	U
Nickel	7440-02-0	µg/L	0.5	U	0.5	U	0.6		1.8		0.5	U	0.5	U	0.5	U
Vanadium	7440-62-2	µg/L	1.1		0.8		1.5		3.7		1.3		1.3		0.8	
Zinc	7440-66-6	µg/L	4	U	4	U	4	U	7		4	U	4	U	4	U
Dioxins/furans[1]																
Total hepta-dioxins	37871-00-4	pg/L	1.11	UJ	1.00	J	2.57	J	3.83	J	1.30	J	–		–	
Total octa-dioxins	3268-87-9	pg/L	6.53	UJ	5.81	UJ	18.2	UJ	24.8		11.9	J	–		–	
Total hepta-furans	38998-75-3	pg/L	0.474	UJ	0.484	UJ	0.950	J	1.02	J	0.518	J	–		–	
Total octa-furans	39001-02-0	pg/L	0.474	UJ	0.484	UJ	2.40	J	2.61	J	0.685	UJ	–		–	
Total dioxins/furans	na	pg/L	6.53	UJ	1.00	J	5.92	J	32.3	J	13.7	J	–		–	
Total dioxins/furans	na	pg TEQ/L	0.753	UJ	0.792	J	0.800	J	0.851	J	0.826	J				
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])[1]																
Total monochloro biphenyls	27323-18-8	pg/L	7.46	UJ	8.44		1.96	J	2.71	J	7.81	J	–		–	
Total dichloro biphenyls	25512-42-9	pg/L	6.79		10.8		58.9	UJ	12.0		16.1		–		–	
Total trichloro biphenyls	25323-68-6	pg/L	9.19	J	4.38	J	2.38	J	7.16	J	17.0	J	–		–	
Total tetrachloro biphenyls	26914-33-0	pg/L	23.2	UJ	7.12	J	21.8	J	28.5	J	10.6	J	–		–	
Total pentachloro biphenyls	25429-29-2	pg/L	10.1	J	19.8		51.0		40.4	J	17.8	J	–		–	
Total hyexachloro biphenyls	26601-64-9	pg/L	19.8	J	11.3	J	52.1	J	60.5	J	9.99	J	–		–	
Total heptachloro biphenyls	28655-71-2	pg/L	10.1	J	8.61	J	22.6		28.4	J	0.851	J	–		–	
Total octachloro biphenyls	55722-26-4	pg/L	2.01	UJ	1.45	J	3.38	J	4.38	J	1.75	UJ	–		–	
Total nonachloro biphenyls	53742-07-7	pg/L	2.85	UJ	3.87	UJ	3.04	J	4.57	UJ	2.30	UJ	–		–	
Total decachloro biphenyls	2051-24-3	pg/L	2.1	UJ	1.59	J	1.85	UJ	2.88	UJ	1.55	UJ	–		–	
Total PCBs (by HRMS)[1]	1336-36-3	pg/L	56.0	J	73.5	J	158	J	184	J	80.1	J	–		–	
Polychlorinated biphenyl (PCB) Aroclors (by high-resolution mass spectrometry [HRMS])[1]																
Aroclor 1242	53469-21-9	pg/L	14.8	UJ	19.5		12.3	UJ	15.3		16.6		–		–	
Aroclor 1254	11097-69-1	pg/L	11.9	UJ	10.7	UJ	16.7	UJ	13.4	UJ	6.70	UJ	–		–	
Aroclor 1260	11096-82-5	pg/L	19.1		19.9	J	74.9		61.8	J	1.45	UJ	–		–	
Polychlorinated biphenyl (PCB) Aroclors (by low-resolution mass spectrometry [LRMS])																
Aroclor 1242	53469-21-9	µg/L	0.01	U	0.01	U	0.01	U	0.01	U	0.01	U	–		–	
Aroclor 1254	11097-69-1	µg/L	0.01	U	0.01	U	0.01	U	0.01	U	0.01	U	–		–	
Aroclor 1260	11096-82-5	µg/L	0.01	U	0.01	U	0.01	U	0.01	U	0.01	U	–		–	

[1]Concentrations of dioxins/furans and PCB congeners in the field blank were similar to these environmental concentrations (see table 5).

Suspended-Sediment Chemistry Data

In suspended-sediment samples, TOC, metals, PAHs, dioxins/furans, and PCBs were detected during low precipitation periods and storm samples (table 10). Because of limited sample mass and analyte prioritization, no analysis was done for the following compound groups: other semivolatile organic compounds, VOCs, pesticides, butyltins, and hexavalent chromium. Total organic carbon ranged from 3.60 to 6.38 percent. Total cPAHs during the rising limb and storm peak were approximately 50 µg TEQ/kg. Concentrations of total dioxins/furans increased with increasing precipitation, from 1.27 ng TEQ/kg (0.21 in. rainfall) to 4.20 ng TEQ/kg (1.3 in. rainfall). Similarly, total PCBs increased from 2,430 ng/kg (0.21 in. rainfall) up to 5,360 ng/kg (1.3 in. rainfall). Nine metals were detected–the same eight that were detected in water samples, plus mercury (table 10). During a low precipitation period (May 13, 2013), very elevated concentrations of chromium (2,180 mg/kg) and nickel (1,130 mg/kg) were measured and confirmed during laboratory re-analyses (table 10). Both compounds were not detected in the corresponding water sample (table 9). On that day, there was a short period of intense precipitation that included rain and hail and caused local storm drain runoff and a doubling of turbidity (table 4) that occurred after the water sample had been collected, but during the suspended-sediment sample collection.

Table 10. Compounds detected in suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); na, not applicable; U, not detected above reporting limit; J, estimated; **Abbreviations:** cPAH, carcinogenic polycyclic aromatic hydrocarbon; HPAH, high molecular-weight polycyclic aromatic hydrocarbon; LPAH, low molecular-weight polycyclic aromatic hydrocarbon; mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanogram per liter; PCB, polychlorinated biphenyl; TEQ, toxic equivalent; –, no analysis done]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type									
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		05-13-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Total organic carbon	na	percent	–		–		3.60		4.32		6.38	
Metals												
Arsenic	7440-38-2	mg/kg	–		–		10.7		15.7		12.0	
Barium	7440-39-3	mg/kg	–		–		117		214		129	
Chromium	7440-47-3	mg/kg	–		–		75.0		170		2,180	
Copper	7440-50-8	mg/kg	–		–		32.0		57.0		86.0	
Lead	7439-92-1	mg/kg	–		–		11.1		17.7		10.0	
Mercury	7439-97-6	mg/kg	–		–		0.1		0.2		0.1	U
Nickel	7440-02-0	mg/kg	–		–		50.0		114		1,130	
Vanadium	7440-62-2	mg/kg	–		–		59.0		107		56.0	
Zinc	7440-66-6	mg/kg	–		–		110		170		100	
Polycyclic aromatic hydrocarbons												
Naphthalene	91-20-3	µg/kg	–		–		9.15		27.6		–	
2-Methylnaphthalene	91-57-6	µg/kg	–		–		19.1		54.4		–	
1-Methylnaphthalene	90-12-0	µg/kg	–		–		8.25		29.3		–	
Acenaphthylene	208-96-8	µg/kg	–		–		3.7	U	4.58		–	
Acenaphthene	83-32-9	µg/kg	–		–		3.7	U	3.66		–	
Fluorene	86-73-7	µg/kg	–		–		3.7	U	9.31		–	
Phenanthrene	85-01-8	µg/kg	–		–		44.7		76.5		–	
Anthracene	120-12-7	µg/kg	–		–		4.51		15.5		–	
Fluoranthene	206-44-0	µg/kg	–		–		71.6		78.4		–	
Pyrene	129-00-0	µg/kg	–		–		73.3		80.9		–	
Benzo(a)anthracene	56-55-3	µg/kg	–		–		25.5		29.3		–	
Chrysene	218-01-9	µg/kg	–		–		59.2		55.9		–	
Benzo(a)pyrene	50-32-8	µg/kg	–		–		37.5		32.6		–	
Indeno(1,2,3-cd)pyrene	193-39-5	µg/kg	–		–		36.8		28.8		–	
Dibenz(a,h)anthracene	53-70-3	µg/kg	–		–		9.27		8.05		–	
Benzo(g,h,i)perylene	191-24-2	µg/kg	–		–		56.0		43.3		–	
Dibenzofuran	132-64-9	µg/kg	–		–		5.76		13.8		–	
Total benzofluoranthenes	TOTBFA	µg/kg	–		–		97.0		78.5		–	

Table 10. Compounds detected in suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type									
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		05-13-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polycyclic aromatic hydrocarbons—Continued												
LPAH	na	µg/kg	–		–		58.4		137		–	
HPAH	na	µg/kg	–		–		466		436		–	
Total cPAHs	na	µg/kg	–		–		265		233		–	
Total cPAHs	na	µg TEQ/kg	–		–		54.9		47.6		–	
Dioxins/furans												
Total tetra-dioxins	41903-57-5	ng/kg	0.153	J	0.346		0.236		0.365		–	
Total penta-dioxins	36088-22-9	ng/kg	0.289	J	0.619	J	0.577	J	0.845	J	–	
Total hexa-dioxins	34465-46-8	ng/kg	2.90	J	5.97		9.36		12.3		–	
Total hepta-dioxins	37871-00-4	ng/kg	27.4		61.3		76.9		92.3		–	
Total octa-dioxins	3268-87-9	ng/kg	217		470		501		606		–	
Total tetra-furans	55722-27-5	ng/kg	0.383		0.795		0.569		0.881		–	
Total penta-furans	30402-15-4	ng/kg	0.304	J	0.616	J	0.535	J	0.436	J	–	
Total hexa-furans	55684-94-1	ng/kg	0.966	J	2.04	J	2.41	J	3.36	J	–	
Total hepta-furans	38998-75-3	ng/kg	5.57		13.3		19.4		22.9		–	
Total octa-furans	39001-02-0	ng/kg	13.9		30.5		56.4		62.4		–	
Total dioxins/furans	na	ng/kg	269		585		667		801		–	
Total dioxins/furans	na	ng TEQ/kg	1.27	J	2.73	J	3.12	J	4.20	J	–	
Polychlorinated biphenyl homologues (by high-resolution mass spectrometry [HRMS])												
Total monochloro biphenyls	27323-18-8	ng/kg	6.21		13.4		8.07		12.4		–	
Total dichloro biphenyls	25512-42-9	ng/kg	107		154		191		173		–	
Total trichloro biphenyls	25323-68-6	ng/kg	233		322		294		326		–	
Total tetrachloro biphenyls	26914-33-0	ng/kg	397		601		533		672		–	
Total pentachloro biphenyls	25429-29-2	ng/kg	639		1,160		1,110		1,540		–	
Total hexachloro biphenyls	26601-64-9	ng/kg	582		1,030		1,130		1,520		–	
Total heptachloro biphenyls	28655-71-2	ng/kg	308		408		594		744		–	
Total octachloro biphenyls	55722-26-4	ng/kg	101		168		258		268		–	
Total nonachloro biphenyls	53742-07-7	ng/kg	35.6		49.9		82.2		72.9		–	
Total decachloro biphenyls	2051-24-3	ng/kg	16.3		22.7		15.9		30.5		–	
Total PCBs (by HRMS)	1336-36-3	ng/kg	2,430		3,930		4,210		5,360		–	
Polychlorinated biphenyl Aroclors (by high-resolution mass spectrometry [HRMS])												
Aroclor 1242	53469-21-9	ng/kg	397		553		505		571		–	
Aroclor 1254	11097-69-1	ng/kg	991		1,740		1,670		2,320		–	
Aroclor 1260	11096-82-5	ng/kg	676		796		1,370		1,710		–	
Polychlorinated biphenyl Aroclors (by low-resolution mass spectrometry [LRMS])												
Aroclor 1242	53469-21-9	µg/kg	–		–		–		–		–	
Aroclor 1254	11097-69-1	µg/kg	–		–		–		–		–	
Aroclor 1260	11096-82-5	µg/kg	–		–		–		–		–	

Bed-Sediment Chemistry Data

Results from the bed-sediment samples are presented by date, but were not storm driven. Rather, all samples were collected during low-flow, low-precipitation conditions when the 72-hour antecedent rainfall was less than 0.2 in. In the six bulk bed-sediment samples (<2 mm), TOC, metals, VOCs and other semivolatile compounds, PAHs, dioxins/furans, and PCBs were detected (table 11). TOC ranged from 1.28 to 2.27 percent. Total cPAHs ranged from 5.91 to 17.6 µg TEQ/kg. Total dioxins/furans ranged from 0.620 ng TEQ/kg (J-qualified) to 0.944 ng TEQ/kg (J-qualified). Total PCBs ranged from 1,390 to 3,710 ng/kg. Eleven metals were detected–the same nine detected in suspended-sediment samples, plus beryllium and cadmium. Numerous VOCs and other semivolatile compounds were detected, including benzyl alcohol, benzoic acid, and bis(2-ethylhexyl)phthalate.

During each of the last three bed-sediment sampling periods, a fine bed-sediment sample (<62.5 µm) was analyzed in addition to the bulk bed sediment sample. The same groups of compounds that were detected in the bulk bed sediment samples also were detected in the fine bed sediment samples (table 12). TOC ranged from 1.28 to 2.56 percent. Total cPAHs ranged from 14.8 to 22.4 µg TEQ/kg. Total dioxins/furans ranged from 1.84 ng TEQ/kg (J-qualified) to 4.39 ng TEQ/kg. Total PCBs ranged from 3,280 ng/kg to 8,680 ng/kg. The same metals that were detected in bulk bed sediment samples were detected in fine bed sediment samples, except for beryllium. Diethylphthalate and butyl tin were detected in fine bed material, but not bulk bed material.

In 78 percent of cases where analyte concentrations were compared between paired bulk and fine bed sediment samples, the concentration in the fine bed sediment sample (<62.5 µm) was greater than the concentration in the bulk bed sediment sample (<2 mm). Total organic carbon increased by an average of 16 percent in the fine sediment as compared to the bulk sediment. Concentrations of individual metals increased between 21 percent (barium) and 400 percent (mercury). Total dioxins/furans (as ng TEQ/kg) increased to between 150 and 370 percent. Total PCBs (as ng/kg) ranged from less than 5 percent difference to 325 percent. Numerous PAHs had lower concentrations in the fine sediment than in the bulk sediment, particularly the LPAH compounds (average LPAH percent difference = –23 percent). The HPAH compounds and the total cPAHs (as µg TEQ/kg) increased in fine sediment as compared to bulk sediment (46 and 47 percent, respectively).

Table 11. Compounds detected in bulk bed-sediment samples (<2 millimeters), Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; **Abbreviations:** cPAH, carcinogenic polycyclic aromatic hydrocarbon; HPAH, high molecular-weight polycyclic aromatic hydrocarbon; LPAH, low molecular-weight polycyclic aromatic hydrocarbon; mg/L, milligram per liter; µg/L, microgram per liter; na, not applicable; ng/L, nanogram per liter; TEQ, toxic equivalent; –, not analyzed]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date											
			02-26-2013		03-29-2013		04-26-2013		05-09-2013		05-31-2013		06-21-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Total organic carbon	na	percent	2.27		1.76		1.41		1.88		2.07		1.28	
Metals														
Arsenic	7440-38-2	mg/kg	6.5		5.8		5		4.7		6		5.4	
Barium	7440-39-3	mg/kg	96.1		83.6		76.5		81.6		91.7		83	
Beryllium	7440-41-7	mg/kg	0.4		0.3	U	0.3	U	0.3		0.3	U	0.3	
Cadmium	7440-43-9	mg/kg	0.2	U	0.2		0.2	U	0.2	U	0.2		0.2	
Chromium	7440-47-3	mg/kg	20		18.7		15.9		16.4		18.9		18.7	
Copper	7440-50-8	mg/kg	21.9		20.5		18.6		19.1		21		18.2	
Lead	7439-92-1	mg/kg	6.2		5.5		5.2		5.1		5.5		4.9	
Mercury	7439-97-6	mg/kg	0.04		0.04		0.04		0.05		0.04	U	0.04	
Nickel	7440-02-0	mg/kg	18.3		18.1		16.7		16.9		18.7		18.1	
Vanadium	7440-62-2	mg/kg	53		41.2		37.1		37.5		47		45.1	
Zinc	7440-66-6	mg/kg	60		59		51		56		58		53	
Volatile organic compounds and semivolatile compounds														
Phenol	108-95-2	µg/kg	97		38		25		53		18	U	19	U
Benzyl alcohol	100-51-6	µg/kg	570		280		190		220		170	J	160	
4-methylphenol	106-44-5	µg/kg	23		15	J	19	U	26		20		13	J
Benzoic acid	65-85-0	µg/kg	400		260	J	380	U	210	J	190	J	190	J
bis(2-ethylhexyl)phthalate	117-81-7	µg/kg	56		69		38		64	U	35		53	
Acetone	67-64-1	µg/kg	29		15		64	U	28		8.1	U	41	
2-butanone	78-93-3	µg/kg	8.4	U	8.4	U	7.1	U	7.7	U	14		6.8	U
4-isopropyltoluene	99-87-6	µg/kg	1.7	U	1.7	U	1.4	U	1.5	U	1.2	J	1.4	U
Polycyclic aromatic hydrocarbons														
Naphthalene	91-20-3	µg/kg	9.05		6.97		13.1		12.4		7.43		11.1	
2-methylnaphthalene	91-57-6	µg/kg	15.7		10.8		24		27.4		10.2		22.9	
1-methylnaphthalene	90-12-0	µg/kg	13		8.8		20.3		19.9		9.27		17.5	
Acenaphthylene	208-96-8	µg/kg	0.92		0.59		0.7		2.49	U	0.71		0.95	
Acenaphthene	83-32-9	µg/kg	1.62		0.78		0.78		2.49	U	1.57		0.98	
Fluorene	86-73-7	µg/kg	1.83		0.88	U	1.03		1.78	J	1.71		1.59	
Phenanthrene	85-01-8	µg/kg	33		15.2		27.6		39.4		27.5		25.8	
Anthracene	120-12-7	µg/kg	3.21		1.62	U	2.49		5.23		3.19		3.36	
Fluoranthene	206-44-0	µg/kg	21.4		10.7		13.4		31.8		15.1		16.4	

Table 11. Compounds detected in bulk bed-sediment samples (<2 millimeters), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date											
			02-26-2013		03-29-2013		04-26-2013		05-09-2013		05-31-2013		06-21-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polycyclic aromatic hydrocarbons—Continued														
Pyrene	129-00-0	µg/kg	22.6		10.2		14.5		28.5		22.6		16.6	
Benzo(a)anthracene	56-55-3	µg/kg	9.05		4.3		6.6		12.8		9.53		8.62	
Chrysene	218-01-9	µg/kg	16.4		7.15		11.1		20.6		14.3		13	
Benzo(a)pyrene	50-32-8	µg/kg	8.74		4.13		5.45		12.5		8.4		7.08	
Indeno(1,2,3-cd)pyrene	193-39-5	µg/kg	6.67		2.87		3.7		7.21		5.83		4.46	
Dibenz(a,h)anthracene	53-70-3	µg/kg	2.1		0.97		1.41		2.48	J	1.68		1.74	
Benzo(g,h,i)perylene	191-24-2	µg/kg	10.3		4.31		5.88		11.1		8.5		6.7	
Dibenzofuran	132-64-9	µg/kg	6.5		3.67		7.36		7.42		5.43		7.45	
Total benzofluoranthenes	TOTBFA	µg/kg	20.1		8.99		11.7		26.8		17.6		15.1	
LPAH	na	µg/kg	49.6		23.5		45.7		58.8		42.1		43.8	
HPAH	na	µg/kg	117		53.6		73.7		154		104		89.7	
Total cPAHs	na	µg/kg	63.1		28.4		40.0		82.4		57.3		50	
Total cPAHs	na	µg TEQ/kg	12.7		5.91		7.90		17.6		12.0		10.2	
Dioxins/furans														
Total tetra-dioxins	41903-57-5	ng/kg	0.129	J	0.103	J	0.095	J	0.104	UJ	0.126	J	0.142	UJ
Total penta-dioxins	36088-22-9	ng/kg	0.158	J	0.195	UJ	0.150	UJ	0.184	J	0.414	UJ	0.132	UJ
Total hexa-dioxins	34465-46-8	ng/kg	1.65	J	2.08	J	1.32	J	1.83	J	3.50	J	1.11	J
Total hepta-dioxins	37871-00-4	ng/kg	14.5		18.5		8.80		13.0		17.0		8.93	
Total octa-dioxins	3268-87-9	ng/kg	120		131		65.7		95.4		97.6		63.1	
Total tetra-furans	55722-27-5	ng/kg	0.254		0.232		0.200		0.194	J	0.253		0.241	
Total penta-furans	30402-15-4	ng/kg	0.161	J	0.130	J	0.201	J	0.236	J	0.081	J	0.184	J
Total hexa-furans	55684-94-1	ng/kg	0.366	J	0.704	J	0.424	J	0.583	J	0.681	J	1.55	
Total hepta-furans	38998-75-3	ng/kg	2.95		4.91		2.25		2.57		3.51	J	4.41	
Total octa-furans	39001-02-0	ng/kg	6.38		17.1		3.96		5.26		6.84		0.745	
Total dioxins/furans	na	ng/kg	146		175		82.9		119		129		80.0	
Total dioxins/furans	na	ng TEQ/kg	0.754	J	0.769	J	0.556	J	0.814	J	0.944	J	0.620	J
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])														
Total monochloro biphenyls	27323-18-8	ng/kg	3.38		3.01		3.90		4.47		9.81		4.86	
Total dichloro biphenyls	25512-42-9	ng/kg	31.0		23.2		21.2		27.7		34.0		22.6	
Total trichloro biphenyls	25323-68-6	ng/kg	98.8		85.0		64.4		90.8		85.5		77.3	
Total tetrachloro biphenyls	26914-33-0	ng/kg	212		193		176		318		228		202	
Total pentachloro biphenyls	25429-29-2	ng/kg	428		392		528		1,280		572		501	
Total hexachloro biphenyls	26601-64-9	ng/kg	407		391		1,240		1,120		697		641	
Total heptachloro biphenyls	28655-71-2	ng/kg	210		193		1,280		458		444		427	
Total octachloro biphenyls	55722-26-4	ng/kg	70.8		79.1		355		138		143		135	

Table 11. Compounds detected in bulk bed-sediment samples (<2 millimeters), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date											
			02-26-2013		03-29-2013		04-26-2013		05-09-2013		05-31-2013		06-21-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polychlorinated biphenyl homologues (by high-resolution mass spectrometry [HRMS])—Continued														
Total nonachloro biphenyls	53742-07-7	ng/kg	18.7		22.0		36.2		24.2		24.9		20.2	
Total decachloro biphenyls	2051-24-3	ng/kg	7.62		8.89		6.06		7.96		8.24		6.42	
Total PCBs (by HRMS)	1336-36-3	ng/kg	1,490		1,390		3,710		3,470		2,250		2,040	
Polychlorinated biphenyl (PCB) Aroclors (by high-resolution mass spectrometry [HRMS])														
Aroclor 1242	53469-21-9	ng/kg	172		149		111		156		148		137	
Aroclor 1254	11097-69-1	ng/kg	676		585		723		2,010		847		775	
Aroclor 1260	11096-82-5	ng/kg	457		444		2,670		1,010		966		897	
Polychlorinated biphenyl (PCB) Aroclors (by low-resolution mass spectrometry [LRMS])														
Aroclor 1242	53469-21-9	μg/kg	3.8	U	3.8	U	3.8	U	3.8	U	3.9	U	3.8	U
Aroclor 1254	11097-69-1	μg/kg	3.8	U	3.8	U	3.8	U	3.8	U	4.7		3.8	U
Aroclor 1260	11096-82-5	μg/kg	3.8	U	3.8	U	3.8	U	3.8	U	3.5	J	3.8	U

Table 12. Compounds detected in fine bed sediment samples (<62.5 micrometers), Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; **Abbreviations:** cPAH, carcinogenic polycyclic aromatic hydrocarbon; HPAH, high molecular-weight polycyclic aromatic hydrocarbon; LPAH, low molecular-weight polycyclic aromatic hydrocarbon; mg/kg, milligram per kilogram; mg/L; na, not applicable; ng/L, nanogram per liter; TEQ, toxic equivalent; VOCs, volatile organic compounds; µg/L, microgram per liter; µg/kg, microgram per kilogram; –, not analyzed]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date					
			05-09-2013		05-31-2013		06-21-2013	
			Result	Q	Result	Q	Result	Q
Total organic carbon	na	percent	2.56		2.34		1.28	
Metals								
Arsenic	7440-38-2	mg/kg	7.4		10.2		10.6	
Barium	7440-39-3	mg/kg	99		134		114	
Cadmium	7440-43-9	mg/kg	0.3	U	0.4		0.4	
Chromium	7440-47-3	mg/kg	24		31		27	
Copper	7440-50-8	mg/kg	32		39		33	
Lead	7439-92-1	mg/kg	9.9		11.7		10.8	
Mercury	7439-97-6	mg/kg	0.1		0.09		0.2	
Nickel	7440-02-0	mg/kg	25		28		24	
Vanadium	7440-62-2	mg/kg	54.6		73.5		63	
Zinc	7440-66-6	mg/kg	80		90		80	
Volatile organic compounds, semivolatile compounds, others								
Phenol	108-95-2	µg/kg	–		120		20	U
Benzyl Alcohol	100-51-6	µg/kg	–		470	J	560	
4-Methylphenol	106-44-5	µg/kg	–		440		20	U
Benzoic Acid	65-85-0	µg/kg	–		350	J	500	
Diethylphthalate	84-66-2	µg/kg	–		150		53	U
bis(2-Ethylhexyl)phthalate	117-81-7	µg/kg	–		82		170	
Acetone	67-64-1	µg/kg	–		–		78	
Butyltin	78763-54-9	µg/kg	2.2	J	3.5	J	3.9	U
Polycyclic aromatic hydrocarbons								
Naphthalene	91-20-3	µg/kg	3.97		4.84		7.08	
2-Methylnaphthalene	91-57-6	µg/kg	6.36		4.89		14.7	
1-Methylnaphthalene	90-12-0	µg/kg	3.42		3.08		6.14	
Acenaphthylene	208-96-8	µg/kg	0.7		0.59		1.61	
Acenaphthene	83-32-9	µg/kg	0.68		0.6		4.38	
Fluorene	86-73-7	µg/kg	1.52		1		6.17	
Phenanthrene	85-01-8	µg/kg	17.1		13.1		35.8	
Anthracene	120-12-7	µg/kg	1.75		1.41		4.51	
Fluoranthene	206-44-0	µg/kg	26.3		15.8		37.6	
Pyrene	129-00-0	µg/kg	25.6		21.4		36.2	
Benzo(a)anthracene	56-55-3	µg/kg	9.25		7.61		15	
Chrysene	218-01-9	µg/kg	18.2		15		28.7	
Benzo(a)pyrene	50-32-8	µg/kg	12.4		10.5		15.2	
Indeno(1,2,3-cd)pyrene	193-39-5	µg/kg	9.76		9.01		14	
Dibenz(a,h)anthracene	53-70-3	µg/kg	2.6		2.29		3.91	
Benzo(g,h,i)perylene	191-24-2	µg/kg	13.9		13.3		19.1	
Dibenzofuran	132-64-9	µg/kg	2.33		1.73		7.17	
Total benzofluoranthenes	TOTBFA	µg/kg	28.5		22.3		35.8	
LPAH	na	µg/kg	25.7		21.5		59.6	

Table 12. Compounds detected in fine bed sediment samples (<62.5 micrometers), Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date					
			05-09-2013		05-31-2013		06-21-2013	
			Result	Q	Result	Q	Result	Q
Polycyclic aromatic hydrocarbons—Continued								
HPAH	na	µg/kg	147		117		206	
Total cPAHs	na	µg/kg	80.7		66.7		113	
Total cPAHs	na	µg TEQ/kg	17.6		14.8		22.4	
Dioxins/furans								
Total tetra-dioxins	41903-57-5	ng/kg	0.204		0.345	UJ	0.415	
Total penta-dioxins	36088-22-9	ng/kg	0.419	J	1.17		0.672	J
Total hexa-dioxins	34465-46-8	ng/kg	4.36	J	14.6		6.83	J
Total hepta-dioxins	37871-00-4	ng/kg	37.2		73.0		67.2	
Total octa-dioxins	3268-87-9	ng/kg	277		423		489	
Total tetra-furans	55722-27-5	ng/kg	0.468		0.677		0.793	
Total penta-furans	30402-15-4	ng/kg	0.376	J	0.629	J	0.275	J
Total hexa-furans	55684-94-1	ng/kg	1.30	J	2.84	J	2.20	J
Total hepta-furans	38998-75-3	ng/kg	7.39		14.9		13.3	
Total octa-furans	39001-02-0	ng/kg	20.6		32.6		34.2	
Total dioxins/furans	na	ng/kg	349		563		614	
Total dioxins/furans	na	ng TEQ/kg	1.84	J	4.39		3.03	J
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])								
Total monochloro biphenyls	27323-18-8	ng/kg	6.06		6.62		10.9	
Total dichloro biphenyls	25512-42-9	ng/kg	44.9		67.4		70.4	
Total trichloro biphenyls	25323-68-6	ng/kg	126		183		213	
Total tetrachloro biphenyls	26914-33-0	ng/kg	327		513		714	
Total pentachloro biphenyls	25429-29-2	ng/kg	847		1,390		2,030	
Total hexachloro biphenyls	26601-64-9	ng/kg	1,060		2,000		2,730	
Total heptachloro biphenyls	28655-71-2	ng/kg	610		1,420		1,970	
Total octachloro biphenyls	55722-26-4	ng/kg	198		552		758	
Total nonachloro biphenyls	53742-07-7	ng/kg	46.4		103		139	
Total decachloro biphenyls	2051-24-3	ng/kg	17		37.4		41.3	
Total PCBs (by HRMS)	1336-36-3	ng/kg	3,280		6,270		8,680	
Polychlorinated biphenyl (PCB) Aroclors (by high-resolution mass spectrometry [HRMS])								
Aroclor 1242	53469-21-9	ng/kg	217		324		375	
Aroclor 1254	11097-69-1	ng/kg	1,240		2,020		2,980	
Aroclor 1260	11096-82-5	ng/kg	1,350		3,070		4,220	
Polychlorinated biphenyl (PCB) Aroclors (by low-resolution mass spectrometry [LRMS])								
Aroclor 1242	53469-21-9	µg/kg	15	U	3.9	U	4	U
Aroclor 1254	11097-69-1	µg/kg	15	U	4.6		12	
Aroclor 1260	11096-82-5	µg/kg	15	U	3.2	J	12	

Comparison of Suspended-Sediment and Bed-Sediment Data

Average concentrations of individual compounds (table 13) in suspended sediment (n=2–4) were greater than average concentrations in fine bed sediment (n=3), which were greater than average concentrations in bulk bed-sediment samples (n=6). Average concentrations of LPAH in bed sediment, however, were greater than in fine bed sediment. Additionally, average total dioxin/furan TEQ concentrations, total PCBs, Aroclor 1254, and Aroclor 1260 were greater in fine bed sediment than in suspended sediment. Suspended-sediment samples were collected on days targeting high flow and (or) high suspended sediment, whereas the bed-sediment samples were collected on different days targeting low-flow conditions (72-hour antecedent rainfall <0.2 in). When the dry weight concentrations were normalized for organic carbon content (table 13), the average concentrations of dioxins/furans and PCBs in fine bed sediment were greater than average concentrations in suspended sediment and bulk bed sediment. In contrast, LPAHs were highest in bulk bed sediment, and HPAHs and total cPAHs were highest in suspended sediment.

The bed-sediment grain-size distribution was similar across the six sampling periods (fig. 5). Between 89.3 and 93.2 percent of the weight was comprised of particles less than or equal to 250 µm, with most of the total weight (64.4–78.0 percent) comprised of particles between 62.5 and 250 µm, whereas 15.1–24.9 percent was fine material less than 62.5 µm. In contrast, the percentage of fine material less than 62.5 µm for the suspended-sediment samples was higher, ranging from 44 percent during the storm peak to 80 percent during a low-precipitation period. A full particle-size analysis of the storm-peak suspended-sediment sample (fig. 5) indicated that the suspended sediment was comprised of very fine material and large particles. Approximately 25 percent of the storm-peak suspended-sediment weight was comprised of particles smaller than 8 µm, compared to 4 percent for the bed-sediment samples (fig. 5). Approximately 23 percent of the storm-peak suspended-sediment sample was comprised of particles greater than 250 µm, compared to 6.8–12.6 percent in bed-sediment samples (fig. 5).

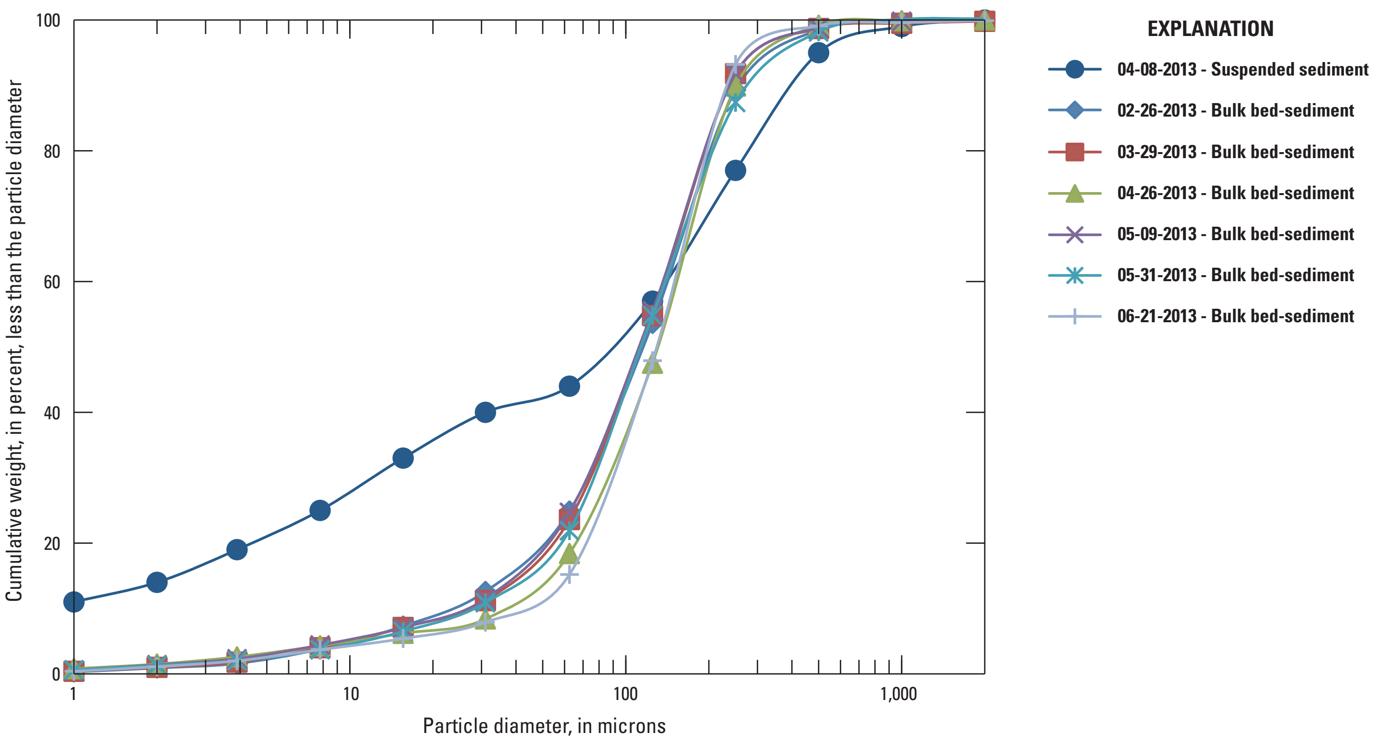

Figure 5. Grain-size distribution of bulk bed-sediment samples (<2 millimeters) and a single storm sample of suspended sediment, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table 13. Comparison of total organic carbon, percent fines, average dry weight concentrations, and average organic carbon normalized concentrations of compounds in suspended sediment, fine bed sediment (<62.5 micrometers), and bulk bed sediment (<2 millimeters), Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample type: Q, qualifer** (Blank cells indicate an unqualified detection); U, not detected above reporting limit; J, estimated. **Abbreviations:** cPAH, carcinogenic polycyclic aromatic hydrocarbon; HPAH, high molecular-weight polycyclic aromatic hydrocarbon; LPAH, low molecular-weight polycyclic aromatic hydrocarbon; mg/kg, milligram per kilogram; mg/L, milligram per liter; mm, millimeter; n, number of samples; ng/L, nanogram per liter; PCB, polychlorinated biphenyl; TEQ, toxic equivalent; TOC, total organic carbon; µg/kg, microgram per kilogram; µg/L, microgram per liter; µm, micrometer; <, less than; >, greater than]

Parameter name	Unit	Suspended sediment (n=2–4)						Fine bed sediment, <62.5 µm (n=3)						Bulk bed sediment, <2 mm (n=6)					
		Average	Q	Minimum	Q	Maximum	Q	Average	Q	Minimum	Q	Maximum	Q	Average	Q	Minimum	Q	Maximum	Q
Total organic carbon	percent	4.77		3.60		6.38		2.06		1.28		2.56		1.78		1.28		2.27	
Fines	percent	61		44		78		98		97		>99		21		15		25	
Dry weight concentrations																			
Metals																			
Arsenic	mg/kg	12.8		10.7		15.7		9.4		7.4		10.6		5.57		4.7		6.5	
Copper	mg/kg	58.3		32.0		86.0		34.7		32.0		39.0		19.9		18.2		21.9	
Mercury	mg/kg	0.15		0.10	U	0.20		0.13		0.09		0.20		0.042		0.04	U	0.05	
Polycyclic aromatic hydrocarbons																			
LPAH	µg/kg	97.8		58.4		137		35.6		21.5		59.6		43.9		23.5		58.8	
HPAH	µg/kg	451		436		466		156		117		206		98.6		53.6		154	
Total cPAHs	µg/kg	249		233		265		86.7		66.7		112.6		53.5		28.4		82.4	
Total cPAHs	µg TEQ/kg	51.3		47.6		54.9		18.2		14.8		22.4		11.1		5.91		17.6	
Dioxins/furans																			
Total dioxins/furans	ng/kg	580		269		801		509		349		614		122		80.0		175	
Total dioxins/furans	ng TEQ/kg	2.83	J	1.27	J	4.20	J	3.08		1.84	J	4.39		0.743		0.556	J	0.944	J
Polychlorinated biphenyl (PCB) homologues by high-resolution mass spectrometry (HRMS)																			
Total PCBs	µg/kg	3.98		2.43		5.36		6.08		3.28		8.68		2.39		1.39		3.71	
Aroclor 1242	µg/kg	0.507		0.397		0.571		0.305		0.217		0.375		0.146		0.111		0.172	
Aroclor 1254	µg/kg	1.68		0.991		2.32		2.08		1.24		2.98		0.936		0.585		2.01	
Aroclor 1260	µg/kg	1.14		0.676		1.71		2.88		1.35		4.22		1.07		0.444		2.67	
Organic carbon-normalized concentrations																			
Polycyclic aromatic hydrocarbons																			
LPAH	mg/kg TOC	2.05		1.62		2.15		1.73		1.68		2.33		2.47		1.84		2.59	
HPAH	mg/kg TOC	9.46		12.1		7.31		7.59		9.16		8.03		5.55		4.19		6.77	
Total cPAHs	mg/kg TOC	5.23		6.48		4.16		4.21		5.21		4.40		3.01		2.22		3.63	
Total cPAHs	mg TEQ/kg TOC	1.08		1.32		0.861		0.885		1.15		0.873		0.622		0.462		0.777	
Dioxins/furans																			
Total dioxins/furans	ng/kg TOC	12.2		7.47		12.6		24.7		27.3		24.0		6.87		6.27		7.70	
Total dioxins/furans	ng TEQ/kg TOC	62.0	J	36.8	J	68.2	J	149		144	J	167		42.7		42.1	J	45.9	J
Polychlorinated biphenyl (PCB) homologues by high-resolution mass spectrometry (HRMS)																			
Total PCBs	µg/kg TOC	83.5		67.4		84.0		295		256		339		134		109		163	
Aroclor 1242	µg/kg TOC	10.6		11.0		9.0		14.8		17.0		14.6		8.2		8.7		7.6	
Aroclor 1254	µg/kg TOC	35.3		27.5		36.4		101		96.9		116		52.6		45.7		88.5	
Aroclor 1260	µg/kg TOC	23.9		18.8		26.8		140		105		165		60.4		34.6		118	

Instantaneous-Load Estimates

Instantaneous chemical loads based on concentrations in whole water are presented in table 14. The highest loads occurred during the storm-peak sampling because of the high discharge and high whole-water concentrations. For example, TOC loading was 2–5 times higher, arsenic loading was 3–10 times higher, and total PCBs were 2–8 times higher during the storm peak than during other sampling periods. Instantaneous suspended-sediment loads (table 15) ranged from approximately 1,000 kg/hr during a low-precipitation period to more than 40,000 kg/hr during the storm peak. The highest chemical loads based on suspended-sediment chemical concentrations (table 15) occurred during the storm-peak sampling because of the elevated discharge, elevated suspended-sediment concentrations, and elevated chemical concentrations on suspended sediment. For example, TOC loading was 3–11 times higher, arsenic was 6–14 times higher, and total PCBs were more than 50 times higher during the storm peak than during other sampling periods.

Table 14. Instantaneous chemical loads based on concentrations in whole water, Duwamish River, Washington, 2013.

[Non-detected compounds (U or UJ) were assigned a zero value for loading calculations. **Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); na, not applicable; U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; **Abbreviations:** ft^3/s, cubic foot per second; g/hr, gram per hour; kg/hr, kilogram per hour; L/s, liter per second; µg/hr, microgram per hour; mg/hr, milligram per hour; TEQ, toxic equivalent; –, not analyzed]

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type													
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		04-29-2013		05-13-2013		06-19-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
72-hour antecedent precipitation	na	inch	0.21		0.22		0.90		1.3		0.09		0.40		0.04	
Discharge	na	ft^3/s	2,460		1,480		2,490		4,955		2,620		2,750		816	
Discharge	na	L/s	69,700		41,900		70,500		140,000		74,200		77,900		23,100	
Total organic carbon	na	kg/hr	574		281		0	U	1,400		692		0	U	0	U
Metals																
Arsenic	7440-38-2	g/hr	150		91		178		606		160		140		58	
Barium	7440-39-3	g/hr	828		468		1,090		5,610		1,020		1,090		283	
Chromium	7440-47-3	g/hr	577		151		355		1,520		454		224		50	
Copper	7440-50-8	g/hr	0	U	0	U	0	U	758		0	U	0	U	0	U
Lead	7439-92-1	g/hr	50		30		102		354		53		56		0	U
Nickel	7440-02-0	g/hr	0	U	0	U	152		909		0	U	0	U	0	U
Vanadium	7440-62-2	g/hr	276		121		381		1,870		347		364		67	
Zinc	7440-66-6	g/hr	0	U	0	U	0	U	3,540		0	U	0	U	0	U
Dioxins/furans[1]																
Total hepta-dioxins	37871-00-4	µg/hr	0	UJ	151	J	652	J	1,935	J	347	J	–		–	
Total octa-dioxins	3268-87-9	µg/hr	0	UJ	0	UJ	0	UJ	12,527		3,178	J	–		–	
Total hepta-furans	38998-75-3	µg/hr	0	UJ	0	UJ	241	J	515	J	138	J	–		–	
Total octa-furans	39001-02-0	µg/hr	0	UJ	0	UJ	609	J	1,318	J	0	UJ	–		–	
Total dioxins/furans	na	µg/hr	0	UJ	151	J	1,503	J	16,295	J	3,664	J	–		–	
Total dioxins/furans	na	µg TEQ/hr	0	UJ	119	J	203	J	430	J	221	J	–		–	
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])[1]																
Total monochloro biphenyls	27323-18-8	mg/hr	0	UJ	1.27		0.50	J	1.37	J	2.09	J	–		–	
Total dichloro biphenyls	25512-42-9	mg/hr	1.70		1.63		0	UJ	6.07		4.29		–		–	
Total trichloro biphenyls	25323-68-6	mg/hr	2.31	J	0.66	J	0.60	J	3.62	J	4.53	J	–		–	
Total tetrachloro biphenyls	26914-33-0	mg/hr	0	UJ	1.07	J	5.54	J	14.4	J	2.84	J	–		–	
Total pentachloro biphenyls	25429-29-2	mg/hr	2.53	J	2.99		12.9		20.4	J	4.75	J	–		–	
Total hexachloro biphenyls	26601-64-9	mg/hr	4.96	J	1.71	J	13.2	J	30.5	J	2.67	J	–		–	
Total heptachloro biphenyls	28655-71-2	mg/hr	2.54	J	1.30	J	5.73		14.3	J	0.23	J	–		–	
Total octachloro biphenyls	55722-26-4	mg/hr	0	UJ	0.22	J	0.86	J	2.21	J	0	UJ	–		–	

Table 14. Instantaneous chemical loads based on concentrations in whole water, Duwamish River, Washington, 2013.—Continued

Parameter name	Chemical Abstracts Service No.	Unit	Sample date and type													
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		04-29-2013		05-13-2013		06-19-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])[1]—Continued																
Total nonachloro biphenyls	53742-07-7	mg/hr	0	UJ	0	UJ	0.77	J	0	UJ	0	UJ	–		–	
Total decachloro biphenyls	2051-24-3	mg/hr	0	UJ	0.24	J	0	UJ	0	UJ	0	UJ	–		–	
Total PCBs (by HRMS)[1]	1336-36-3	mg/hr	14.0	J	11.1	J	40.2	J	92.9	J	21.4	J	–		–	
Polychlorinated biphenyl Aroclors (by high-resolution mass spectrometry [HRMS])[1]																
Aroclor 1242	53469-21-9	mg/hr	0	UJ	2.94		0	UJ	7.73		4.43		–		–	
Aroclor 1254	11097-69-1	mg/hr	0	UJ	0	UJ	0	UJ	0	UJ	0	UJ	–		–	
Aroclor 1260	11096-82-5	mg/hr	4.79		2.99	J	19.0		31.2	J	0	UJ	–		–	
Polychlorinated biphenyl Aroclors (by low-resolution mass spectrometry [LRMS])																
Aroclor 1242	53469-21-9	mg/hr	0	U	0	U	0	U	0	U	0	U	–		–	
Aroclor 1254	11097-69-1	mg/hr	0	U	0	U	0	U	0	U	0	U	–		–	
Aroclor 1260	11096-82-5	mg/hr	0	U	0	U	0	U	0	U	0	U	–		–	

Table 15. Instantaneous suspended-sediment loads and chemical loads based on concentrations in suspended-sediment, Duwamish River at Golf Course at Tukwila, Washington, 2013.

[**Sample date and type: Q, qualifer** (Blank cells indicate an unqualified detection); na, not applicable; U, not detected above reporting limit; UJ, not detected above detection limit; J, estimated; **Abbreviations:** cm, centimeter; mg/L, ft^3/s, cubic feet per second; g/hr, gram per hour; kg/hr, kilogram per hour; L/s, liter per second; µg/hr, microgram per hour; mg/hr, milligram per hour; mg/L, milligram per liter; TEQ, toxic equivalent; –, not analyzed]

Parameter name	Chemical Abstract Service No.	Unit	Sample date and type									
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		05-13-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
72-hour antecedent precipitation	na	inch	0.21		0.22		0.90		1.3		0.40	
Discharge	na	ft^3/s	2,460		1,480		2,490		4,955		2,750	
Discharge	na	L/s	69,700		41,900		70,500		140,000		77,900	
Suspended sediment concentration	na	mg/L	12		7		17		81		31	
Instantaneous suspended-sediment load	na	kg/hr	3,010		1,060		4,320		40,900		8,690	
Total organic carbon	na	kg/hr	–		–		155		1,770		554	
Metals												
Arsenic	7440-38-2	g/hr	–		–		46.2		642		104	
Barium	7440-39-3	g/hr	–		–		505		8,760		1,120	
Chromium	7440-47-3	g/hr	–		–		324		6,960		18,900	
Copper	7440-50-8	g/hr	–		–		138		2,330		747	
Lead	7439-92-1	g/hr	–		–		47.9		724		86.9	
Mercury	7439-97-6	g/hr	–		–		0.432		8.18		0	U
Nickel	7440-02-0	g/hr	–		–		216		4,660		9,820	
Vanadium	7440-62-2	g/hr	–		–		255		4,380		487	
Zinc	7440-66-6	g/hr	–		–		475		6,960		869	
Polycyclic aromatic hydrocarbons												
Naphthalene	91-20-3	mg/hr	–		–		39.5		1,130		–	
2-methylnaphthalene	91-57-6	mg/hr	–		–		82.4		2,230		–	
1-methylnaphthalene	90-12-0	mg/hr	–		–		35.6		1,200		–	
Acenaphthylene	208-96-8	mg/hr	–		–		0	U	187		–	
Acenaphthene	83-32-9	mg/hr	–		–		0	U	150		–	
Fluorene	86-73-7	mg/hr	–		–		0	U	381		–	
Phenanthrene	85-01-8	mg/hr	–		–		193		3,130		–	
Anthracene	120-12-7	mg/hr	–		–		19.5		634		–	
Fluoranthene	206-44-0	mg/hr	–		–		309		3,210		–	
Pyrene	129-00-0	mg/hr	–		–		316		3,310		–	
Benzo(a)anthracene	56-55-3	mg/hr	–		–		110		1,200		–	
Chrysene	218-01-9	mg/hr	–		–		255		2,290		–	
Benzo(a)pyrene	50-32-8	mg/hr	–		–		162		1,330		–	
Indeno(1,2,3-cd)pyrene	193-39-5	mg/hr	–		–		159		1,180		–	

Table 15. Instantaneous suspended-sediment loads and chemical loads based on concentrations in suspended-sediment, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstract Service No.	Unit	Sample date and type									
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		05-13-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polycyclic aromatic hydrocarbons—Continued												
Dibenz(a,h)anthracene	53-70-3	mg/hr	–		–		40.0		329		–	
Benzo(g,h,i)perylene	191-24-2	mg/hr	–		–		242		1,770		–	
Dibenzofuran	132-64-9	mg/hr	–		–		24.9		565		–	
Total benzofluoranthenes	TOTBFA	mg/hr	–		–		419		3,210		–	
LPAH	na	mg/hr	–		–		252		5,610		–	
HPAH	na	mg/hr	–		–		2,010		17,800		–	
Total cPAHs	na	mg/hr	–		–		1,150		9,540		–	
Total cPAHs	na	mg TEQ/hr	–		–		237		1,950		–	
Dioxins/furans												
Total tetra-dioxins	41903-57-5	µg/hr	0.460	J	0.365		0	U	14.9		–	
Total penta-dioxins	36088-22-9	µg/hr	0.870	J	0.654	J	2.49	J	34.6	J	–	
Total hexa-dioxins	34465-46-8	µg/hr	8.73		6.30		40.4		504		–	
Total hepta-dioxins	37871-00-4	µg/hr	82.5		64.7		332		3,780		–	
Total octa-dioxins	3268-87-9	µg/hr	653		496		2,160		24,800		–	
Total tetra-furans	55722-27-5	µg/hr	1.15		0.840		2.46		36.0		–	
Total penta-furans	30402-15-4	µg/hr	0.915	J	0.651	J	2.31	J	17.8	J	–	
Total hexa-furans	55684-94-1	µg/hr	2.91	J	2.15	J	10.4	J	138	J	–	
Total hepta-furans	38998-75-3	µg/hr	16.7		14.1		83.8		937			
Total octa-furans	39001-02-0	µg/hr	41.8		32.2		243		2,553		–	
Total dioxins/furans	na	µg/hr	808		618		2,878		32,779		–	
Total dioxins/furans	na	µg TEQ/hr	3.83		2.89		13.4		172		–	
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])												
Total monochloro biphenyls	27323-18-8	mg/hr	0.019		0.014		0.035		0.506		–	
Total dichloro biphenyls	25512-42-9	mg/hr	0.323		0.163		0.823		7.07		–	
Total trichloro biphenyls	25323-68-6	mg/hr	0.700		0.340		1.27		13.3		–	
Total tetrachloro biphenyls	26914-33-0	mg/hr	1.20		0.635		2.30		27.5		–	
Total pentachloro biphenyls	25429-29-2	mg/hr	1.92		1.23		4.77		62.9		–	
Total hexachloro biphenyls	26601-64-9	mg/hr	1.75		1.08		4.87		62.2		–	
Total heptachloro biphenyls	28655-71-2	mg/hr	0.927		0.431		2.56		30.4		–	

Table 15. Instantaneous suspended-sediment loads and chemical loads based on concentrations in suspended-sediment, Duwamish River at Golf Course at Tukwila, Washington, 2013.—Continued

Parameter name	Chemical Abstract Service No.	Unit	Sample date and type									
			02-07-2013		03-13-2013		04-05-2013		04-08-2013		05-13-2013	
			Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polychlorinated biphenyl (PCB) homologues (by high-resolution mass spectrometry [HRMS])—Continued												
Total octachloro biphenyls	55722-26-4	mg/hr	0.303		0.177		1.11		10.9		–	
Total nonachloro biphenyls	53742-07-7	mg/hr	0.107		0.053		0.354		2.98		–	
Total decachloro biphenyls	2051-24-3	mg/hr	0.049		0.024		0.069		1.25		–	
Total PCBs (by HRMS)	1336-36-3	mg/hr	7.30		4.15		18.2		219		–	
Polychlorinated biphenyl Aroclors (by high-resolution mass spectrometry [HRMS])												
Aroclor 1242	53469-21-9	mg/hr	1.19		0.584		2.18		23.4		–	
Aroclor 1254	11097-69-1	mg/hr	2.98		1.84		7.21		94.9		–	
Aroclor 1260	11096-82-5	mg/hr	2.03		0.841		5.91		70.0		–	
Polychlorinated biphenyl Aroclors (by low-resolution mass spectrometry [LRMS])												
Aroclor 1242	53469-21-9	mg/hr	–		–		–		–		–	
Aroclor 1254	11097-69-1	mg/hr	–		–		–		–		–	
Aroclor 1260	11096-82-5	mg/hr	–		–		–		–		–	

Summary

Data were collected between February and June 2013 by the U.S. Geological Survey to provide sediment and chemical concentrations and preliminary load estimates to the Lower Duwamish Waterway from upstream sources transported by the Green River, Washington. During five low-precipitation periods, the rising limb of a storm, and the peak of a storm, measurements were collected of instantaneous discharge, field parameters, whole water chemistry, suspended-sediment concentration, and suspended-sediment chemistry. Stream discharge, suspended-sediment concentration, and chemical concentrations in whole water and associated with suspended sediment generally were higher during the storm than during low-precipitation periods. This resulted in higher sediment and chemical-loading estimates during the storm than during low-precipitation periods.

Acknowledgments

This work was done under USGS-Ecology Interagency Agreement 13WNWA3005. The following USGS employees and volunteers provided invaluable field and laboratory help: Curtis Chabot, James Foreman, Andrew Gendaszek, Raegan Huffman, Greg Justin, Cameron Marshall, Fred Reed, Rich Sheibley, Stephen Sissel, Andrew Spanjer, and David Steele. We are very grateful to Kelly Smalling and Ronald Baker for conducting the time-intensive Level 4 data validation in a timely manner. We thank Curt Chandler and staff at the Foster Golf Course in Tukwila, Washington for access and use of the bridge and facilities throughout the project.

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Appendix A. Analytical Laboratory Qualifier Descriptions, Result Amendments, and Complete Analytical Chemistry Results

Qualifiers were used by each of the two analytical chemistry laboratories and amendments were made to these qualifiers to be consistent with Ecology protocols. Then, the complete analytical results, including non-detected compounds, are reported (with amended qualifiers) in six tables.

The following qualifiers were used by Analytical Resources, Inc. (ARI):

B	Analyte detected in an associated method blank at a concentration greater than one-half of ARI's reporting limit (RL), or 5 percent of the regulatory limit, or 5 percent of the analyte concentration in the sample.
J	Estimated concentration when the value is less than ARI's established reporting limits (RL>result>detection limit [DL]).
Q	A detected analyte with an initial or continuing calibration that does not meet established acceptance criteria (<20 percent Relative Standard Deviation, <20 percent drift, or minimum Relative Response Factor).
U	Indicates that the target analyte was not detected at the RL.
Y	The analyte was not detected at or above the RL. The RL was raised due to chromatographic interference. The Y flag is equivalent to the U flag with a raised reporting limit.

The following qualifiers were used by AXYS Analytical, Ltd.:

B	Analyte detected in the sample and the associated blank.
C	Congener co-elution.
D	Dilution data.
G	Disturbance of the mass ion used to monitor instrument performance (lock-mass) present.
J	Indicates an estimated value where the concentration of the analyte is less than the RL, but greater than the detection limit (DL).
K	A peak was detected that did not meet all the criteria for identification as the target analyte; the reported value is the estimated maximum possible concentration (EMPC). This is equivalent to the N qualifier used in Ecology's Environmental Information Management system.
NQ	Not quantifiable.
U	Not detected at DL.

Differences between various laboratory and agency protocols for coding analytical data to address measurement considerations and (or) abnormalities are common.

Adjustments to the laboratory-provided qualifiers from laboratories used in this study were made to be consistent with Ecology's Toxics Cleanup Program data reporting protocols (Washington State Department of Ecology, 2008), as outlined in the U.S. Environmental Protection Agency Functional Guidelines (U.S. Environmental Protection Agency, 2008, 2009, 2010, and 2011). Briefly, data that had been flagged or qualified by the laboratory or during the Level 2 or Level 4 review process with qualifiers other than U- and J-containing qualifiers were amended following these protocols:

For non-detect high-resolution mass spectrometery (HRMS) values, the DL was reported with a UJ qualifier.

For all other non-detected analytes, the RL was reported with a U qualifier.

For ease of viewing, informational qualifiers (C and D) were removed.

Y qualifiers were changed to U.

Q-containing qualifiers and G-containing qualifiers were changed to J.

NQ qualifiers were changed to R, indicating that the sample was rejected because of the inability to analyze the sample and meet quality control objectives.

K qualifiers, which can be interpreted as the estimated maximum possible concentration, were changed to UJ.

If the K was qualifying method blank results, the B qualifier was removed from associated sample results

B qualifiers were removed or changed according to the following rules:

- If the sample concentration is greater than five times the associated laboratory blank, sample results are considered as positive without qualifiers (action: remove B). For common laboratory contaminants (acetone, 2-butanone, methylene chloride, toluene, phthalate esters), metals, and HRMS compounds, 10 times was used instead of 5 times.
- If the sample concentration was less than 5 times (≤10 times was used for common laboratory contaminants, metals, and HRMS compounds), the associated laboratory blank and greater than the RL, it was reported at the detected sample concentration with U qualifier.
- If the sample concentration was less than or equal to 5 times (≤10 times was used for common laboratory contaminants, metals, and HRMS compounds), the associated laboratory blank and less than the RL.
- For non-HRMS compounds, it was reported at the RL with a U qualifier for non-HRMS compounds (there were no cases in this data set).
- For HRMS compounds, it was reported at the detected sample concentration with UJ qualifier.

The data presented in tables A1–A6 are the complete results from Analytical Resources, Inc. and AXYS Analytical, Ltd., with amended qualifiers by the U.S. Geological Survey. The tables can be accessed at http://pubs.usgs.gov/ds/0880.

Table A1. Whole water results, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table A2. Whole water-quality assurance results, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table A3. Suspended-sediment results, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table A4. Suspended-sediment quality assurance results Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table A5. Bed-sediment results, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Table A6. Bed-sediment quality assurance results, Duwamish River at Golf Course at Tukwila, Washington, 2013.

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the
Director, Washington Water Science Center
U.S. Geological Survey
934 Broadway, Suite 300
Tacoma, Washington 98402
http://wa.water.usgs.gov

Conn and Black—**Data Compilation for Assessing Sediment and Toxic Chemical Loads, Green River to Lower Duwamish Waterway, Washington**—Data Series 880

ISSN 2327-638X (online)
http://dx.doi.org/10.3133/ds880