

Prepared in cooperation with the Washington State Department of Ecology

Chemical Concentrations and Instantaneous Loads, Green River to the Lower Duwamish Waterway near Seattle, Washington, 2013–15



Data Series 973

Cover: Photographs of the Duwamish River at the bridge at U.S. Geological Survey streamgage 12113390 during baseline conditions, January 4, 2013 (left), as compared to near-flood conditions driven by precipitation and operations at the Howard Hanson Dam in the upper watershed, March 7, 2015 (right). Photographs by Kathleen Conn, U.S. Geological Survey.

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By Kathleen E. Conn, Robert W. Black, Ann M. Vanderpool-Kimura, James R. Foreman, Norman T. Peterson, Craig A. Senter, and Stephen K. Sissel

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Conversion Factors

Inch/Pound to International System of Units

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)

Conversion Factors

International System of Units 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)
Area		
square kilometer (km ²)	247.1	acre
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
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)
picogram per liter (pg/L)		part per quadrillion (ppqn, 10 ¹⁵)

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

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

Datums

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

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

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Turbidity is given in Formazin Nephelometric Units (FNU).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g}/\text{L}$), or picograms per liter (pg/L).

Abbreviations

ARI	Analytical Resources, Inc.
AXYS	AXYS Analytical Services, Ltd.
cPAHs	carcinogenic polycyclic aromatic hydrocarbons
CVO	U.S. Geological Survey Cascades Volcano Observatory Sediment Laboratory
DL	detection limit
DOC	dissolved organic carbon
Ecology	Washington State Department of Ecology
EDI	equal-discharge increment
FNU	Formazin Nephelometric Units
GC/MS	gas chromatography/mass spectrometry
HPAH	high molecular-weight polycyclic aromatic hydrocarbons
HRMS	high-resolution mass spectrometry
LDW	Lower Duwamish Waterway
LPAH	low molecular-weight polycyclic aromatic hydrocarbons
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PSD	particle-size distribution
RKM	river kilometer
RL	reporting limit
SRM	Sediment Reference Material
SSC	suspended-sediment concentration
STM	Sediment Transport Model
TEQ	toxic equivalent
TOC	total organic carbon
EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOCs	volatile organic compounds

Chemical Concentrations and Instantaneous Loads, Green River to the Lower Duwamish Waterway near Seattle, Washington, 2013–15

By Kathleen E. Conn, Robert W. Black, Ann M. Vanderpool-Kimura, James R. Foreman, Norman T. Peterson, Craig A. Senter, and Stephen K. Sissel

Abstract

In November 2013, U.S. Geological Survey streamgaging equipment was installed at a historical water-quality station on the Duwamish River, Washington, within the tidal influence at river kilometer 16.7 (U.S. Geological Survey site 12113390; Duwamish River at Golf Course at Tukwila, WA). Publicly available, real-time continuous data includes river streamflow, stream velocity, and turbidity. Between November 2013 and March 2015, the U.S. Geological Survey collected representative samples of water, suspended sediment, or bed sediment from the streamgaging station during 28 periods of differing flow conditions. Samples were analyzed by Washington-State-accredited laboratories for a large suite of compounds, including metals, dioxins/furans, semivolatile compounds including polycyclic aromatic hydrocarbons, pesticides, butyins, polychlorinated biphenyl (PCB) Aroclors and the 209 PCB congeners, volatile organic compounds, hexavalent chromium, and total and dissolved organic carbon. Metals, PCB congeners, and dioxins/furans were frequently detected in unfiltered-water samples, and concentrations typically increased with increasing suspended-sediment concentrations. Chemical concentrations in suspended-sediment samples were variable between sampling periods. The highest concentrations of many chemicals in suspended sediment were measured during summer and early autumn storm periods.

Median chemical concentrations in suspended-sediment samples were greater than median chemical concentrations in fine bed sediment (less than 62.5 μm) samples, which were greater than median chemical concentrations in paired bulk bed sediment (less than 2 mm) samples. Suspended-sediment concentration, sediment particle-size distribution, and general water-quality parameters were measured concurrent with the chemistry sampling. From this discrete data, combined with the continuous streamflow record, estimates of instantaneous sediment and chemical loads from the Green River to the Lower Duwamish Waterway were calculated. For most compounds, loads were higher during storms than during baseline conditions because of high streamflow and high

chemical concentrations. The highest loads occurred during dam releases (periods when stored runoff from a prior storm is released from the Howard Hanson Dam into the upper Green River) because of the high river streamflow and high suspended-sediment concentration, even when chemical concentrations were lower than concentrations measured during storm events.

Introduction

The Lower Duwamish Waterway (LDW) is the final 8-km-long reach of the Green/Duwamish River. The LDW enters Puget Sound's Elliott Bay 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 manufacturing of airplane parts, boats, concrete, food processing, marinas, and roads. 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 1.8 km² LDW under the Federal Superfund law and the Washington Model Toxics Control Act because of concerns 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, about 47 compounds (including individual metals, polycyclic aromatic hydrocarbons [PAHs], phthalates, and other volatile and semivolatile organic compounds) have numeric criteria in the Ecology 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 complete or near completion (with a target date of 2015). The EPA's final cleanup plan for the remaining areas was released in November 2014 and includes using combinations of dredging, capping, natural sedimentation, and enhanced natural recovery.

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2013 NAIP (National Agricultural Imagery Program) 1 meter imagery,
U.S. Department of Agriculture's Farm Service Agency,
Washington State Plane South, NAD83

Figure 1. U.S. Geological Survey (USGS) sampling station relative to the Lower Duwamish Waterway, Seattle, Washington. Modified from Conn and Black (2014).

To support the implementation of a cleanup plan of contaminated sediments in the LDW, Ecology is leading source control activities and a watershed-scale pollutant loading assessment 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 (1) resuspended bed sediment within the LDW, (2) lateral sources from land adjacent to the LDW, and (3) 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 [fig. 1]). The river originates in the Cascade Mountains and travels approximately 150 km through an increasingly developed watershed to Elliott Bay, Puget Sound, Washington. The Howard Hanson Dam located at RKM 103 regulates streamflow primarily for flood control. During winter, the reservoir behind Howard Hanson Dam collects excess runoff from the upper 570 square kilometers of the Green River basin. Between storms, the reservoir is kept nearly empty and the river flows through the dam in a gate-controlled tunnel. The gates are adjusted to hold back excess runoff in the reservoir during storms, and the stored runoff is released at relatively high rates that stay within the capacity of the downstream channel soon after a storm. The stored runoff is released as soon as safely possible to make storage space available for subsequent storm runoff, and this cycle is repeated as often as necessary during fall through spring. These periods of high rates of release are referred to in this report as dam releases.

The Sediment Transport Model (STM) developed for the LDW by AECOM Technology Corporation estimates that, on average, more than 185,000 metric tons of sediment enters the LDW each year. Greater than 99 percent of the sediment originates at upstream sources, whereas 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 estimates that about 90 percent of the total bed area in the LDW will receive 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.

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 streamflow 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 streamflow data were from a U.S. Geological Survey (USGS) streamgaging station located in Auburn, Washington, more than 40 RKM upstream of the LDW. The

Lower Duwamish Waterway Group (2008) 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 were extrapolated from five historical data sets from Ecology, the U.S. Army Corps of Engineers, and King County, Washington. Only one of those data sets, from Ecology (Gries and Sloan, 2009), measured contaminants in suspended sediment (the other studies measured surficial bed-sediment or unfiltered 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 a hydrograph of high flow periods. 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 surficial bed-sediment data, and 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 numerous factors, including antecedent weather, precipitation, streamflow, seasonality, suspended-sediment concentration (SSC), sediment organic carbon content, particle-size distribution (PSD), and upstream activities including dam operations. The USGS, in cooperation with Ecology, is providing estimates of annual sediment loading and toxic chemical loading from suspended sediment from the Green River to the LDW based on concurrent, representative measurements of streamflow, SSC, 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 of the river mouth. During low-flow conditions (for example, less than 500 ft³/s), tidal influences extend at least 27 km upstream. The upstream boundary of the LDW, determined by the Lower Duwamish Superfund Site (Lower Duwamish Waterway Group, 2012) to be at RKM 8, is an estuarine environment strongly influenced by the tidal cycle. The sole location of operation for this study was USGS streamgaging station Duwamish River at Golf Course at Tukwila, Washington; site 12113390 (figs. 1 and 2). This sampling area has a private bridge that facilitates access to the river at about RKM 16.7, which is upstream of the estuarine environment but still within the tidally-influenced section of the basin. Sampling at this streamgauge minimized the potential for collection of re-suspended sediment from the LDW and transported upstream during high tides. Historical water and

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bed-sediment chemistry data were collected at this station under the USGS National Water Quality Assessment Program between 1995 and 2004. Development along the river between the upper boundary of the LDW (RKM 8) and the sampling station (RKM 16.7) includes a golf course, a small commercial complex, and residential properties. The contaminant contributions to the river from this reach, which were not measured in this study, primarily consist of stormwater outfalls.



Figure 2. U.S. Geological Survey field personnel measuring streamflow at the Duwamish River at Golf Course at Tukwila, Washington (12113390), at river kilometer 16.7. Photograph by Kathleen Conn, U.S. Geological Survey, January 11, 2014.

This report presents data from discrete sampling of water, suspended sediment, and bed sediment at USGS streamgage 12113390 on the Duwamish River upstream of the LDW between November 2013 and March 2015. Unfiltered-water, suspended-sediment, and bed-sediment samples were analyzed for PCB congeners and Aroclors, dioxins/furans, metals, PAHs and other semivolatile organic compounds, volatile organic compounds (VOCs), pesticides, butyltins, hexavalent chromium, total organic carbon (TOC), and PSD. Filtered-water samples were analyzed for dissolved organic carbon (DOC) and metals. Field measurements were made of temperature, pH, specific conductance, dissolved oxygen, turbidity, and barometric pressure. The chemical results coupled with the continuous record of river streamflow and turbidity from the co-located USGS streamgaging station and measurements of SSC provide estimates of instantaneous sediment and chemical loads associated with upstream sources in the Green River to the LDW.

Methods

Continuous Real-Time Monitoring

In November 2013, USGS streamgaging equipment was installed at a historical water-quality station (USGS site 12113390; Duwamish River at Golf Course at Tukwila, Washington) on the Duwamish River, Washington, within the tidal influence at river kilometer 16.7 (fig. 3A). Instrumentation at the station includes an in-river DTS-12 turbidity sensor (Forest Technology Systems, LTD, fig. 3B), a wire-weight gage and pressure transducer for stage measurement, and two submerged acoustic Doppler velocity meters (a Sontek SL 1500 and a SonTek Argonaut SW [fig. 3C], installed side-by-side by USGS divers [fig. 3D]). Using methods described by Levesque and Oberg (2012), data from acoustic Doppler velocity meters are indexed to derive a mean velocity for a designated standard-area cross section that is then used in conjunction with the stage-derived area (for the same cross section) to compute 15-minute forward or reverse streamflow information, in cubic feet per second, past the tidally-influenced station. Positive streamflow values indicate flow to the northwest toward the LDW, whereas negative streamflow values indicate upstream flow to the southeast (fig. 1). The provisional real-time data, including streamflow, stream velocity, gage height, turbidity, and water temperature



Figure 3. (A) real-time streamgaging station, (B) turbidity sensor, (C) acoustic Doppler velocity meters, and (D) installation by U.S. Geological Survey divers at Duwamish River at Golf Course at Tukwila (12113390), Washington. Photographs by Kathleen Conn, U.S. Geological Survey, on (A) November 22, 2013, (B) November 7, 2013, and (C–D) November 22, 2013.

were publicly available for the duration of the USGS-Ecology agreement (http://waterdata.usgs.gov/nwis/inventory/?site_no=12113390&agency_cd=USGS&?). The records were compiled, reviewed, and approved by the USGS in a timely manner consistent with USGS protocols (Levesque and Oberg, 2012).

Field Sampling and Processing

Between November 2013 and March 2015, 24 bridge-based sampling efforts were completed by the USGS over a range of flow and sediment conditions. Additionally, four sets of bed-sediment samples were collected by boat or from the bank during separate low-flow conditions. Real-time

turbidity and streamflow conditions from the co-located USGS streamgaging station were used to initiate sampling periods. During each bridge-based sampling period, as many as five concurrent tasks included measurement of instantaneous streamflow, general water quality, water chemistry, suspended-sediment physical parameters, and suspended-sediment chemistry. Fewer than five tasks occurred on days when personnel or equipment were limited (for example, a hydrographer or equipment was unavailable for an instantaneous streamflow measurement) or when the river conditions did not justify the field effort required for suspended-sediment chemistry sampling (for example, a predicted storm did not occur). A sixth task, bed-sediment chemistry, occurred during the four bed-sediment sampling periods. A summary of these tasks is contained in [table 1](#).

Table 1. Field tasks, parameters collected, collection methods, references, and laboratories completing each task, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[Task No.: Corresponds to the task Nos. in the text. **Abbreviations:** ARI, Analytical Resources, Inc., Tukwila, Washington; AXYS, AXYS Analytical, LTD, Sidney, British Columbia, Canada; CVO, U.S. Geological Survey Cascades Volcano Observatory Sediment Laboratory, Vancouver, Washington; FNU, Formazin Nephelometric Units; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; USGS WAWSC, U.S. Geological Survey Washington Water Science Center, Tacoma, Washington; cm, centimeter; °C, degrees Celsius; ft³/s, cubic foot per second; L, liter; m, meter; mg/L, milligram per liter; mm Hg, millimeters of mercury; µg/L, microgram 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 method	Analyzing laboratory	Notes
1	Instantaneous streamflow	River streamflow (ft ³ /s)	Acoustic Doppler current profiler (ADCP)	Mueller and others (2009)	USGS WAWSC	–
2	General water quality (field parameters)	Water temperature (°C), pH, dissolved oxygen (mg/L), specific conductance (µS/cm), turbidity (FNU), barometric pressure (mm Hg)	YSI Inc. multiparameter sonde deployed with VOC sampler (see Task 3b) at 60 percent of depth in the river thalweg	Wilde (variously dated)	USGS WAWSC	–
3a	Water chemistry	High-resolution dioxins/furans and 209 PCB congeners. Also metals, PAHs and other semivolatile compounds, pesticides, butyltins, PCB Aroclors, 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 (2005); U.S. Geological Survey (2006)	AXYS (high-resolution parameters) and ARI	–
3b	Water chemistry (volatile organic compounds)	Volatile organic compounds (µg/L). See appendix A for analyte list.	USGS hand-held sampler designed to minimize chemical loss. Sample collected at 60 percent of depth in thalweg.	Shelton (1997)	ARI	–
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)	CVO	These samples did not receive any chemical analyses. Results were used with the suspended-sediment chemistry sampling results (see task 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, 2013–15.—Continued

Task No.	Field tasks	Parameter collected	Collection method	Published collection method	Analyzing laboratory	Notes
5	Suspended-sediment chemistry	High-resolution dioxins/furans and 209 PCB congeners. Also metals, PAHs and other semivolatile compounds, pesticides, butyltins, PCB Aroclors, hexavalent chromium, total organic carbon. See appendix A for analyte list.	Concurrent with water chemistry sampling, 700–10,000 L of sediment-laden water pumped from the thalweg at 80 percent of depth through Teflon tube into Teflon lined buckets. Suspended sediment collected by flow-through centrifuge for chemical analysis.	Sample collection method: Conn and Black (2013). Sediment handling methods: Shelton and Capel (1994)	AXYS (high-resolution parameters) and ARI	An additional 3 L of water was pumped to assess particle-size distribution and suspended-sediment concentration. This additional sample was not be analyzed for chemistry, but was compared to the results from task 4.
6	Bed-sediment chemistry	High-resolution dioxins/furans and 209 PCB congeners. Also metals, PAHs and other semivolatile compounds, pesticides, butyltins, PCB Aroclors, hexavalent chromium, total organic carbon, grain size. See appendix A for analyte list.	Top 10 cm of sediment collected from up to 10 depositional areas containing fine-grained particles located 1,000 m downstream of water chemistry sampling. Sediment samples collected and composited with Teflon and glass sampling equipment. All samples sieved to less than 2 mm. Metals samples sieved with nylon sieve. Organic samples sieved with stainless steel sieve.	Radtke (2005); Shelton and Capel (1994); Ecology (2008)	AXYS (high-resolution parameters) and ARI	Samples were also sieved to less than 62.5 µm and both size fractions were submitted for chemistry analysis.

[Task No.: Corresponds to the task Nos. in the text. **Abbreviations:** ARI, Analytical Resources, Inc., Tukwila, Washington; AXYS, AXYS Analytical, LTD, Sidney, British Columbia, Canada; CVO, U.S. Geological Survey Cascades Volcano Observatory Sediment Laboratory, Vancouver, Washington; FNU, Formazin Nephelometric Units; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; USGS WAWSC, U.S. Geological Survey Washington Water Science Center, Tacoma, Washington; cm, centimeter; °C, degrees Celsius; ft³/s, cubic foot per second; L, liter; m, meter; mg/L, milligram per liter; mm Hg, millimeters of mercury; µg/L, microgram per liter; µm, micrometer; µS/cm, microsiemens per centimeter at 25 °C; mm, millimeter; –, none]

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Task 1 (instantaneous streamflow): River streamflow was measured using an acoustic Doppler current profiler following standard USGS protocols described by Mueller and others (2009).

Task 2 (general water quality): Water-quality field parameters (water temperature, pH, dissolved oxygen, specific conductance, turbidity, and barometric pressure) were measured using a multiparameter sonde (Wilde, variously dated). Previous water-quality measurements (Conn and Black, 2014) indicated a well-mixed cross section; therefore, during all sampling periods, the sonde was co-located with the VOC sampler (see task 3) in the thalweg at 60 percent of depth (typically 1.5–2.5 m above the bed).

Task 3a (water chemistry): Based on total streamflow 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 width- and depth-integrated USGS protocols (U.S. Geological Survey, 2006). For this sampling technique, a flow-weighted, depth-integrated sample is collected that is representative of the entire river cross-section at that sampling site. Briefly, a sampler was 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 a US D-96 sampler with Teflon nozzle and nozzle holder (fig. 4A; Davis, 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 (Wilde and others, 2004) to ensure sample homogenization prior to bottle filling. Bottles were pre-acidified for total and dissolved metals, TOC, and DOC. Samples for dissolved metals and DOC were field-filtered through a pre-conditioned 0.45-micrometer (µm) capsule filter.

Task 3b (water chemistry): Volatile organic compounds were collected separately (table 1, task 3b) using a hand-held sampler designed and tested by USGS to avoid losses resulting from sample pouring, transferring, and churning (fig. 4B), as described by Shelton (1997). The VOC sampler, containing as many as four 40 mL glass vials, was lowered to 60 percent of depth at a single station in the centroid of flow. The vials were filled slowly with water 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, except for the samples for high-resolution mass spectrometry (HRMS) analysis for dioxins/furans and the 209 PCB congeners, which were transported to the USGS Washington Water Science Center and stored at 4 °C until shipment to AXYS Analytical Services, Ltd. (AXYS) for

analysis. The HRMS samples had a 1-year holding time limit, and samples were shipped in batches of 4–10 bottles or jars approximately every 3–4 months.

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 used in task 3 (fig. 4A), 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 single point through Teflon tubing into 100-L Teflon-lined drums for suspended-sediment chemistry analysis (fig. 4C) using a programmable peristaltic pump (6712 sampler, Teledyne Isco). Pre-cleaned Teflon tubing was installed through permanent rigid housing from the bank for each sampling period, then removed and cleaned after each sampling period. The tubing intake was located about 0.5 m above the bed and 9 m from the left edge of water. The pump was operated either in a continuous pumping mode or a cycling mode. The continuous pumping mode (approximately 4 L/min) typically was used for short-duration sampling (hours) during high-sediment periods (for example, to capture the turbidity peak of a storm). The cycling mode (on for about 25 of every 90 minutes or 1.2 L/min) typically was used for long-duration sampling (days) during low-sediment periods (for example, to capture baseline conditions). Each of the 22 suspended-sediment samples represented a composite sample collected from a minimum of 4 hours to a maximum of 7 days, depending on the sampling conditions.

Water in the 100-L drum(s) was pumped at a flow rate of 600 mL/min through Teflon tubing into a continuous-flow centrifuge (CFC Express, Scientific Methods, Inc.) that captures sediment in a bowl and continuously discharges clarified water. Sediment-capture efficiencies of the centrifuge, which runs at a fixed rate of 10,000 revolutions per minute, are greater than 90 percent at an inflow rate of 600 mL/min under sediment conditions typical of the Duwamish River (Conn and Black, 2013). Two centrifuges were used in parallel for a combined processing rate of 1.2 L/min. The tubing was floated near the water surface of the drum to allow sediment to settle to the bottom of the drum. The captured sediment in the centrifuge bowls was emptied into a sample jar every 24 hours or less and stored undisturbed at 4 °C. After the water was pumped from the drum(s), the settled sediment at the bottom of the drum was composited with the bowl sediment in the sample jar. The sample jar was



Figure 4. (A) US D-96 sampler for water chemistry and suspended-sediment physical parameters, (B) volatile organic compound sampler, (C) continuous-flow centrifuges for suspended-sediment chemistry, and (D) Teflon™ spatula from an inflatable kayak used for bed-sediment sampling at Duwamish River at Golf Course at Tukwila, Washington. Photographs taken by Kathleen Conn on (A) January 11, 2014, (B) May 26, 2015, (C) April 15, 2014, and (D) September 17, 2014.

transferred on ice to the Washington Water Science Center laboratory in Tacoma, Washington, and stored quiescently at 4 °C. The overlying water in the sample jar was carefully removed by pipette and centrifuged on a floor centrifuge (IEC Model K, Needham Heights, Massachusetts) for about 30 minutes at a maximum speed of 5,200 revolutions per minute. The centrifuged sediment was added to the sample jar. The

sample was homogenized, and a subsample was collected for HRMS analysis. The HRMS sample was frozen until shipment to AXYS. The remaining sample was delivered to ARI for analysis of non-HRMS analytes. The time from when the sample was collected to when it was frozen or delivered to ARI ranged between 3 and 7 days. During that time, the sample was held at 4 °C.

Task 6 (bed-sediment chemistry): A bed-sediment sample was collected during four low flow and low tide conditions when depositional areas were exposed along the river bank (fig. 4D). 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. Sites were accessed by kayak or on foot, and subsamples (0–10 cm depth) from as many as 10 locations marked by geographic information systems within 1,000 m downstream of the bridge were composited with a Teflon spatula into a single sample in a Teflon-lined container during each of the four sample collection periods. Locations were selected to focus on areas with a high deposition of fine material. The composited sample 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. 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 (less than 2 mm) to results from the fine bed sediment (less than 62.5 μm). Overlying water from the wet-sieving procedure was decanted from the jars and discarded prior to chemical analysis. A summary of sampling dates and completed tasks is given in table A1.

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- or USGS-approved methods (table 2). A single liquid/liquid extraction was done for the dioxins/furans and the 209 PCB congeners. Dioxins/furans were analyzed by gas chromatography/HRMS according to EPA SW-846 (U.S. Environmental Protection Agency, 2015) Method 1613B. The 209 PCB congeners were analyzed by gas chromatography/HRMS according to SW-846 Method 1668C. Samples for trace elements underwent an acid digestion followed by inductively coupled plasma-mass spectrometry according to SW-846 Method 6020 (similar to EPA Method 200.8). Low-level mercury was analyzed by cold-vapor atomic absorption spectrometry according to

SW-846 Method 7470A (for water samples) and 7471A (for sediment samples). Volatile organic compounds were analyzed by purge and trap followed by gas chromatography/mass spectrometry (GC/MS) according to SW-846 Method 8260C. Semivolatile compounds were analyzed by continuous liquid/liquid extraction followed by GC/MS according to SW-846 Method 8270D. A second GC/MS analysis according to SW-846 8270D was conducted for low-level PAH determination using Selected-Ion Monitoring mode. PCB Aroclors were analyzed by separatory funnel liquid/liquid extraction and gas chromatography/electron capture detector according to SW-846 Method 8082A. Pesticides were analyzed by separatory funnel liquid/liquid extraction and gas chromatography/electron capture detector by SW-846 Method 8081B. Butyltins were analyzed by separatory funnel liquid/liquid extraction GC/MS according to SW-846 Method 8270D. Samples for hexavalent chromium underwent a diphenylcarbazide reaction for colorimetric analysis according to SW-846 Method 7196A. Total and dissolved organic carbon was determined by high-temperature combustion according to SW-846 Method 5310B (for water samples) and as described in Puget Sound Estuary Program (1986) (for sediment samples). Percentage of solids was determined by each analyzing laboratory for reporting concentrations in sediment samples on a dry weight basis.

Depth- and width-integrated samples of water (task 4) were analyzed for SSC by the USGS CVO sediment laboratory by weighing oven-dried solids (Guy, 1969). When there was sufficient suspended sediment in the water sample, a full PSD analysis also was done by CVO by washed sieving of particles greater than 62.5 μm or by settling velocity for particles less than 62.5 μm (Guy, 1969). The PSD of bed-sediment samples was determined by ARI using similar washed sieving and settling velocity methods (Puget Sound Estuary Program, 1986). Parameter group, method, and analyzing laboratory are listed in table 2. A complete list of analytes for each media is contained in appendix A. During low-turbidity sampling periods, even with consecutive days of water collection, there was insufficient suspended-sediment concentrated from the centrifuges to analyze all parameters. In these cases, parameters were analyzed in this priority order: (1) dioxins/furans and PCB congeners; (2) metals, including mercury; (3) low-level PAHs; (4) TOC; (5) semivolatile compounds; (6) pesticides; (7) butyltins; (8) hexavalent chromium; (9) PCB Aroclors; and (10) VOCs.

Table 2. Analytical parameter groups, methods, and analyzing laboratories for samples collected at Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[Unless an alternate reference is given, method numbers refer to the U.S. Environmental Protection Agency's SW-846 (U.S. Environmental Protection Agency, 2015). **Abbreviations:** ARI, Analytical Resources, Inc., Tukwila, Washington; ASTM, American Society for Testing and Materials; AXYS, AXYS Analytical, Ltd., Sidney, British Columbia, Canada; CVO, U.S. Geological Survey Cascades Volcano Observatory Sediment Laboratory; SIM, selected ion monitoring; SM, standard methods; μm , micrometer; mm, millimeter]

Analytical parameter	Analysis method	Analysis method description	Analyzing laboratory
Total organic carbon, dissolved organic carbon	5310B—water; Puget Sound Estuary Program (1986)—sediment	High-temperature combustion	ARI
Hexavalent chromium	7196A	Colorimetric	ARI
Trace elements	6020	Inductively coupled plasma-mass spectrometry	ARI
Low-level mercury	7470A—water; 7471A—sediment	Cold-vapor atomic absorption spectrometry	ARI
Low-level polycyclic aromatic hydrocarbons	8270D SIM	Gas chromatography/mass spectrometry	ARI
Semivolatile compounds	8270D	Gas chromatography/mass spectrometry	ARI
Butyltins	8270D	Gas chromatography/mass spectrometry	ARI
Pesticides	8081B	Gas chromatography/electron capture detector	ARI
Volatile organic compounds	8260C	Gas chromatography/mass spectrometry	ARI
Dioxins/furans	1613B	High-resolution gas chromatography mass spectrometry	AXYS
209 polychlorinated biphenyl congeners	1668C	High-resolution gas chromatography mass spectrometry	AXYS
Polychlorinated biphenyl Aroclors	8082A	Gas chromatography/electron capture detector	ARI
Suspended-sediment concentration	ASTM D3977-97(2013)e1 and Guy (1969)	Weight of oven-dried solids	CVO
Particle-size distribution (suspended sediment)	Guy (1969)	Washed sieve (less than 2 mm), settling velocity (less than 62.5 μm)	CVO
Particle-size distribution (bed sediment)	Puget Sound Estuary Program (1986)	Washed sieve (less than 2 mm), settling velocity (less than 62.5 μm)	ARI

Quality Assurance and Quality Control

Standard USGS quality-assurance procedures for surface-water measurements and water-quality sampling and analysis were followed (Wagner and others, 2007; U.S. Geological Survey, 2006; Wilde, 2004; Wilde and others, 2004; Wilde, 2005; Wilde and others, 2014). These procedures included proper equipment selection, cleaning procedures, personnel training, 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 two-person “clean hands, dirty hands” technique and processing of water samples in a clean mobile laboratory. Hydrologists and hydrologic technicians on this project were trained at the USGS National Training Center in the collection of water-quality samples, including samples for trace organic and low-level mercury analyses.

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A trip blank for VOCs was included in each of the sampling trips for unfiltered water, in which a sample of deionized water filled in a VOC vial at the analyzing laboratory 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 A1](#), included:

- Five pairs of blank samples of water, with each pair consisting of a trip blank and a field equipment blank sample of water for each parameter. The trip blank was a sample of laboratory blank water filled directly into each sample bottle by the analyzing laboratory and was transported in the cooler to and from the site during field sampling. The unopened sample bottles were labeled in the mobile laboratory then returned to the cooler. Trip blank samples requiring filtration were laboratory-filtered prior to analysis. Each laboratory provided blank water for the equipment blank, which was transported in the mobile laboratory to the field site where it was poured through the pre-cleaned Teflon nozzle, 3-L bag and churn, churned, and then filled into sample bottles in the mobile laboratory. Equipment blank samples requiring filtration were field-filtered in the same manner as river water processing. The five blank pairs were collected throughout the study (approximately every 3 months) to identify any contamination associated with field sampling and processing protocols.
- Two concurrent replicates of water, in which a second sample was collected at each EDI station immediately following the first sample, were composited in a second pre-cleaned Teflon churn.
- One centrifuge equipment blank sample of suspended sediment, in which a commercial fine silica sand (in which approximately 50 percent of particles were less than 100 μm and 90 percent were less than 300 μm) was burned in a muffle furnace at 450 $^{\circ}\text{C}$ for 6 hours, cooled, then mixed with organic-free blank water to form a slurry. The slurry was pumped and processed through all of the field and laboratory equipment for suspended-sediment sampling (that is, Teflon tubing, Teledyne Isco pump, Teflon bag, Teflon tubing, centrifuge bowl, and glass jar).
- One centrifuge source sediment sample, in which the fine silica sand that had been burned in a muffle furnace at 450 $^{\circ}\text{C}$ for 6 hours was directly placed into a sample jar for analysis.
- Two field splits of bed sediment, in which the less than 2 mm-sieved, homogenized material was split into two sample jars for analysis.
- Two centrifuged splits of bed sediment, in which splits of less than 2-mm bed sediment were mixed to a slurry with deionized water and processed through the suspended-sediment sampling equipment (pumps, tubing, and centrifuge) to assess compound recovery.

One split (processed on March 23, 2015) was compared to the corresponding 2-mm-sieved bed-sediment sample. The other split (processed on February 23, 2015) was additionally sieved through a 62.5- μm sieve after centrifuging and the results were compared to the corresponding 62.5- μm -sieved bed-sediment sample.

- One Puget Sound Sediment Reference Material (SRM), 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 TOC. Laboratory results were compared to the average concentration of the standard as determined during previous round robin laboratory testing.

Both analytical laboratories processed laboratory blank, spike, and replicate analyses according to their quality-assurance plan, that is, with every batch of approximately 20 samples (Analytical Resources, Inc., 2014; AXYS Analytical, LTD, 2015). Matrix spike, matrix spike duplicates, and laboratory replicate analyses were processed with one to four water samples and two bed-sediment samples from this project for each method. If values exceeded control limits for analytes detected in associated environmental samples then corrective actions were taken such as re-runs and re-extractions. Additional details regarding the field and laboratory methods are available in Conn and Black (2013).

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 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 (about 10 percent) of data packages were reviewed by the Quality Assurance Coordinator at the Ecology Manchester Environmental Laboratory in Port Orchard, Washington 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. A report summarizing the Level 4 validation results for each method was issued to the USGS

and Ecology project managers. Discrepancies identified by the Level 4 validation were resolved through coordination between Ecology, USGS, and the analytical laboratories.

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 for non-HRMS analyses 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. The RL for non-HRMS analyses is defined as the lowest concentration that can be reliably achieved within specific limits of precision and accuracy during routine operating conditions. The DL for compounds analyzed by HRMS (the dioxins/furans and PCB congeners) is defined as the concentration equivalent to three times the estimated chromatographic noise height, determined individually for each compound for every sample analysis run. The RL for HRMS compounds is determined by prorating the concentration of the lowest calibration limit for sample size and extract volume by using the following equation:

$$RL = [(lowest\ level\ calibration\ standard) \times (extract\ volume)] / sample\ size. \quad (1)$$

Differences between various laboratory and agency protocols for qualifying analytical data to address measurement considerations and abnormalities are common. Adjustments to the laboratory-provided qualifiers from laboratories used in this study were made to be consistent with the Ecology 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 qualified by the laboratory or during the Level 2 or Level 4 review process with qualifiers other than U-, J-, N-, and R-containing qualifiers were amended following the protocols described in [appendix A](#) and summarized here. In section “[Chemical Concentrations](#),” summary tables of detected compounds are presented, which includes detections (unqualified) and estimated detections (J-qualified) and does not include non-detections (U- or UJ-qualified), detections that did not meet all criteria for identification of the target analyte (NJ-qualified, often referred to as the estimated maximum possible concentration), or unquantifiable results (R-qualified). The complete analytical results for all individual compounds with USGS-amended qualifiers are presented in [appendix A](#) and are stored in the publicly available Ecology Environmental Information Management database (Washington State Department of Ecology, 2015). The USGS-amended qualifier is contained in the “Result_Data_Qualifier” column and the original laboratory qualifier(s) is contained in the “Result_Additional_Comment” column. The complete results from quality control samples are presented in [appendix A](#).

Both analytical laboratories reported detections with “J” qualifiers that were greater than the DL but less than the RL for all mass spectrometry-based methods (all parameters except hexavalent chromium, TOC, and DOC). When a compound was not detected greater than the DL, the DL value was reported with a “UJ” qualifier for HRMS compounds and the RL was reported with a “U” qualifier for non-HRMS compounds. The DL and RL varied over the course of the project between compounds and for an individual compound between samples, owing to annual laboratory RL and DL updates, sample dilutions, and sample-specific calculations. The DL and RL values are stored with the sample results in the publicly available Ecology Environmental Information Management database (State of Washington Department of Ecology, 2015).

The result from the most sensitive method is reported when a parameter was analyzed by more than one method, unless otherwise noted. The Aroclor results from both the HRMS method and the non-HRMS method are presented for comparison. Data with “J” qualifiers are included in the summed or calculated values. Toxic Equivalent (TEQ) concentrations are reported for dioxins/furans and cPAHs. If a compound was not detected greater than the DL, a value of one-half of the DL was used in the TEQ calculations. The TEQ values are presented to facilitate comparison to other Duwamish data sets; however, the use of a substituted value for censored data can result in large differences in the resulting estimates of summary statistics (Helsel and Hirsch, 2002). The summed and calculated values are presented in the data results.

Dioxins/Furans

- Total dioxins/furans, as a sum of 17 congener concentrations.
- Total dioxins/furans, as a TEQ according to the World Health Organization 2005 guidelines (Van den Berg and others, 2006). If a compound was not detected at greater than the detection level, a value of one-half the DL 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 (2005). If a compound was not detected at greater than the DL, a value of one-half the DL was used in the calculations.

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- Total high molecular-weight PAHs (HPAH) as a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzofluoranthenes (sum of b-, j-, and k- isomers), 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

- Total PCBs, as a sum of the 209 congeners.
- Summed homologues (for example, total monochloro biphenyls, total dichloro biphenyls).
- Aroclors, 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 (determined from the HRMS method EPA 1668C) are summed and multiplied by a quantification factor:
 - Aroclor 1242 = (8, 18/30, 20/28, 31) × 3.0
 - Aroclor 1254 = (83/99, 86/87/97/109/119/125) × 8.0
 - Aroclor 1260 = (170, 180/193, 183/185) × 5.0.The empirical factors have been developed by the high-resolution laboratory through analysis of Aroclor standards and comparison to published data (Schulz and others, 1989; Rushneck and others, 2004).
- A second laboratory presented PCB detections as Aroclors using a low-resolution mass spectrometry method (EPA Method SW8082A) that compares environmental results to Aroclor calibration standards. Results from the low-resolution method are presented as Aroclors 1242, 1254, and 1260. Although this method is less sensitive than the high-resolution congener method, the detections are presented for inter-laboratory Aroclor comparison.

Other than the TEQ calculations (in which a value of one-half the DL 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 DL (with a UJ qualifier) or RL (with a U 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 water chemical concentrations and a method based on suspended-sediment chemical concentrations. Instantaneous unfiltered-water chemical loads in grams per hour were calculated using the following equation:

$$\text{Water chemical load (g/hr)} = C_w \text{ (g/L)} \times Q \text{ (L/hr)} \quad (2)$$

where

- C_w is chemical concentration in water, in grams per liter;
- Q is the median 15-minute river streamflow during sample collection, in liters per hour;

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

$$\text{Sediment chemical load (g/hr)} = C_s \text{ (g/kg} \times \text{kg/10}^6 \text{ mg)} \times Q \text{ (L/hr)} \times \text{SSC (mg/L)} \quad (3)$$

where

- C_s is chemical concentration in suspended sediment, in grams per kilogram;
- Q is the median 15-minute river streamflow during sample collection, in liters per hour; and
- SSC is suspended-sediment concentration, in milligrams per liter.

Non-detects were assigned the DL concentration for instantaneous loading calculations and the resulting value was reported with a “<” symbol.

Hydrology and Field Parameter Data

The 24 bridge-based sampling periods for water and suspended sediment during 2013–15 occurred over a range of precipitation and streamflow conditions (table 3, see also table A2). The sampling periods are overlaid on the hydrograph from the co-located streamgage (fig. 5). Three sets of sampling periods are shown: water (EDI measurements), suspended sediment (pumping periods for suspended-sediment chemistry by centrifugation), and bed sediment. The duration of the pumping period for suspended-sediment chemistry depended on a number of variables including the weather forecast, river streamflow and turbidity conditions, operations at the Howard Hanson Dam (located upstream at RKM 103), and personnel availability and safety. The duration ranged between 4 hours and 7 days, resulting in 740 to 10,550 L of water processed during each sampling period (table A2).

Table 3. Summary statistics of general hydrology, water quality, and field conditions during bridge-based sampling at Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[Parameter name: 72-hour antecedent precipitation is the sum of the daily totals on the sampling date and two previous days from the National Oceanic and Atmospheric Administration precipitation station at Seattle-Tacoma Airport (GHCND:USW00024233). 30-day antecedent precipitation is the sum of the daily totals from the previous 30 days from the National Oceanic and Atmospheric Administration precipitation station at Seattle-Tacoma Airport (GHCND:USW00024233). Instantaneous streamflow was measured with an acoustic Doppler current profiler. Instantaneous turbidity was measured with a hand-held multi-parameter sonde. **Abbreviations:** in., inch; ft³/s, cubic foot per second; °C, degrees Celsius; µS/cm, microsiemens per centimeter at °C; mg/L, milligram per liter; mm/Hg, millimeters of mercury; FNU, Formazin Nephelometric Unit; L, liter]

Parameter name	Unit of measure	All water samples (n=24)			Sampling periods		
		Median	Minimum	Maximum	Baseline (n=7)	Storm (n=11)	Dam release (n=6)
					Median	Median	Median
72-hour antecedent precipitation	in.	0.77	0.00	2.61	0.14	1.41	0.75
30-day antecedent precipitation	in.	4.78	0.17	9.71	3.78	3.86	5.28
Instantaneous streamflow	ft ³ /s	2,140	496	7,180	1,190	1,960	6,960
Water temperature	°C	7.6	4.9	16.5	9.6	7.6	6.7
pH	unitless	6.91	6.78	7.26	6.98	6.90	6.86
Specific conductance	µS/cm	83	37	159	124	84	46
Dissolved oxygen	mg/L	11.2	8.3	12.2	10.7	11.3	11.7
Barometric pressure	mm/Hg	760.0	748.2	771.1	761.6	754.7	767.0
Instantaneous turbidity	FNU	17	3	170	3	14	67
Suspended-sediment concentration	mg/L	56	6	555	9	51	327
Fine suspended sediment (less than 62.5 µm)	percent	80	56	95	83	81	69
Pump duration (for sediment chemistry)	hour	23	4	147	93	17	5
Estimated pumped volume (for sediment chemistry)	L	1,990	740	10,600	6,720	1,600	1,050

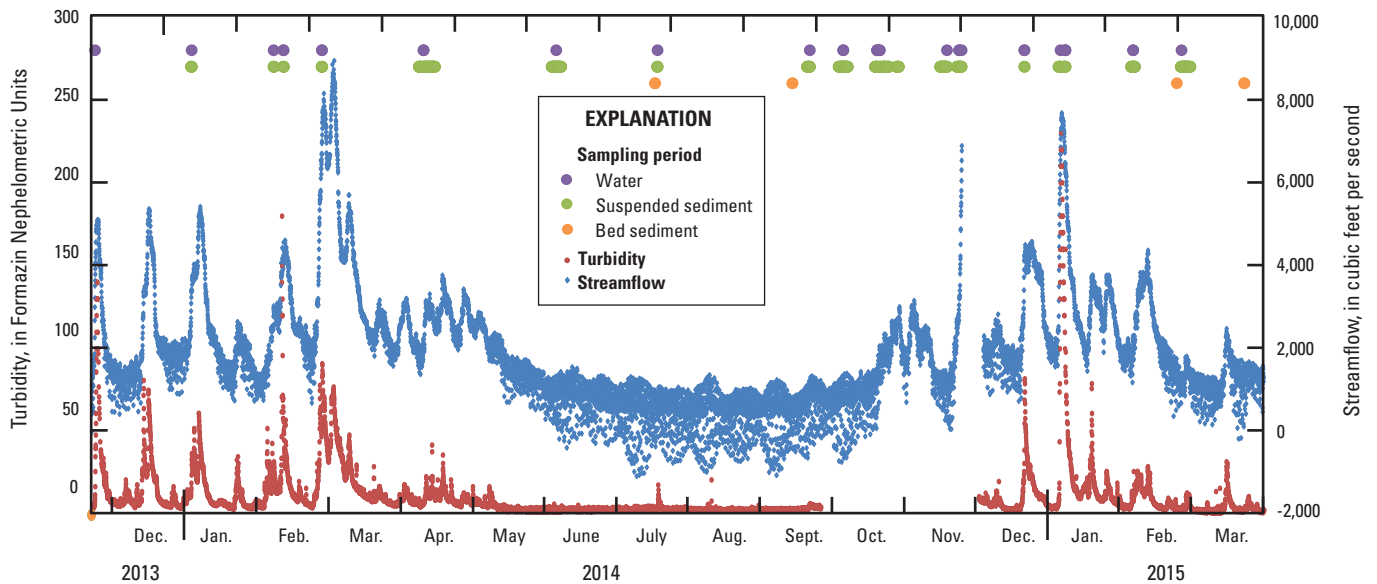


Figure 5. Sampling periods for water, suspended sediment, and bed sediment overlaid on the hydrograph of streamflow and turbidity at the Duwamish River at Golf Course at Tukwila, Washington, November 2013–March 2015.

The 24 bridge-based sampling periods were classified into three general categories—baseline conditions, storm periods, and dam releases (periods when stored runoff from a prior storm is released from Howard Hanson Dam into the upper Green River)—determined subjectively from a combination of factors including antecedent precipitation, precipitation duration, intensity and location during sampling, Howard Hanson Dam operations, and site conditions such as streamflow and turbidity during sampling. Of the 24 bridge-based sampling periods, 11 were during storms, 6 were during dam releases, and 7 were during baseline conditions (table 3). Baseline sampling occurred during periods of low precipitation (72-hour antecedent precipitation less than 0.5 in.) except for winter baseline sampling which captured daily low-intensity precipitation characteristic of the Pacific Northwest. Storm sampling captured a range of precipitation conditions (72-hour antecedent precipitation ranged from 0.39 to 2.21 in.). Sampling periods characterized as dam releases had 72-hour antecedent precipitation less than 1 in. except for one period (March 6, 2014) in which there had been 2.61 in. of precipitation in the previous 72 hours (the highest precipitation sampled in the project) that resulted in a near-flood dam release. In this report, 72-hour antecedent precipitation is defined as the sum of the daily total for the sampling date (or the first day of sampling if it was a multi-day collection period) and 2 previous days from the National

Oceanic and Atmospheric Administration precipitation station at Seattle-Tacoma Airport (GHCND:USW00024233), located approximately 6 km southwest of the station at 47.4444 N 122.3138 W. The 30-day antecedent precipitation, defined as the sum of the previous 30 daily-precipitation totals from the Seattle-Tacoma Airport precipitation station, ranged from 0.17 (July 23, 2014) to 9.71 in. (March 6, 2014) (table 3) and was greater than 3 in. for 18 of the 24 sampling periods (table A2). Sampling periods captured a range of conditions in this hydrologically complex river system, including the rising limb, peak, or falling limb on the turbidity hydrograph caused by local-scale or watershed-scale storms, dam releases from the Howard Hanson Dam, channel and bank storage release, and bi-directional flows resulting from tidal effects. River system complexity is illustrated by the lack of relation between 72-hour antecedent precipitation and SSC (fig. 6). In a river system affected primarily by overland flow, river SSC typically increases with increasing precipitation as sediment-laden runoff enters the river. The Green/Duwamish River system is affected by overland flow and other sources of sediment, such as releases of water and sediment from the Howard Hanson Dam. Four of the five highest SSC values (between 200 and 600 mg/L) were measured during dam releases when there was little precipitation on the day of sampling.

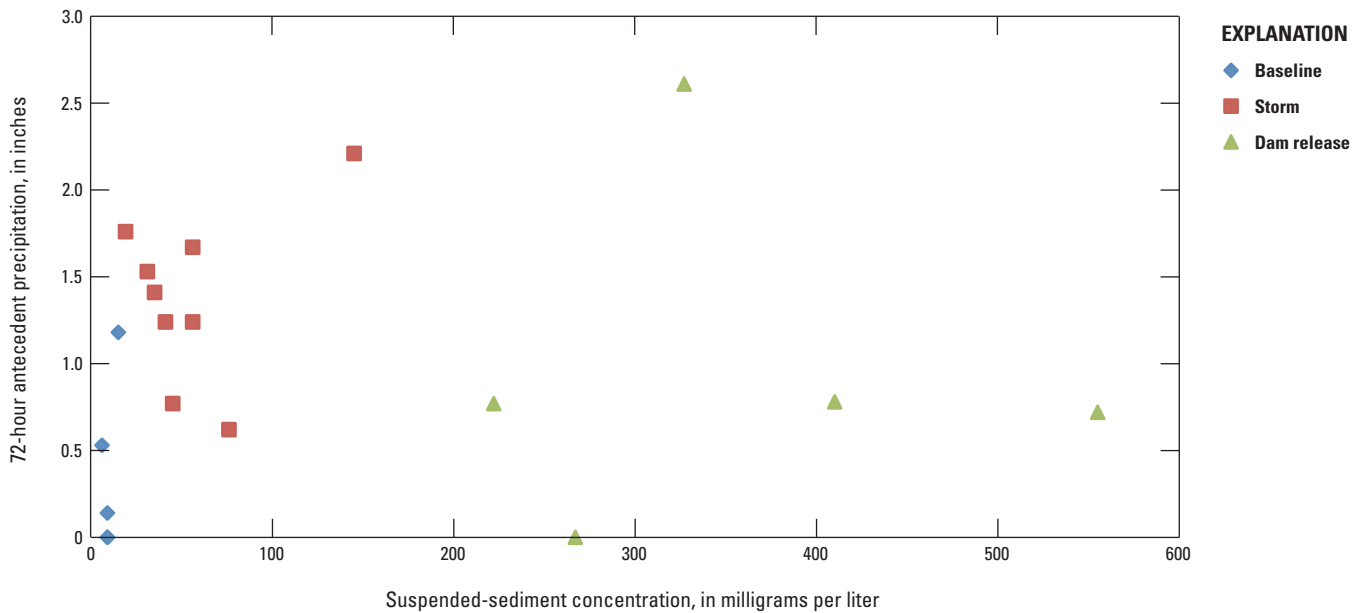


Figure 6. Relation between precipitation and suspended-sediment concentration during sampling periods, Duwamish River at Golf Course at Tukwila, Washington, 2013–15. Precipitation is the sum of the daily total for the sampling date and two previous days from the National Oceanic and Atmospheric Administration precipitation station at Seattle-Tacoma Airport (GHCND:USW00024233).

During the study period (November 26, 2013, through March 31, 2015), median turbidity, as determined in 15-minute increments from the continuous turbidity sensor, ranged from 1.2 to 240 Formazin Nephelometric Units (FNU), and was less than 10 FNU more than 75 percent of the time (fig. 5). Median streamflow, as determined in 15-minute increments from the index velocity rating curve at the co-located streamgage, ranged from -1,110 ft³/s during a summer high tide that resulted in up-river flow to 9,190 ft³/s during an early spring storm and dam release. The median 15-minute streamflow during the study period was 1,640 ft³/s. Instantaneous water-quality parameters were measured during each sampling period (tables 3 and A2). Water temperature during sampling periods ranged from 4.9 (February 18, 2014) to 16.5 °C (September 24, 2014). Specific conductance during sampling periods ranged from 37 µS/cm at 25 °C (µS/cm) during a large dam release on January 6, 2015 to 159 µS/cm on July 23, 2014 during a low-precipitation, low-flow summer period. Suspended-sediment concentration, measured using representative streamflow-weighted, depth integrated methods, ranged from 6 mg/L during a baseline period on February 26, 2015 to 555 mg/L during a large dam release on January 6, 2015. The percentage of fines (less than 62.5 µm) in the suspended sediment ranged from 56 percent during a large storm event on February 18, 2014 to 95 percent during a low-precipitation summer period on July 23, 2014 (table 3), with a median of 80 percent. There was sufficient suspended sediment during 13 sampling periods to analyze a full PSD (see section, “Comparison of Suspended Sediment and Bed Sediment”).

The four sets of bed-sediment samples (fig. 5) were collected when the gage height was less than or equal to 6.5 ft, the turbidity was less than 4.0 FNU, and the 72-hour antecedent precipitation was less than or equal to 0.51 in. (table A3).

Chemical Concentrations

Analytical chemistry results are presented for unfiltered-water samples, filtered-water samples, suspended-sediment samples, bed-sediment samples, and quality-control samples.

Unfiltered-Water Chemical Concentrations

The compounds or compound groups detected in one or more unfiltered-water river samples were: TOC, metals, PAHs, dioxins/furans, and PCB congeners. Total organic carbon in all 19 river water samples ranged from 1.50 to 7.39 mg/L, with a median of 2.77 mg/L (table 4). The three samples in which TOC exceeded 6 mg/L were collected when there were only trace amounts of precipitation on the day of sampling but SSC was greater than 200 mg/L owing to a large release of

water from the Howard Hanson Dam. Each of the 18 metals that were analyzed for were detected in at least one unfiltered-water sample during the study (tables 4 and A4). Nine metals were detected in greater than 75 percent of unfiltered-water samples: arsenic, barium, chromium, cobalt, copper, lead, manganese, nickel, and vanadium. Arsenic was detected in all 19 unfiltered-water samples ranging in concentration from 0.6 to 2.7 µg/L, with a median of 1.0 µg/L. Median concentrations of TOC and many metals were higher during dam releases than during storms or baseline conditions (table 4). Concentrations of metals in unfiltered-water samples increased with increasing SSC (see fig. 7 for arsenic as an example).

Polycyclic aromatic hydrocarbons were detected infrequently and at low concentrations in unfiltered-water samples (tables 4 and A4). Most detections occurred during storms. LPAHs were detected in 5 of 19 samples, owing entirely to detections of phenanthrene ranging from 0.0052 J to 0.016 µg/L. Concentrations of naphthalene in river water samples were U-qualified owing to detections in water field-blank samples (see section, “Quality-Control Chemical Concentrations”). HPAHs were detected in 5 of 19 samples at concentrations as much as 0.25 µg/L. Carcinogenic PAHs (cPAHs) were detected in 4 of 19 samples at concentrations as much as 0.031 J µg TEQ/L. The four samples in which cPAHs were detected included a summer hail storm, a “first flush” autumn sample, and two February storms—one in 2014 and one in 2015.

Dioxins/furans were detected in 16 of 19 samples at concentrations as much as 1.30 J picograms TEQ per liter (pg TEQ/L) (tables 4 and A4). The regulated congener 2,3,7,8-tetrachlorodibenzo-*p*-dioxin was not detected at greater than the reporting level (table A4). PCB congeners were detected in all 19 unfiltered-water samples; the summed concentration of the 209 congeners ranged from 32.7 J to 6,790 pg/L, with a median concentration of 163 J pg/L (tables 4 and A4). The summed concentration of the 209 PCB congeners was greater than 500 pg/L in 3 of the 19 water samples during (1) an intense, multi-day winter storm, (2) a summer hail storm, and (3) a “first flush” autumn storm. The PCB congeners are reported as total PCBs, homologue totals, and Aroclors in table 4. The individual congener results are presented in table A4. In comparison, PCB Aroclors, determined by low-resolution mass spectrometry, were not detected in unfiltered water (table 4).

The common contaminant *bis*(2-ethylhexyl)phthalate (2.9 J µg/L) and methylene chloride (0.61 J µg/L) were each detected once in unfiltered water. The methylene chloride concentration was similar to concentrations measured in trip-blank samples (see section, “Quality-Control Chemical Concentrations” for additional details). The compound groups that were analyzed for, but were not detected were: semivolatile organic compounds (other than *bis*(2-ethylhexyl)phthalate), pesticides, VOCs (other than methylene chloride), hexavalent chromium, and butyltins (table A4).

Table 4. Summary statistics of detected compounds in unfiltered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q₁ qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); NJ, result did not meet all quantitation criteria (an estimated maximum possible concentration is reported in “Result” column); U, not detected above detection limit (reporting limit is reported in “Result” column); UJ, not detected above detection limit (detection limit is reported in “Result” column). **Abbreviations:** µg/L, microgram per liter; µg TEQ/L, microgram toxic equivalent per liter; mg/L, milligram per liter; pg/L, picogram per liter; pg TEQ/L, picogram toxic equivalent per liter; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	All water samples (n=19)										Sampling periods			
			Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Median	Storm (n=9)	Baseline (n=5)	Dam release (n=5)	Result	Q	Result	Q	Result
Organic carbon																
Total organic carbon	mg/L	na	19/19	na	2.77	1.50	7.39	1.75	2.80	6.30						
Metals																
Antimony	µg/L	7440-36-0	5/19	60	0.12	0.04	0.20	0.05	0.13	0.12	U	U	U	U	U	U
Arsenic	µg/L	7440-38-2	19/19	0	1.0	0.6	2.7	0.7	1.0	1.9	U	U	U	U	U	U
Barium	µg/L	7440-39-3	19/19	0	8.6	3.7	55.1	4.0	8.6	28.3	U	U	U	U	U	U
Beryllium	µg/L	7440-41-7	9/19	89	0.2	0.07	0.2	0.2	0.2	0.14	U	U	U	U	U	J
Cadmium	µg/L	7440-43-9	9/19	67	0.1	0.03	0.1	0.1	0.1	0.07	U	U	U	U	U	J
Chromium	µg/L	7440-47-3	15/19	40	0.70	0.27	4.0	0.25	0.70	3.2	U	J	J	J	J	J
Cobalt	µg/L	7440-48-4	15/16	20	0.35	0.11	3.6	0.14	0.35	1.7	U	U	U	U	U	U
Copper	µg/L	7440-50-8	17/19	0	2.5	0.8	12.1	0.8	2.5	6.4	U	U	U	U	U	U
Lead	µg/L	7439-92-1	19/19	0	0.70	0.10	2.8	0.10	0.70	1.6	U	U	U	U	U	U
Manganese	µg/L	7439-96-5	16/16	0	98.7	43.9	262	72.7	93.4	139	U	U	U	U	U	U
Mercury	µg/L	7439-97-6	6/19	67	0.02	0.006	0.019	0.02	0.02	0.019	U	J	J	J	J	J
Molybdenum	µg/L	7439-98-7	8/16	38	0.16	0.02	0.40	0.19	0.25	0.13	U	U	U	U	U	U
Nickel	µg/L	7440-02-0	19/19	0	1.1	0.48	4.9	0.50	1.1	4.5	U	U	U	U	U	U
Selenium	µg/L	7782-49-2	3/19	67	0.5	0.5	0.14	0.5	0.5	0.5	U	U	U	U	U	U
Silver	µg/L	7440-22-4	7/19	100	0.20	0.01	0.03	0.2	0.2	0.2	U	J	J	J	J	J
Thallium	µg/L	7440-28-0	3/19	100	0.03	0.01	0.03	0.01	0.02	0.05	U	J	J	J	J	J
Vanadium	µg/L	7440-62-2	19/19	0	2.8	0.80	19	0.90	2.8	8.5	U	U	U	U	U	U
Zinc	µg/L	7440-66-6	12/19	8	7.0	1.9	28	4.0	7.0	13	U	U	U	U	U	U
Polycyclic aromatic hydrocarbons																
LPAH ¹	µg/L	na	5/19	80	0.01	0.008	0.016	0.010	0.012	0.01	U	U	U	U	U	U
HPAH ²	µg/L	na	5/19	80	0.02	0.01	0.25	0.02	0.026	0.02	U	J	J	J	J	J
cPAH ³	µg/L	na	4/19	75	0.02	0.01	0.14	0.02	0.02	0.02	U	U	U	U	U	U
cPAH ³	µg TEQ/L	na	4/19	75	0.002	0.002	0.031	0.002	0.002	0.002	U	J	J	J	J	J

Table 4. Summary statistics of detected compounds in unfiltered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection, J, estimated (result between detection limit and reporting limit); NJ, result did not meet all quantitation criteria (an estimated maximum possible concentration is reported in “Result” column); U, not detected above detection limit (reporting limit is reported in “Result” column); UJ, not detected above detection limit (detection limit is reported in “Result” column). **Abbreviations:** µg/L, microgram per liter; mg/L, milligram per liter; pg/L, picogram per liter; pg TEQ/L, picogram toxic equivalent per liter; pg TEQ/L, picogram toxic equivalent per liter; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	All water samples (n=19)										Sampling periods		
			Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Baseline (n=5) Median	Storm (n=9) Median	Dam release (n=5) Median	Result	Q	Result	Q	Result
Dioxins/furans															
Total dioxins/furans ⁴	pg/L	na	16/19	63	26.9	J	8.90	UJ	186	1.06	J	37.2	J	31.0	J
Total dioxins/furans ⁴	pg TEQ/L	na	16/19	81	0.956	J	0.843	UJ	1.30	0.892	J	1.01	J	0.956	J
Polychlorinated biphenyls (by high-resolution mass spectrometry)															
Total polychlorinated biphenyls ⁵	pg/L	1336-36-3	19/19	79	163	J	32.7	J	6,790	53.8	J	376	J	233	J
Total monochloro biphenyls	pg/L	27323-18-8	6/17	100	7.48	UJ	1.11	UJ	51.0	2.12	J	8.63	UJ	2.97	UJ
Total dichloro biphenyls	pg/L	25512-42-9	10/19	50	4.31	J	6.04	NJ	16.9	7.20	J	63.9	UJ	9.70	J
Total trichloro biphenyls	pg/L	25323-68-6	19/19	95	11.4	J	3.00	J	159	5.63	J	12.6	J	11.1	J
Total tetrachloro biphenyls	pg/L	26914-33-0	19/19	95	11.9	J	2.10	J	835	9.84	J	13.1	J	17.1	J
Total pentachloro biphenyls	pg/L	25429-29-2	19/19	68	39.1	J	5.72	J	2,630	11.1	J	90.8	J	49.5	J
Total hexachloro biphenyls	pg/L	26601-64-9	19/19	63	76.7	J	3.80	J	2,180	5.98	J	143	J	76.7	J
Total heptachloro biphenyls	pg/L	28655-71-2	18/19	67	20.6	J	5.76	UJ	803	2.11	J	92.4	J	29.5	J
Total octachloro biphenyls	pg/L	55722-26-4	18/19	89	6.56	J	1.91	NJ	150	1.59	J	16.2	J	6.56	J
Total nonachloro biphenyls	pg/L	53742-07-7	11/19	91	1.12	J	0.57	UJ	39.3	1.05	UJ	2.44	J	1.03	J
Total decachloro biphenyls	pg/L	2051-24-3	6/19	100	3.70	NJ	1.13	NJ	3.83	1.51	J	2.92	NJ	2.54	NJ
Aroclor 1242	pg/L	53469-21-9	7/19	14	28.9	UJ	6.54	UJ	275	16.0	UJ	28.9	UJ	37.1	UJ
Aroclor 1254	pg/L	11097-69-1	5/19	20	19.4	UJ	4.31	UJ	4,050	11.4	NJ	26.1	UJ	9.30	UJ
Aroclor 1260	pg/L	11096-82-5	16/19	50	58.8	UJ	5.76	UJ	1,790	9.05	J	213	J	90.3	J
Polychlorinated biphenyls (by low-resolution mass spectrometry)															
Aroclor 1242	pg/L	53469-21-9	0/19	na	10,000	U	10,000	U	10,000	10,000	U	10,000	U	10,000	U
Aroclor 1254	pg/L	11097-69-1	0/19	na	10,000	U	10,000	U	10,000	10,000	U	10,000	U	10,000	U
Aroclor 1260	pg/L	11096-82-5	0/19	na	10,000	U	10,000	U	10,000	10,000	U	10,000	U	10,000	U

¹LPAH is a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

²HPAH is a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzofluoranthenes (sum of b-, j-, and k- isomers), benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene.

³cPAH is 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).

⁴Total dioxins/furans is a summed concentration of 17 congeners.

⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

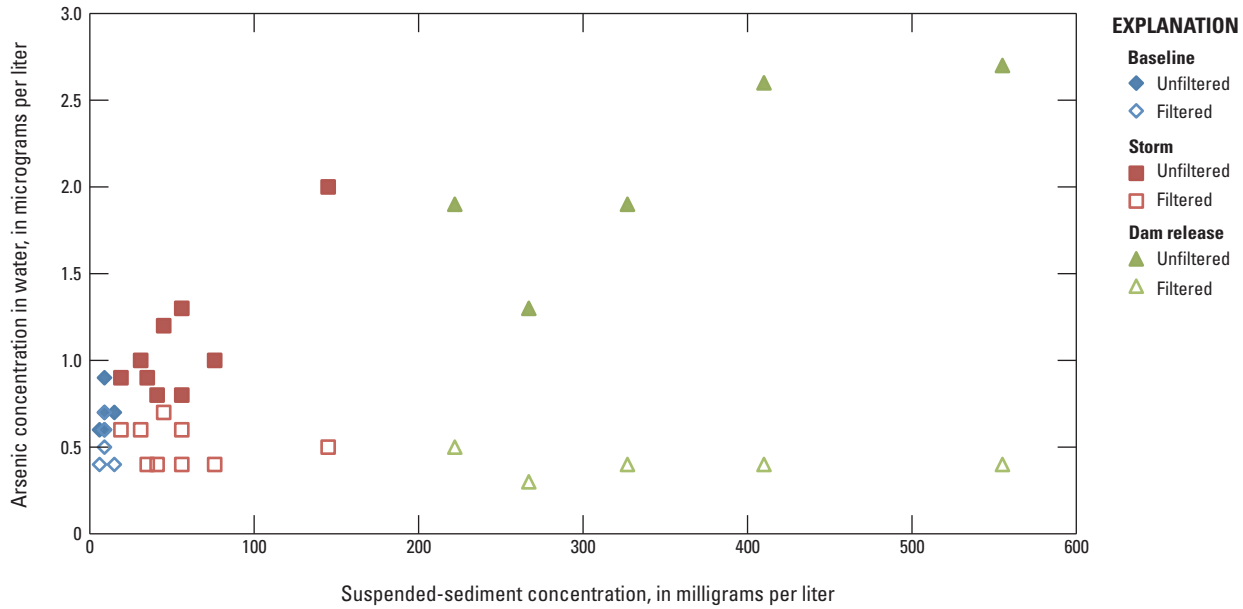


Figure 7. Relation between arsenic concentrations in paired unfiltered-water and filtered-water samples and suspended-sediment concentration during each sampling period, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Filtered-Water Chemical Concentrations

Dissolved organic carbon and metals were detected frequently in filtered-water samples collected at study sites (tables 5 and A5). Dissolved organic carbon was detected in 17 of the 18 samples ranging in concentration from the reporting limit of 1.5 to 4.56 mg/L, with a median of 2.44 mg/L. Dissolved organic carbon accounted for 50–100 percent of TOC, with a median of 79 percent. All but one of the metals that were analyzed for were detected in at least one filtered-water sample (silver was not detected). The same nine metals that were detected in greater than 75 percent of unfiltered-water samples were detected in greater than 40 percent of filtered-water samples. Arsenic was measured in all 19 filtered-water samples, ranging in concentration from 0.3 to 0.7 $\mu\text{g/L}$, with a median concentration of 0.4 $\mu\text{g/L}$. Metals concentrations in unfiltered water generally increased with increasing SSC, whereas metals concentrations in the filtered (dissolved) fraction were similar between sampling periods (see fig. 7 for arsenic as an example). This suggests that the sediment-bound chemicals are an important fraction of the unfiltered-water concentration and that these chemicals should be considered when assessing downstream chemical loading.

Suspended-Sediment Chemical Concentrations

Many compounds were detected in suspended-sediment samples, including TOC, metals, PAHs and other semivolatile compounds, butyltins, pesticides, dioxins/furans, and PCBs

(tables 6 and A6). All sediment concentrations are reported as a dry weight concentration. Total organic carbon content ranged from 0.93 to 10.2 percent with a median of 3.57 percent in the 21 suspended-sediment samples. The highest value occurred during a “first flush” autumn storm in September when there was noticeable biogenic material such as algae in the water. With the exception of antimony, which was detected in 2 of 21 samples, the remaining 17 metals were detected in all or nearly all suspended-sediment samples (tables 6 and A6). Arsenic was detected in all 21 samples, ranging in concentration from 6.6 to 28.0 mg/kg, with a median of 12.7 mg/kg. During this study, all arsenic concentrations greater than 15 mg/kg were measured between July and November. Chromium was detected in all 21 samples at concentrations ranging from 16.5 to 54.0 mg/kg. Copper was detected in all 21 samples at concentrations ranging from 31.0 to 84.0 mg/kg. Mercury also was detected in all 21 samples at concentrations ranging from 0.06 J to 0.20 mg/kg. Zinc was detected in all 21 samples at concentrations ranging from 67.0 to 350 mg/kg. The highest concentrations of many metals, including copper, chromium, mercury, and zinc, were detected during a summer hail storm and an early autumn storm (table A6). Median concentrations of many metals, including chromium, copper, lead nickel, and zinc, were highest in storm samples, as compared to baseline samples and dam samples. However, median concentrations of metals with naturally-occurring sources, such as arsenic and manganese, were highest in baseline samples of suspended sediment.

Table 5. Summary statistics of detected compounds in filtered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Q₁ qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit; U, not detected above detection limit (reporting limit is reported in “Result” column). **Abbreviations:** µg/L, microgram per liter; mg/L, milligram per liter; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	All water samples (n=19)											Sampling period					
			Number of detects/samples	Detections with J qualifier (percent)	Median			Minimum			Maximum			Baseline (n=5)		Storm (n=9)		Dam release (n=5)	
					Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result
Organic carbon																			
Dissolved organic carbon	mg/L	na	17/18	na	2.44	1.50	U	4.56	1.90	2.44	3.13								
Metals																			
Antimony	µg/L	7440-36-0	8/19	88	0.13	U	0.05	U	0.2	0.07	U	0.13	U	0.09	J				
Arsenic	µg/L	7440-38-2	19/19	0	0.40	0.30	0.70	0.50	0.40	0.50	0.50	2.6	1.4	0.40					
Barium	µg/L	7440-39-3	19/19	0	2.5	1.3	4.0	2.9	1.4	2.9	2.6	0.2	U	0.2	U				
Beryllium	µg/L	7440-41-7	1/19	100	0.2	U	0.08	J	0.2	0.2	U	0.2	U	0.2	U				
Cadmium	µg/L	7440-43-9	2/19	100	0.1	U	0.02	J	0.1	0.1	U	0.1	U	0.1	U				
Chromium	µg/L	7440-47-3	8/19	100	1.0	U	0.14	J	0.1	0.1	J	0.5	U	0.1	J				
Cobalt	µg/L	7440-48-4	15/16	40	0.2	U	1.2	0.2	0.5	0.2	0.6	0.6	0.5	0.5					
Copper	µg/L	7440-50-8	19/19	0	0.9	0.6	1.6	0.6	0.9	0.6	0.9	0.9	0.9	0.9					
Lead	µg/L	7439-92-1	9/19	78	0.1	U	0.08	U	0.1	0.1	U	0.06	J	0.06	J				
Manganese	µg/L	7439-96-5	16/16	0	29.6	8.4	84.8	51.1	12.7	51.1	27.1	12.7	12.7	12.7					
Mercury	µg/L	7439-97-6	2/19	100	0.02	U	0.003	J	0.02	0.02	U	0.02	U	0.02	U				
Molybdenum	µg/L	7439-98-7	16/16	63	0.18	J	0.3	0.18	0.3	0.18	J	0.2	0.1	0.1	J				
Nickel	µg/L	7440-02-0	18/19	61	0.41	0.5	1.0	0.43	0.39	0.43	J	0.5	0.39	0.39	J				
Selenium	µg/L	7782-49-2	2/19	100	0.5	U	0.13	J	0.5	0.5	U	0.5	U	0.5	U				
Thallium	µg/L	7440-28-0	1/19	100	0.2	U	0.01	J	0.2	0.2	U	0.2	U	0.2	U				
Vanadium	µg/L	7440-62-2	19/19	0	0.60	0.40	1.0	0.50	0.80	0.50	0.60	0.60	0.80	0.80					
Zinc	µg/L	7440-66-6	5/19	80	2.9	1.3	5.0	2.1	2.4	2.1	U	4	U	2.4	U				

Table 6. Summary statistics of detected compounds in suspended-sediment samples, Duwamish River at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is in Result column). **Abbreviations:** mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	All water samples (n=22)										Sampling periods			
			Number of detects/samples	Detections with J qualifier (percent)	Median		Minimum		Maximum		Baseline (n=6)		Storm (n=10)		Dam release (n=6)	
					Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Polycyclic aromatic hydrocarbons and other semivolatile compounds—Continued																
2-Methylnaphthalene	µg/kg	91-57-6	17/20	0	15.8	62.0	U	48.4	U	15.8	16.1	13.5	U	U	U	
2-Methylphenol	µg/kg	95-48-7	1/19	100	58	U	29	J	U	24	82	20	U	U	U	
4-Methylphenol	µg/kg	106-44-5	13/19	31	36	J	19	930	U	144	47	25	J	J	J	
Benzoic acid	µg/kg	65-85-0	18/19	44	990	J	110	3,200	J	1,280	1,100	560	J	J	J	
Benzyl alcohol	µg/kg	100-51-6	18/19	17	600	J	81	1,100	U	430	740	500	J	J	J	
bis(2-ethylhexyl)phthalate	µg/kg	117-81-7	19/19	0	1,400	210	3,900	U	395	2,000	515	U	U	U	U	
Butylbenzylphthalate	µg/kg	85-68-7	15/19	27	82	U	19	1,400	U	39	820	46	U	U	U	
Carbazole	µg/kg	86-74-8	4/19	75	62	U	19	470	U	20	99	20	U	U	U	
Dibenzofuran	µg/kg	132-64-9	17/20	12	8.0	62	U	15.4	U	8.6	9.3	5.5	U	U	U	
Diethylphthalate	µg/kg	84-66-2	3/19	0	60	U	19	500	U	20	99	20	U	U	U	
Di-n-Butylphthalate	µg/kg	84-74-2	5/19	60	62	U	19	460	U	20	120	20	U	U	U	
Di-n-Octyl phthalate	µg/kg	117-84-0	9/19	22	12	J	19	450	U	15	94	20	U	U	U	
Pentachlorophenol	µg/kg	87-86-5	3/19	100	300	U	95	90	J	19	400	99	U	U	U	
Phenol	µg/kg	108-95-2	15/19	13	150	19	390	U	225	150	65	U	U	U	U	
Butyltins																
Butyltin	µg/kg	78763-54-9	7/15	14	14	U	3.8	61	U	4.6	8.6	3.9	U	U	U	
Dibutyltin ion	µg/kg	14488-53-0	5/15	0	5.7	U	5.4	39	U	5.7	15	5.5	U	U	U	
Tributyltin ion	µg/kg	36643-28-4	0/15	na	3.7	U	3.6	13	U	3.7	3.7	3.7	U	U	U	
Pesticides																
Dieldrin	µg/kg	60-57-1	1/18	100	3.3	U	1.3	1.0	J	3.3	3.3	3.2	U	U	U	
Endosulfan sulfate	µg/kg	1031-07-8	1/18	0	3.3	U	1.3	1.8	U	3.3	3.3	3.2	U	U	U	
p,p'-DDD	µg/kg	72-54-8	1/18	0	3.3	U	1.3	3.0	U	3.3	3.3	3.2	U	U	U	
p,p'-DDT	µg/kg	50-29-3	1/18	0	3.3	U	1.3	2.6	U	3.3	3.3	3.2	U	U	U	
Dioxins/furans																
Total dioxins/furans ⁴	ng/kg	na	22/22	0	707	72.7	4,210	J	707	1,370	148	J	J	J	J	
Total dioxins/furans ⁴	ng TEQ/kg	na	22/22	86	3.25	J	0.526	19.3	J	3.25	6.42	0.850	J	J	J	

Table 6. Summary statistics of detected compounds in suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is in Result column). **Abbreviations:** mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	All water samples (n=22)										Sampling periods					
			Number of detects/samples	Detections with J qualifier (percent)	Median		Minimum		Maximum		Baseline (n=6)		Storm (n=10)		Dam release (n=6)			
					Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q		
Polychlorinated biphenyls (by high-resolution mass spectrometry)																		
Total polychlorinated biphenyls ⁵	µg/kg	1336-36-3	22/22	0	7.93	0.448	83.9	7.93	0.009	J	15.8	0.869						
Total monochloro biphenyls	µg/kg	27323-18-8	22/22	5	0.008	0.186	0.003	0.009	J	0.014	0.003							
Total dichloro biphenyls	µg/kg	25512-42-9	22/22	0	0.107	0.022	1.45	0.100	0.245	0.035								
Total trichloro biphenyls	µg/kg	25323-68-6	22/22	0	0.289	0.036	3.13	0.289	0.596	0.064								
Total tetrachloro biphenyls	µg/kg	26914-33-0	22/22	0	1.02	0.059	9.23	1.04	1.70	0.119								
Total pentachloro biphenyls	µg/kg	25429-29-2	22/22	0	2.56	0.119	26.8	2.40	4.50	0.224								
Total hexachloro biphenyls	µg/kg	26601-64-9	22/22	0	2.47	0.129	27.6	2.36	5.03	0.255								
Total heptachloro biphenyls	µg/kg	28655-71-2	22/22	0	1.05	0.045	11.1	1.05	2.32	0.089								
Total octachloro biphenyls	µg/kg	55722-26-4	22/22	0	0.396	0.019	3.58	0.396	0.733	0.045								
Total nonachloro biphenyls	µg/kg	53742-07-7	22/22	0	0.102	0.009	0.893	0.102	0.187	0.013								
Total decachloro biphenyls	µg/kg	2051-24-3	21/22	0	0.030	0.004	0.161	0.036	0.064	0.009								
Aroclor 1242	µg/kg	53469-21-9	22/22	0	0.509	0.067	5.18	0.509	1.03	0.116								
Aroclor 1254	µg/kg	11097-69-1	22/22	0	3.83	0.195	39.4	3.51	6.54	0.359								
Aroclor 1260	µg/kg	11096-82-5	22/22	0	2.18	0.127	26.0	2.18	5.98	0.254								
Polychlorinated biphenyls (by low-resolution mass spectrometry)																		
Aroclor 1242	µg/kg	53469-21-9	0/13	na	4.0	U	3.8	U	32	U	4.0	U	4.0	U				
Aroclor 1254	µg/kg	11097-69-1	8/13	13	6.5	U	3.9	U	40	U	8.0	U	4.0	U				
Aroclor 1260	µg/kg	11096-82-5	9/13	33	4.2	U	3.9	U	19	U	5.6	U	4.0	U				

¹LPAH is a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

²HPAH is a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzofluoranthenes (sum of b-, j-, and k- isomers), benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene.

³cPAH is 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).

⁴Total dioxins/furans is a summed concentration of 17 congeners.

⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

One or more PAHs were detected in all 20 suspended-sediment samples. Carcinogenic PAHs were detected in all 20 samples, ranging from 3.69 J to 292 $\mu\text{g TEQ/kg}$, with a median of 39.9 $\mu\text{g TEQ/kg}$ (tables 6 and A6). Concentrations of cPAHs were much higher during storms (median 148 $\mu\text{g TEQ/kg}$) than during baseline events (median 36.0 $\mu\text{g TEQ/kg}$) or dam releases (median 11.7 $\mu\text{g TEQ/kg}$). Other than PAHs, the most commonly detected semivolatile compounds included benzoic acid, benzyl alcohol, and *bis*(2-ethylhexyl)phthalate (tables 6 and A6). Of the butyltin species, butyltin was detected in 7 of 15 samples with a maximum concentration of 61 $\mu\text{g/kg}$, dibutyltin was detected in 5 of 15 samples with a maximum concentration of 39 $\mu\text{g/kg}$, and tributyltin was not detected. The pesticides dieldrin, endosulfan sulfate, *p,p'*-DDD, and *p,p'*-DDT were detected in 1 of 18 samples, during a large winter storm. All other pesticides were not detected.

Dioxins/furans were detected in all 22 suspended-sediment samples ranging in concentration from 0.526 J to 19.3 J ng TEQ/kg, with a median of 3.25 J ng TEQ/kg (tables 6 and A6). Total PCBs also were detected in all 22 suspended-sediment samples ranging in concentration from 0.448 to 83.9 $\mu\text{g/kg}$, with a median of 7.93 $\mu\text{g/kg}$ (tables 6 and A6). Similar to metals and PAHs, median concentrations of dioxins/furans and median concentrations of PCBs were higher during storm sampling, especially in summer and early autumn storms, as compared to median concentrations of samples collected during baseline or dam release periods (table 6). Results for PCB Aroclor concentrations were compared between a low-resolution method and a high-resolution method. One laboratory calculated Aroclors using a low-resolution mass spectrometry method (EPA 8082A) in which the chromatogram of the environmental sample is compared to Aroclor calibration standards. The other laboratory calculated Aroclors from equations summing the results of individual congeners determined using a high-resolution mass spectrometry methods (EPA 1668C).

Concentrations determined from the low-resolution method were typically two to four times higher than concentrations reported from the high-resolution method (tables 6 and A6).

The three samples in which there was sufficient sediment for VOC analysis included one detection each of acetone at 34 J $\mu\text{g/kg}$ and toluene at 1.5 J $\mu\text{g/kg}$ (table A6). All other VOCs, as well as hexavalent chromium, were not detected.

Bed-Sediment Chemical Concentrations

The four sets of bed-sediment samples were collected during low-flow, low-precipitation conditions when the 72-hour antecedent precipitation was less than or equal to 0.51 in (table A3). Total organic carbon, metals, PAHs and other semivolatile compounds, VOCs, dioxins/furans, and PCBs were detected in the four bulk (sieved to less than 2 mm) bed-sediment samples (tables 7 and A7). All sediment concentrations are reported as a dry weight concentration. Concentrations of TOC ranged from 0.95 to 1.10 percent. Seventeen of the 18 metals were detected, including arsenic (4.4 to 5.6 mg/kg) and mercury (0.02 J to 0.05 mg/kg). Total cPAHs ranged in concentration from 9.46 J to 18.7 $\mu\text{g TEQ/kg}$. Total dioxins/furans ranged in concentration from 0.409 J to 0.575 J ng TEQ/kg. Total PCBs ranged in concentration from 0.918 to 2.59 $\mu\text{g/kg}$. Several VOCs and other semivolatile compounds were detected, including benzoic acid, benzyl alcohol, and *bis*(2-ethylhexyl)phthalate.

The same suite of compounds was detected in the four fine (sieved to less than 62.5 μm) bed-sediment samples as in the corresponding bulk bed-sediment samples (tables 7 and A7). Additionally, hexavalent chromium and diethylphthalate were each detected once in fine bed material, but neither was detected in bulk bed material. When analyte concentrations were compared between paired bulk and fine bed-sediment samples, the concentration in the fine bed-sediment sample was similar to or greater than the concentration in the bulk bed-sediment sample for all analytes, except for a few PAHs such as 2-methylnaphthalene and 1-methylnaphthalene.

Table 7. Summary statistics of detected compounds in bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is in Result column). **Abbreviations:** mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; na, not applicable]

Parameter name	Chemical Abstracts Service (CAS) No.	Unit of measure	Bed-sediment samples (<2 mm [n=4])						Bed-sediment samples (<62.5 µm [n=4])					
			Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum		
Organic carbon														
Total organic carbon	na	percent	4/4	na	1.02	0.95	1.10	4/4	na	2.27	1.48	2.50		
Hexavalent chromium														
Hexavalent chromium	18540-29-9	mg/kg	0/4	na	0.642	0.569	0.703	1/4	na	3.73	1.14	1.17		
Metals														
Arsenic	7440-38-2	mg/kg	4/4	0	4.7	4.4	5.6	4/4	0	10.3	9.0	13.0		
Barium	7440-39-3	mg/kg	4/4	0	73.3	70.8	93.2	4/4	0	116	73.0	127		
Beryllium	7440-41-7	mg/kg	4/4	50	0.29	J	0.27	J	100	0.46	J	0.55		
Cadmium	7440-43-9	mg/kg	3/4	67	0.075	J	0.20	U	75	0.51	J	1.0		
Chromium	7440-47-3	mg/kg	4/4	0	16.7	15.5	20.0	4/4	0	28.5	17.0	31.0		
Cobalt	7440-48-4	mg/kg	4/4	0	6.45	6.40	8.00	4/4	0	10.3	6.00	11.2		
Copper	7440-50-8	mg/kg	4/4	0	16.4	15.5	21.2	4/4	0	33.5	23.0	39.0		
Lead	7439-92-1	mg/kg	4/4	0	4.80	4.50	6.10	4/4	0	11.5	8.80	13.0		
Manganese	7439-96-5	mg/kg	4/4	0	502	458	576	4/4	0	935	865	965		
Mercury	7439-97-6	mg/kg	4/4	25	0.04	0.02	J	0.05	33	0.07	J	0.12		
Molybdenum	7439-98-7	mg/kg	3/4	100	0.14	J	0.3	U	67	0.53	J	1.0		
Nickel	7440-02-0	mg/kg	4/4	0	16.6	16.1	21.2	4/4	0	26.5	15.0	30.0		
Selenium	7782-49-2	mg/kg	2/4	100	0.16	J	0.80	U	100	0.5	J	0.70		
Silver	7440-22-4	mg/kg	3/4	100	0.058	J	0.30	U	100	0.11	J	0.16		
Thallium	7440-28-0	mg/kg	3/4	100	0.047	J	0.3	U	100	0.091	J	0.12		
Vanadium	7440-62-2	mg/kg	4/4	0	38.9	36.6	49.0	4/4	0	63.1	46.0	75.0		
Zinc	7440-66-6	mg/kg	4/4	0	49.5	48.0	58.0	4/4	0	85.0	60.0	90.0		
Polycyclic aromatic hydrocarbons and other semivolatile compounds														
LPAH ¹	na	µg/kg	4/4	0	40.9	28.1	57.9	4/4	0	57.7	32.3	88.1		
HPAH ²	na	µg/kg	4/4	25	122	93.5	J	159	50	214	J	420		
cPAH ³	na	µg/kg	4/4	50	66.4	49.3	J	88.1	75	115	J	226		
cPAH ³	na	µg TEQ/kg	4/4	25	13.3	9.46	J	18.7	50	22.8	J	44.6		
1-Methylnaphthalene	90-12-0	µg/kg	4/4	0	11.0	6.32	16.2	4/4	0	4.89	4.32	6.93		

Table 7. Summary statistics of detected compounds in bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers[®] (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. Concentrations are reported as a dry weight concentration. **Parameter name:** ePAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is in Result column). **Abbreviations:** mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; na, not applicable]

Parameter name	Chemical Abstracts Service (CAS) No.	Unit of measure	Bed-sediment samples (<2 mm [n=4])						Bed-sediment samples (<62.5 µm [n=4])							
			Number of detections/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Result	Q	Number of detections/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Result	Q
Polycyclic aromatic hydrocarbons and other semivolatile compounds—Continued																
2-Methylnaphthalene	91-57-6	µg/kg	4/4	0	11.1	7.57	15.2	4/4	0	7.59	5.88	10.8				
4-Methylphenol	106-44-5	µg/kg	4/4	50	18	J 14	J 22	1/3	0	20	U 20	U 28				
Benzoic acid	65-85-0	µg/kg	4/4	50	360	160	J 660	J 3/3	33	560	J 300	1,100				
Benzyl alcohol	100-51-6	µg/kg	3/4	0	165	19	U 210	3/3	0	150	140	470				
bis(2-ethylhexyl)phthalate	117-81-7	µg/kg	3/4	100	32	J 49	U 38	J 3/3	33	51	44	J 110				
Dibenzofuran	132-64-9	µg/kg	4/4	0	4.9	3.6	6.4	4/4	0	5.0	3.1	5.8				
Diethylphthalate	84-66-2	µg/kg	0/0	na	20	U 19	U 240	U 1/3	0	72	U 20	U 34				
Phenol	108-95-2	µg/kg	3/4	0	36	43	U 49	2/3	0	24	110	U 44				
Volatile organic compounds																
2-Butanone	78-93-3	µg/kg	1/4	100	6.6	U 6.3	U 4.7	J 2/4	100	8.4	J 13	U 27	J			
Acetone	67-64-1	µg/kg	2/4	100	6.2	J 8.3	U 13	J 3/4	33	62	J 13	U 110				
Methylene chloride	75-09-2	µg/kg	1/4	0	3.3	U 3.3	U 3.0	1/4	0	18	U 5.1	U 7.9				
Dioxins/furans																
Total dioxins/furans ⁴	na	ng/kg	4/4	0	93.7	82.2	101	4/4	0	470	231	971				
Total dioxins/furans ⁴	na	ng TEQ/kg	4/4	100	0.523	J 0.409	J 0.575	J 4/4	100	2.35	J 1.12	J 4.73	J			
Polychlorinated biphenyls (by high-resolution mass spectrometry)																
Total polychlorinated biphenyls ⁵	1336-36-3	µg/kg	4/4	0	1.50	0.918	2.59	4/4	0	5.49	2.06	12.1				
Total monochloro biphenyls	27323-18-8	µg/kg	4/4	25	0.003	0.002	0.004	J 4/4	75	0.0063	J 0.003	J 0.012	J			
Total dichloro biphenyls	25512-42-9	µg/kg	4/4	0	0.012	0.008	0.026	4/4	0	0.057	0.031	0.172				
Total trichloro biphenyls	25323-68-6	µg/kg	4/4	0	0.071	0.058	0.139	4/4	0	0.213	0.100	0.437				
Total tetrachloro biphenyls	26914-33-0	µg/kg	4/4	0	0.194	0.148	0.386	4/4	0	0.668	0.275	1.21				
Total pentachloro biphenyls	25429-29-2	µg/kg	4/4	0	0.432	0.281	0.842	4/4	0	1.77	0.619	3.39				
Total hexachloro biphenyls	26601-64-9	µg/kg	4/4	0	0.444	0.243	0.781	4/4	0	1.71	0.619	3.77				
Total heptachloro biphenyls	28655-71-2	µg/kg	4/4	0	0.224	0.096	0.333	4/4	0	0.695	0.259	2.01				
Total octachloro biphenyls	55722-26-4	µg/kg	4/4	0	0.066	0.038	0.125	4/4	0	0.258	0.104	0.771				
Total nonachloro biphenyls	53742-07-7	µg/kg	4/4	0	0.017	0.012	0.030	4/4	0	0.083	0.031	0.182				
Total decachloro biphenyls	2051-24-3	µg/kg	4/4	0	0.006	0.005	0.011	4/4	0	0.027	0.014	0.105				

Table 7. Summary statistics of detected compounds in bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection. J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is in Result column). **Abbreviations:** mg/kg, milligram per kilogram; µg/kg, microgram per kilogram; ng TEQ/kg, microgram toxic equivalent per kilogram; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; na, not applicable]

Parameter name	Chemical Abstracts Service (CAS) No.	Unit of measure	Bed-sediment samples (<2 mm [n=4])					Bed-sediment samples (<62.5 µm [n=4])				
			Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum	Number of detects/samples	Detections with J qualifier (percent)	Median	Minimum	Maximum
Aroclor 1242	53469-21-9	µg/kg	4/4	0	0.125	0.101	0.248	4/4	0	0.375	0.172	0.766
Aroclor 1254	11097-69-1	µg/kg	4/4	0	0.658	0.459	1.26	4/4	0	2.72	1.02	5.05
Aroclor 1260	11096-82-5	µg/kg	4/4	0	0.483	0.253	0.746	4/4	0	1.68	0.701	4.75
Polychlorinated biphenyls (by high-resolution mass spectrometry)—Continued												
Aroclor 1242	53469-21-9	µg/kg	0/0	na	4.0	3.8	19	0/2	na	4.0	3.9	4.0
Aroclor 1254	11097-69-1	µg/kg	2/4	100	3.2	4.0	3.7	2/2	100	5.3	3.2	7.4
Aroclor 1260	11096-82-5	µg/kg	1/4	100	4.0	3.8	2.8	2/2	100	3.1	2.4	3.8
Polychlorinated biphenyls (by low-resolution mass spectrometry)												
Aroclor 1242	53469-21-9	µg/kg	0/0	na	4.0	3.8	19	0/2	na	4.0	3.9	4.0
Aroclor 1254	11097-69-1	µg/kg	2/4	100	3.2	4.0	3.7	2/2	100	5.3	3.2	7.4
Aroclor 1260	11096-82-5	µg/kg	1/4	100	4.0	3.8	2.8	2/2	100	3.1	2.4	3.8

¹LPAH is a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

²HPAH is a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzofluoranthenes (sum of b-, j-, and k- isomers), benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene.

³cPAH is 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).

⁴Total dioxins/furans is a summed concentration of 17 congeners.

⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

Quality-Control Chemical Concentrations

Many compounds, including pesticides, butyltins, and hexavalent chromium, were not detected in the five trip-blank samples and five equipment-blank water samples analyzed for all compounds (tables A8 and A9). Naphthalene was detected at concentrations ranging from 0.011 to 0.019 µg/L in three of the five trip-blank samples and at concentrations ranging from 0.011 to 0.033 µg/L in four of the five equipment-blank samples although it was detected in only one of 16 laboratory blank samples at a concentration of 0.0091 µg/L. This suggests that low levels of naphthalene may have been present in sample bottles or introduced during bottle filling at the laboratory or in the field. Naphthalene concentrations in river water samples (maximum concentration=0.027 µg/L; table A4) were similar to these field blank concentrations (0.033 µg/L). All naphthalene detections in river samples were censored as non-detections (U-qualified). No other PAHs were detected in the trip- and equipment-blank samples. There were sporadic detections in the trip- and equipment-blank samples of some common laboratory contaminants such as benzyl alcohol, methylene chloride, benzene, chloroform, and acetone (tables A8 and A10). No other semi-volatile compounds or VOCs were detected. Low-levels of metals were detected in both unfiltered- and filtered-water blank samples, including barium and manganese (table A8). Metals concentrations in river water samples typically were more than 10 times higher than the highest blank concentration; therefore, the environmental results were deemed acceptable and were not qualified.

Concentrations of PCBs in the trip and equipment water blank samples indicate that the sample collection and processing protocol is acceptable for low-level PCB analysis. Concentrations of total PCBs in the five trip-blank and the five field equipment-blank water samples ranged from 9 J to 31 J pg/L and from 28 J to 78 J pg/L, respectively (table A9). These concentrations are less than typical environmental baseline levels (about 100–150 pg/L) and less than the background levels measured in corresponding laboratory blank samples (range: 20.9 to 243 pg/L; median: 188 pg/L). The higher concentrations in the equipment-blank samples in comparison to the trip-blank samples were mostly from the contribution of the dichloro- through hexachloro-homologs (table A9). Dioxins/furans were not detected in trip- and field equipment-blank water samples with the exception of one concentration of 1.37 J pg/L in a trip-blank sample and one concentration of 0.818 J pg/L in an equipment blank sample (table A9).

The fine silica sand source blank used to process the suspended-sediment equipment blank (see section, “Quality Assurance and Quality Control”) contained low concentrations of metals, dioxins/furans, and PCBs (table A11). After the source sediment had been processed through the suspended-sediment sampling equipment (pumps, tubing, and centrifuge), low concentrations of metals, dioxins/furans, and PCBs were detected, as well as bulk organic carbon, diethylphthalate, and a few PAHs. Overall, median environmental concentrations on suspended sediment were 8 to greater than 1,000 times higher than the equipment blank concentrations (table A11).

In addition to testing the suspended-sediment processing equipment for introduction of contaminants, the suspended-sediment sampling process also was tested on two occasions (February 2015 and March 2015) for loss of compounds, particularly of semivolatile compounds during centrifugation (see section, “Quality Assurance and Quality Control”). Recoveries were greater than 65 percent for most detected compounds, including metals, PAHs and other semivolatile compounds (table A12). Some VOCs such as methylene chloride, acetone, and 2-butanone had low recoveries, as expected for volatile compounds during the centrifugation process. Some semivolatile compounds such as benzyl alcohol and benzoic acid also had low recoveries during the March 2015 centrifugation test, but recoveries for these same compounds were high during the February 2015 test. During the March 2015 test, concentrations of most compounds in the centrifuged sample were greater than concentrations in the bulk bed-sediment sample. This is likely owing to the change in PSD from about 17 percent fines in the bulk bed-sediment sample to 75 percent fines in the centrifuged sample. Organic compounds preferentially sorb to fine-grained sediments with high organic carbon contents as compared to bulk bed sediment. During the February 2015 test, the fine fraction of both samples was compared, and percent recovery of individual compounds in the centrifuged sample ranged from 68 percent (naphthalene) to 178 percent (fluoranthene). These recoveries are in the range of expected recoveries for individual compounds in laboratory-spiked samples. The centrifuge experiments confirm that losses of VOCs can occur during the centrifugation process. The results also suggest that centrifugation may result in a finer-grained final sample as compared to the pre-centrifuged sample. In this study, the reported PSD of suspended sediment was determined by analysis of the depth- and width-integrated water sample per USGS methods (see task 4 in table 1) and not by analysis

of the centrifuged sample (because of limited mass). The suspended-sediment sample collection and laboratory-processing protocols for chemical parameters were deemed appropriate for this project, and no individual suspended-sediment data were qualified.

The relative percent difference between individual analyte concentrations detected in concurrent field replicates of water samples ranged from 0 to 89 percent with a median of 12 percent for unqualified detections and a median of 18 percent when one or both concentrations were J-qualified (table A13). The summed concentration (as pg TEQ/L) of 17 dioxins/furans differed by 7 to 10 percent, and the summed concentration of the 209 PCB congeners differed by 32 to 63 percent. The relative percent difference between the parameter concentration in bed-sediment field split samples (table A14) ranged from 0 to 81 percent, with a median of 17 percent.

Acceptance criteria selected for the Puget Sound SRM followed that used by the U.S. Army Corps of Engineers in evaluating analytical performance by commercial laboratories in round-robin tests of the Puget Sound SRM (<http://www.nws.usace.army.mil/Missions/CivilWorks/Dredging/SRM.aspx>), and was plus or minus 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 SRM for this project were within the acceptance criteria for all compounds, with the exception of 1,2,3,7,8,9-hexachlorodibenzofuran, 2,3,4,6,7,8-hexachlorodibenzofuran, PCB congener 37 and PCB congeners 50/53 (table A15).

Other than censoring naphthalene detections in unfiltered-water samples, the results from various field quality-assurance samples were deemed satisfactory and no additional qualifications were applied to the environmental data.

Comparison of Suspended Sediment and Bed Sediment

Median concentrations of individual compounds (table 8) in suspended sediment (sample size of 20–22) were greater than median concentrations in fine bed sediment (sample size of 4), which were greater than median concentrations in bulk bed-sediment samples (sample size of 4). Suspended-sediment samples were collected on days targeting a range of flow and sediment conditions, whereas the bed-sediment samples were collected on different days targeting low-flow conditions (72-hour antecedent precipitation was less than or equal to 0.51 in.). When the dry weight concentrations were normalized for organic carbon content (table 8), the median concentrations of dioxins/furans and PCBs in fine bed sediment were similar to or greater than median 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 PSD was similar across the four sampling periods (fig. 8A). Between 76 and 91 percent of the weight was comprised of particles less than or equal to 250 μm , with most of the total weight (59–70 percent) comprised of particles between 62.5 and 250 μm , whereas 15–24 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 (fig. 8B), ranging from 56 percent during a large lowlands storm to 95 percent during a summer storm (table A2), with a median of 80 percent (table 4). A median of 57 percent of the suspended-sediment weight was composed of particles smaller than 8 μm , compared to 4 percent for the bed-sediment samples (fig. 8).

Table 8. Comparison of select parameters in suspended sediment, bed sediment less than 62.5 µm, and bed sediment less than two mm, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q,** qualifier: Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is reported in “Result” column). **Abbreviations:** µm, micrometer; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; mg/kg, milligram per kilogram; mm, millimeter; ng/kg, nanogram per kilogram; TOC, total organic carbon; <, less than]

Parameter name	Unit of measure	Suspended sediment (n=20–22)				Fine bed sediment (<62.5 µm [n=4])				Bulk bed sediment (<2 mm [n=4])			
		Median	Minimum	Maximum	Q	Median	Minimum	Maximum	Q	Median	Minimum	Maximum	Q
		Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Organic carbon													
Total organic carbon	percent	3.57	0.93	10.2		2.27	1.48	2.5		1.02	0.95	1.1	
Fine sediment (less than 62.5 µm)	percent	80	56	95		99	98	99		18	15	24	
<i>Dry weight concentrations</i>													
Metals													
Arsenic	µg/kg	12.7	6.6	28.0		10.3	9.0	13.0		4.7	4.4	5.6	
Copper	µg/kg	42.0	31.0	84.0		33.5	23.0	39.0		16.4	15.5	21.2	
Lead	µg/kg	14.6	6.6	60.3		11.5	8.8	13.0		4.8	4.5	6.1	
Mercury	µg/kg	0.10	0.063	0.20		0.074	0.20	0.12		0.035	0.024	0.050	
Polycyclic aromatic hydrocarbons													
LPAH	µg/kg	108	35.3	216		57.7	32.3	88.1		40.9	28.1	57.9	
HPAH	µg/kg	457	60.0	2,400		214	140	420		122	93.5	159	
cPAH	µg/kg	225	33.4	1,410		115	78.3	226		66.4	49.3	88.1	
cPAH	µg TEQ/kg	39.9	3.69	292		22.8	15.0	44.6		13.3	9.46	18.7	
Dioxins/furans													
Total dioxins/furans	ng/kg	707	72.7	4,210		470	231	971		93.7	82.2	101	
Total dioxins/furans	ng TEQ/kg	3.25	J	0.526	J	19.3	2.35	J	4.73	J	0.523	J	0.575
Polychlorinated biphenyls (by high-resolution mass spectrometry)													
Total polychlorinated biphenyls	µg/kg	7.93	0.448	83.9		5.49	2.06	12.1		1.50	0.918	2.59	
Aroclor 1242	µg/kg	0.509	0.067	5.18		0.375	0.172	0.766		0.125	0.101	0.248	
Aroclor 1254	µg/kg	3.83	0.195	39.4		2.72	1.02	5.05		0.658	0.459	1.26	
Aroclor 1260	µg/kg	2.18	0.127	26.0		1.68	0.701	4.75		0.483	0.253	0.746	

Table 8. Comparison of select parameters in suspended sediment, bed sediment less than 62.5 µm, and bed sediment less than two mm, Duwamish River at Golf Course at Tukwila, Washington, 2013–15. —Continued

Concentrations are reported as a dry weight concentration. **Parameter name:** cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (reporting limit is reported in “Result” column). **Abbreviations:** µm, micrometer; µg/kg, microgram per kilogram; µg TEQ/kg, microgram toxic equivalent per kilogram; mg/kg, milligram per kilogram; mm, millimeter; ng/kg, nanogram per kilogram; ng TEQ/kg, nanogram toxic equivalent per kilogram; TOC, total organic carbon; <, less than

Parameter name	Unit of measure	Suspended sediment (n=20–22)				Fine bed sediment (<62.5 µm [n=4])				Bulk bed sediment (<2 mm [n=4])			
		Median	Minimum	Maximum	Q	Median	Minimum	Maximum	Q	Median	Minimum	Maximum	Q
		Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Organic carbon-normalized concentrations													
Polycyclic aromatic hydrocarbons													
LPAH ¹	mg/kg TOC	3.2	1.1	9.1	3.3	1.3	3.7	4.0	2.6	6.1			
HPAH ²	mg/kg TOC	16	3.4	72	12.1	5.6	17.3	J	8.7	J			
cPAH ³	mg/kg TOC	8.1	1.9	40	6.4	3.1	9.3	J	4.6	J			
cPAH ³	mg TEQ/kg TOC	1.5	0.2	J	1.3	0.6	1.8	J	0.88	J			
Dioxins/furans													
Total dioxins/furans ⁴	µg/kg TOC	19.4	3.02	75.4	20.7	15.6	40.0	8.93	8.55	9.94			
Total dioxins/furans ⁴	ng TEQ/kg TOC	85.0	19.4	J	334	102	J	195	J	60.2			
Polychlorinated biphenyls (by high-resolution mass spectrometry)													
Total polychlorinated biphenyls ⁵	µg/kg TOC	184	16.8	1,450	233	139	496	138	95.3	271			
Aroclor 1242	µg/kg TOC	15.3	1.50	123	16.1	11.6	31.5	12.1	9.3	25.9			
Aroclor 1254	µg/kg TOC	113	7.59	682	115	68.9	208	63.2	42.5	132			
Aroclor 1260	µg/kg TOC	72.2	5.54	450	72.1	47.4	195	48.6	26.7	67.8			

¹LPAH is a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

²HPAH is a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzo[*a,h*]perylene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene.

³cPAH is a summed concentration of benzo[*a*]anthracene, chrysene, benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenz[*a,h*]anthracene, and total benzo[*a,h*]anthracenes (sum of *b*-, *j*-, and *k*- isomers).

⁴Total dioxins/furans is a summed concentration of 17 congeners.

⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

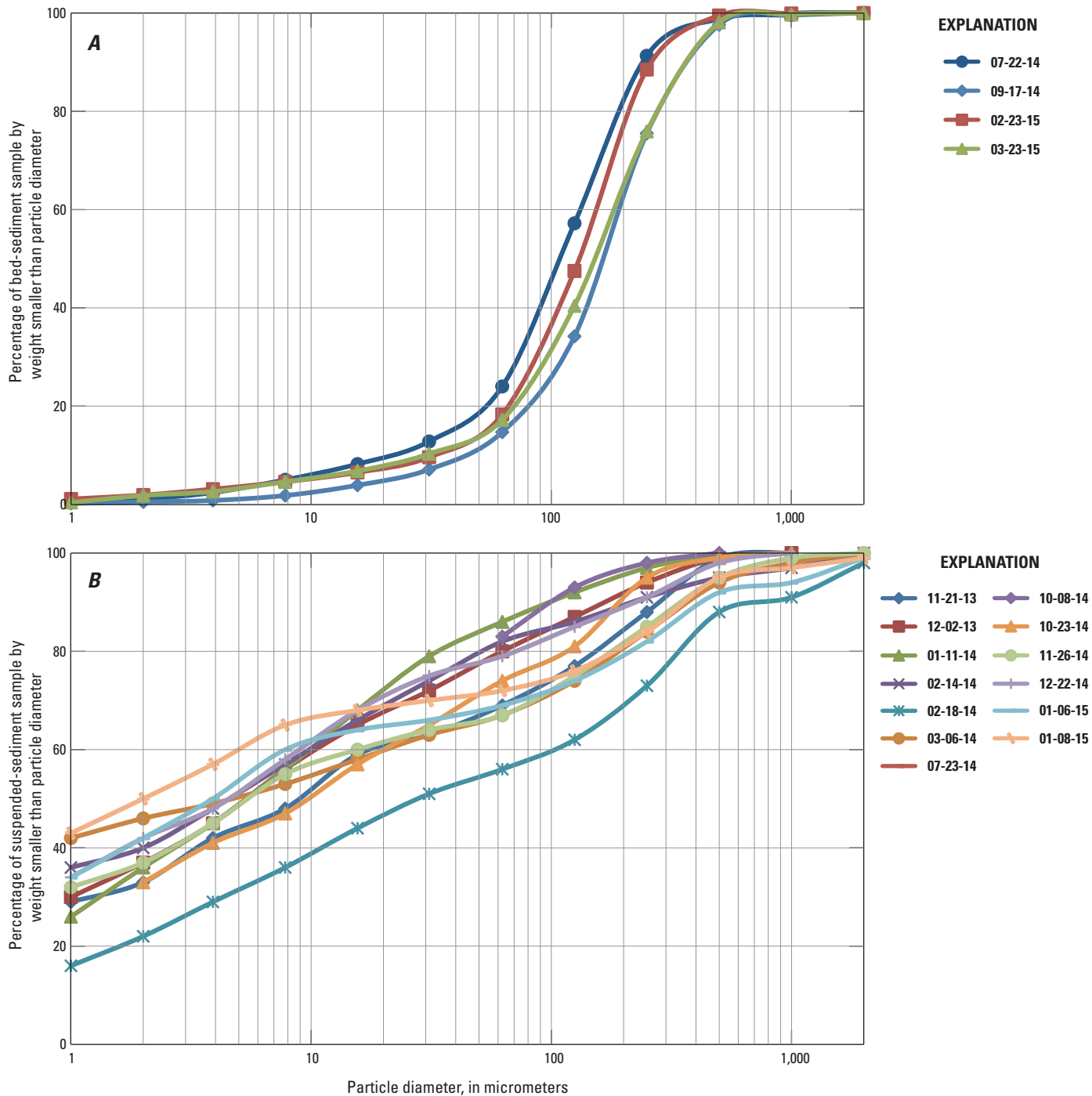


Figure 8. Particle-size distribution of (A) bed-sediment samples, sieved to less than 2 millimeters and (B) suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Instantaneous-Load Estimates

Instantaneous chemical loads based on concentrations in unfiltered water and filtered water are summarized in [table 9](#) and [10](#), respectively (see also [tables A16](#) and [A17](#)). For most detected chemicals, loads were higher during storms than during baseline conditions because of high streamflow and high water concentrations. Streamflow (the median of 15-minute values during the sampling period) ranged from 970 to 2,090 ft³/s during baseline sampling periods, with a median (of the five periods) of 1,150 ft³/s. Storm-period median streamflow values ranged from 520 ft³/s during a summer storm to 4,610 ft³/s during a large winter storm, with a median (of the nine periods) of 1,970 ft³/s. The highest water-derived instantaneous chemical loads occurred during dam releases because of the high river streamflow ([tables 9](#) and [10](#)), even when chemical concentrations were less than concentrations measured during storm events. Dam-release median streamflow values ranged from 4,150 to 7,350 ft³/s, with a median (of the five periods) of 6,770 ft³/s. The median streamflow value of the dam-release sampling periods was 3.4 times greater than the median streamflow value during storm sampling periods, and 5.9 times greater than during baseline sampling periods. Despite median PCB concentrations in unfiltered water that were highest during storm events,

followed by dam releases, and were lowest during baseline conditions, median PCB loads were more than 2 times higher during dam releases than storm periods, and more than 20 times higher during dam releases than baseline periods. Similarly, unfiltered-water arsenic loads were 6 times higher during dam releases than during storm periods, and more than 15 times higher during dam releases than during baseline periods.

Instantaneous suspended-sediment loads ([table A18](#)) ranged from 774 kg/hr during a low-precipitation baseline period to about 396,000 kg/hr during a dam release turbidity peak. Sediment loads were more than 10 times higher during storms than during baseline conditions and nearly 300 times higher during dam releases than during baseline conditions ([table 11](#)) owing to higher SSC and higher streamflow. Because of this, chemical loads estimated from suspended-sediment concentrations were the highest during dam releases, followed by storms, and the lowest loads were observed during baseline periods. Median suspended-sediment-bound PCB loads were two times higher during dam releases than during storm sampling, and more than 20 times higher during dam releases than baseline periods. Arsenic loads were 15 times higher during dam releases than during storm sampling, and more than 80 times higher during dam releases than during baseline periods.

Table 9. Comparison of instantaneous unfiltered-water chemical loads between different sampling event types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); NJ, result did not meet all quantitation criteria (an estimated maximum possible concentration is reported in "Result" column); U, not detected above detection limit (reporting limit is reported in "Result" column); UJ, not detected above detection limit (detection limit is reported in "Result" column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; g TEQ/hr, gram toxic equivalent per hour; mg/hr, milligram per hour; na, not applicable; <, less than]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	Sampling period						Ratio	
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm
			Result	Q	Result	Q	Result	Q		
Streamflow, median during water sampling	ft ³ /s	na	1,150	1,970	1,970	6,770	1.7	5.9	3.4	
Streamflow, median during water sampling	million L/hr	na	117	201	691	1.7	5.9	3.4		
Organic carbon										
Total organic carbon	kg/hr	na	213	605	2,670	2.8	12	4.4		
Metals										
Antimony	g/hr	7440-36-0	<1.17	UJ	<3.29	UJ	<7.50	UJ	na	
Arsenic	g/hr	7440-38-2	85.3	223	1,420	2.6	17	6.4		
Barium	g/hr	7440-39-3	470	1,810	18,400	3.8	39	10		
Beryllium	g/hr	7440-41-7	<2.35	UJ	<6.91	UJ	<58.0	UJ	na	
Cadmium	g/hr	7440-43-9	<1.17	UJ	<3.46	UJ	45.1	J	na	
Chromium	g/hr	7440-47-3	25.0	J	73.7	2,400	3.0	96	33	
Cobalt	g/hr	7440-48-4	18.5	J	53.3	1,200	2.9	65	23	
Copper	g/hr	7440-50-8	79.1	421	4,800	5.3	61	11		
Lead	g/hr	7439-92-1	11.7	160	1,050	14	89	6.5		
Manganese	g/hr	7439-96-5	9,070	12,900	93,000	1.4	10	7.2		
Mercury	g/hr	7439-97-6	<0.305	UJ	<0.394	UJ	14.1	J	na	
Molybdenum	g/hr	7439-98-7	<1.42	UJ	37.1	<6.99	UJ	na	na	
Nickel	g/hr	7440-02-0	59.4	240	3,320	4.0	56	14		
Selenium	g/hr	7782-49-2	<15.2	UJ	<26.1	UJ	<89.8	UJ	na	
Silver	g/hr	7440-22-4	<0.989	UJ	<1.72	UJ	<7.50	UJ	na	
Thallium	g/hr	7440-28-0	<469	UJ	<0.802	UJ	<3.00	UJ	na	
Vanadium	g/hr	7440-62-2	114	515	5,920	4.5	52	12		
Zinc	g/hr	7440-66-6	<58.6	UJ	657	9,750	na	na	15	
Polycyclic aromatic hydrocarbons										
LPAH ¹	g/hr	na	<0.868	UJ	<1.27	UJ	<5.17	UJ	na	
HPAH ²	g/hr	na	<0.493	UJ	1.25	J	<2.90	UJ	na	
cPAH ³	g/hr	na	<0.410	UJ	<1.05	UJ	<2.42	UJ	na	
cPAH ³	g TEQ/hr	na	<0.215	UJ	<0.454	UJ	<1.26	UJ	na	

Table 9. Comparison of instantaneous unfiltered-water chemical loads between different sampling event types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. Q, qualifier: Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); NJ, result did not meet all quantitation criteria (an estimated maximum possible concentration is reported in “Result” column); U, not detected above detection limit (reporting limit is reported in “Result” column); UI, not detected above detection limit (detection limit is reported in “Result” column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; g TEQ/hr, gram toxic equivalent per hour; mg/hr, milligram per hour; na, not applicable; <, less than]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	Sampling period						Ratio		
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm	
			Result	Q	Result	Q	Result	Q			
Dioxins/furans											
Total dioxins/furans ⁴	mg/hr	na	151	J	7,460	J	11,300	J	49	75	1.5
Total dioxins/furans ⁴	mg TEQ/hr	na	99.0	J	218	J	669	J	2.2	6.8	3.1
Polychlorinated biphenyls (by high-resolution mass spectrometry)											
Total polychlorinated biphenyls ⁵	mg/hr	1336-36-3	7.59	J	60.2	J	161	J	7.9	21	2.7
Total monochloro biphenyls	mg/hr	27323-18-8	1.05	J	<3.63	UJ	<2.08	UJ	na	na	na
Total dichloro biphenyls	mg/hr	25512-42-9	0.712	J	<30.0	UJ	4.10	UJ	na	5.8	na
Total trichloro biphenyls	mg/hr	25323-68-6	0.855	J	2.28	J	7.65	J	2.7	9.0	3.4
Total tetrachloro biphenyls	mg/hr	26914-33-0	1.30	J	3.15	J	8.17	J	2.4	6.3	2.6
Total pentachloro biphenyls	mg/hr	25429-29-2	1.43	J	27.2	J	24.8	J	19	17	0.91
Total hexachloro biphenyls	mg/hr	26601-64-9	1.28	J	27.9	J	53.6	J	22	42	1.9
Total heptachloro biphenyls	mg/hr	28655-71-2	0.257	J	9.16	J	19.7	J	20	44	2.1
Total octachloro biphenyls	mg/hr	55722-26-4	0.276	J	3.25	J	4.53	J	12	16	1.4
Total nonachloro biphenyls	mg/hr	53742-07-7	<0.105	UJ	0.490	J	0.664	J	na	na	1.4
Total decachloro biphenyls	mg/hr	2051-24-3	0.215	J	<0.635	UJ	<1.78	NJ	na	na	na
Aroclor 1242	mg/hr	53469-21-9	<3.13	UJ	<2.68	UJ	<27.8	UJ	na	na	na
Aroclor 1254	mg/hr	11097-69-1	<2.43	NJ	<5.34	UJ	<6.50	UJ	na	na	na
Aroclor 1260	mg/hr	11096-82-5	1.05	J	24.2	J	62.3	J	23	59	2.6
Polychlorinated biphenyls (by low-resolution mass spectrometry)											
Aroclor 1242	mg/hr	53469-21-9	<292	UJ	<502	UJ	<1,730	UJ	na	na	na
Aroclor 1254	mg/hr	11097-69-1	<292	UJ	<502	UJ	<1,730	UJ	na	na	na
Aroclor 1260	mg/hr	11096-82-5	<328	UJ	<562	UJ	<1,930	UJ	na	na	na

¹LPAH is a summed concentration of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.
²HPAH is a summed concentration of fluoranthene, pyrene, benz[a]anthracene, chrysene, total benzo[fluoranthenes (sum of b-, j-, and k- isomers), benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, dibenzo[a,h]anthracene, and benzo[ghi]perylene.
³cPAH is a summed concentration of benzo[a]anthracene, chrysene, benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, dibenz[a,h]anthracene, and total benzo[fluoranthenes (sum of b-, j-, and k- isomers).
⁴Total dioxins/furans is a summed concentration of 17 congeners.
⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

Table 10. Comparison of instantaneous filtered-water loads between different sampling types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); UJ, not detected above detection limit (detection limit is reported in "Result" column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; <, less than]

Parameter name	Unit of measure	Chemical Abstracts Service No.	Sampling periods						Ratio			
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm		
			Result	Q	Result	Q	Result	Q				
Streamflow, median during water sampling	ft ³ /s	na	1,150		1,970		6,770		1.7	5.9	3.4	
Streamflow, median during water sampling	million L/hr	na	117		201		691		1.7	5.9	3.4	
Organic carbon												
Dissolved organic carbon	kg/hr	na	255		430		1,810		1.7	7.1	4.2	
Metals												
Antimony	g/hr	7440-36-0	<1.17	UJ	<3.46	UJ	19.3	J	na	na	na	
Arsenic	g/hr	7440-38-2	59.4		103		276		1.7	4.7	2.7	
Barium	g/hr	7440-39-3	340		450		967		1.3	2.8	2.1	
Beryllium	g/hr	7440-41-7	<2.35	UJ	<6.00	UJ	<13.8	UJ	na	na	na	
Cadmium	g/hr	7440-43-9	<1.17	UJ	<2.01	UJ	<6.91	UJ	na	na	na	
Chromium	g/hr	7440-47-3	9.99	J	<12.0	UJ	69.9	J	na	7.0	na	
Cobalt	g/hr	7440-48-4	23.5		40.8		349		1.7	15	8.6	
Copper	g/hr	7440-50-8	70.4		154		622		2.2	8.8	4.0	
Lead	g/hr	7439-92-1	<5.86	UJ	5.30		32.2	J	na	na	6.1	
Manganese	g/hr	7439-96-5	7,270		3,980		7,900		0.5	1.1	2.0	
Mercury	g/hr	7439-97-6	<0.370	UJ	<0.522	UJ	<1.80	UJ	na	na	na	
Molybdenum	g/hr	7439-98-7	21.3	J	30.3		58.0	J	1.4	2.7	1.9	
Nickel	g/hr	7440-02-0	50.4	J	76.2	J	238	J	1.5	4.7	3.1	
Selenium	g/hr	7782-49-2	<15.2	UJ	<26.1	UJ	<89.8	UJ	na	na	na	
Silver	g/hr	7440-22-4	<1.14	UJ	<1.72	UJ	<6.91	UJ	na	na	na	
Thallium	g/hr	7440-28-0	<0.469	UJ	<0.802	UJ	<2.76	UJ	na	na	na	
Vanadium	g/hr	7440-62-2	70.4		120		600		1.7	8.5	5.0	
Zinc	g/hr	7440-66-6	<71.1	UJ	<173	UJ	<349	UJ	na	na	na	

Table 11. Comparison of instantaneous suspended-sediment chemical loads between different sampling event types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); U, not detected above detection limit (detection limit is reported in "Result" column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; mg/hr, milligram per hour; mg TEQ/hr, milligram toxic equivalent per hour; mg/hr, milligram per hour; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	Sampling periods						Ratio		
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm	
			Result	Q	Result	Q	Result	Q			
Streamflow, median during water sampling	ft ³ /s	na	1,180		2,090		6,760		1.8	5.7	3.2
Streamflow, median during water sampling	million L/hr	na	121		213		689		1.8	5.7	3.2
Suspended sediment											
Suspended sediment	kg/hr	na	825		9,260		247,000		11	300	27
Organic carbon											
Total organic carbon	kg/hr	na	40.4		287		6,270		7.1	160	22
Metals											
Arsenic	g/hr	7440-38-2	24.3		134		2,050		5.5	84	15
Barium	g/hr	7440-39-3	176		1,790		30,800		10	180	17
Beryllium	g/hr	7440-41-7	0.674	J	5.05	J	86.3		7.5	130	17
Cadmium	g/hr	7440-43-9	0.690		3.99		42.4	J	5.8	62	11
Chromium	g/hr	7440-47-3	34.2		326		6,490		10	190	20
Cobalt	g/hr	7440-48-4	14.0		120		2,960		8.6	210	25
Copper	g/hr	7440-50-8	53.6		475		8,140		8.9	150	17
Lead	g/hr	7439-92-1	22.9		172		2,000		7.5	87	12
Manganese	g/hr	7439-96-5	2,520		14,100		192,000		5.6	76	14
Mercury	g/hr	7439-97-6	0.157		1.09		24.7		6.9	160	23
Molybdenum	g/hr	7439-98-7	0.744	J	5.83		63.4	J	7.8	85	11
Nickel	g/hr	7440-02-0	31.6		339		6,780		11	210	20
Selenium	g/hr	7782-49-2	0.867	J	6.79	J	69.1	J	7.8	80	10
Silver	g/hr	7440-22-4	0.342	J	2.22	J	42.4	J	6.5	120	19
Thallium	g/hr	7440-28-0	0.157	J	1.51	J	26.4	J	10	170	18
Vanadium	g/hr	7440-62-2	86.2		855		15,500		10	180	18
Zinc	g/hr	7440-66-6	174		1,270		19,500		7.3	110	15
Polycyclic aromatic hydrocarbons and other semivolatile compounds											
LPAH ¹	mg/hr	na	163		1,210		9,470		7.4	58	7.8
HPAH ²	mg/hr	na	711		6,830		31,100		10	44	4.6
cPAH ³	mg/hr	na	392		4,010		17,400		10	44	4.3

Table 11. Comparison of instantaneous suspended-sediment chemical loads between different sampling event types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. **Q, qualifier:** Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); UJ, not detected above detection limit (detection limit is reported in "Result" column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; mg/hr, milligram per hour; mg TEQ/hr, milligram toxic equivalent per hour; mg/hr, milligram per hour; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	Sampling periods						Ratio		
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm	
			Result	Q	Result	Q	Result	Q			
Polycyclic aromatic hydrocarbons and other semivolatile compounds—Continued											
cPAH ³	mg TEQ/hr	na	72.4		830		3,360		11	46	4.0
1-Methylnaphthalene	mg/hr	90-12-0	7.90		148		2,890		19	370	20
2-Methylnaphthalene	mg/hr	91-57-6	13.8		148		3,540		11	260	24
Dibenzofuran	mg/hr	132-64-9	11.9		97.2		1,350		8.1	110	14
2-Methylphenol	mg/hr	95-48-7	<24.3	UJ	213		<2,200	UJ	na	na	10
4-Methylphenol	mg/hr	106-44-5	155		706	J	<5,550	UJ	4.5	na	na
Benzoic Acid	mg/hr	65-85-0	2,610	J	11,100		87,200	J	4.3	33	7.8
Benzyl Alcohol	mg/hr	100-51-6	898		7,300		67,400	J	8.1	75	9.2
bis(2-Ethylhexyl)phthalate	mg/hr	117-81-7	896		19,000		95,100		21	110	5.0
Butylbenzylphthalate	mg/hr	85-68-7	63.7		2,200		7,600		35	120	3.4
Di-n-Octyl phthalate	mg/hr	117-84-0	96.0		591		<2,070	UJ	6.2	na	na
Phenol	mg/hr	108-95-2	194		923		<3,170	UJ	4.8	na	na
Butyltins											
Butyltin	mg/hr	78763-54-9	5.31		79.6		<791	UJ	15	na	na
Dibutyltin Ion	mg/hr	14488-53-0	<11.2	UJ	105		<988	UJ	na	na	na
Tributyltin Ion	mg/hr	36643-28-4	<1.70	UJ	<13.9	UJ	<395	UJ	na	na	na
Dioxins/furans											
Total dioxins/furans ⁴	mg/hr	na	844		11,000		35,600		13	42	3.2
Total dioxins/furans ⁴	mg TEQ/hr	na	5.41	J	45.1	J	235	J	8.3	43	5.2
Polychlorinated biphenyls (by high-resolution mass spectrometry)											
Total polychlorinated biphenyls ⁵	mg/hr	1336-36-3	12.0		103		249		8.6	21	2.4
Total monochloro biphenyls	mg/hr	27323-18-8	0.011		0.131		0.678		12	61	5.2
Total dichloro biphenyls	mg/hr	25512-42-9	0.161		2.15		10.2		13	64	4.8
Total trichloro biphenyls	mg/hr	25323-68-6	0.536		4.17		15.9		7.8	30	3.8
Total tetrachloro biphenyls	mg/hr	26914-33-0	1.42		13.2		31.6		9.3	22	2.4

Table 11. Comparison of instantaneous suspended-sediment chemical loads between different sampling event types, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.—Continued

[This table contains CAS Registry Numbers® (CASRNs), which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM. **Parameter name:** Median streamflow values calculated from 15-minute data at USGS 12113390 Duwamish River at Golf Course at Tukwila, WA. A median chemical value of less than the detection limit is reported if more than one-half of the samples were not detected. cPAH, carcinogenic polycyclic aromatic hydrocarbon. HPAH, high molecular-weight polycyclic aromatic hydrocarbon. LPAH, low molecular-weight polycyclic aromatic hydrocarbon. Q, qualifier: Blank cells indicate an unqualified detection; J, estimated (result between detection limit and reporting limit); UJ, not detected above detection limit (detection limit is reported in "Result" column). **Abbreviations:** ft³/s, cubic foot per second; million L/hr, million liters per hour; kg/hr, kilogram per hour; g/hr, gram per hour; mg/hr, milligram per hour; mg TEQ/hr, milligram toxic equivalent per hour; mg/hr, milligram per hour; na, not applicable]

Parameter name	Unit of measure	Chemical Abstracts Service (CAS) No.	Sampling periods					Ratio		
			Baseline, median (n=5)		Storm, median (n=9)		Dam release, median (n=5)		Storm to baseline	Dam to storm
			Result	Q	Result	Q	Result	Q		
Polychlorinated biphenyls (by high-resolution mass spectrometry)—Continued										
Total pentachloro biphenyls	mg/hr	25429-29-2	3.53		30.7		69.3	8.7	20	2.3
Total hexachloro biphenyls	mg/hr	26601-64-9	3.71		32.6		73.4	8.8	20	2.3
Total heptachloro biphenyls	mg/hr	28655-71-2	1.76		14.0		25.7	8.0	15	1.8
Total octachloro biphenyls	mg/hr	55722-26-4	0.622		5.06		12.5	8.1	20	2.5
Total nonachloro biphenyls	mg/hr	53742-07-7	0.150		1.20		3.44	8.0	23	2.9
Total decachloro biphenyls	mg/hr	2051-24-3	0.043		0.381		3.12	8.9	73	8.2
Aroclor 1242	mg/hr	53469-21-9	0.952		7.54		28.8	7.9	30	3.8
Aroclor 1254	mg/hr	11097-69-1	5.09		47.4		111	9.3	22	2.3
Aroclor 1260	mg/hr	11096-82-5	3.98		38.0		73.4	10	18	1.9
Polychlorinated biphenyls (by low-resolution mass spectrometry)										
Aroclor 1242	mg/hr	53469-21-9	<2.14	UJ	<21.7	UJ	<327	UJ	na	na
Aroclor 1254	mg/hr	11097-69-1	15.7		370		<372	UJ	24	1.0
Aroclor 1260	mg/hr	11096-82-5	11.2		176		<197	UJ	16	1.1

¹LPAH is a summed concentration of naphthalene, acenaphthylene, fluorene, phenanthrene, and anthracene.
²HPAH is a summed concentration of fluoranthene, pyrene, benz[*a*]anthracene, chrysene, total benzo[*a*]fluoranthenes (sum of b-, j-, and k- isomers), benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene.
³cPAH is a summed concentration of benzo[*a*]anthracene, chrysene, benzo[*a*]pyrene, indeno(1,2,3-*c,d*)pyrene, dibenz[*a,h*]anthracene, and total benzo[*a*]fluoranthenes (sum of b-, j-, and k- isomers).
⁴Total dioxins/furans is a summed concentration of 17 congeners.
⁵Total polychlorinated biphenyls is a summed concentration of 209 congeners.

Summary

Data were collected between November 2013 and March 2015 by the U.S. Geological Survey to provide sediment and chemical concentrations and instantaneous load estimates to the Lower Duwamish Waterway from upstream sources transported by the Green River, Washington. During approximately 20 sampling periods including baseline conditions, storms, and dam releases, measurements of instantaneous streamflow and field parameters were made and samples were collected for analysis of unfiltered-water and filtered-water chemistry, suspended-sediment concentration, and suspended-sediment chemistry. Chemical concentrations in unfiltered water generally increased with increasing suspended-sediment concentration, resulting in the highest chemical concentrations during dam releases (for TOC and metals) and storms (for PAHs, dioxins/furans, and PCBs), as compared to baseline periods. Chemical concentrations in filtered water were similar across storms, dam releases, and baseline periods. This suggests that the sediment-bound chemicals are an important fraction of the unfiltered-water concentration. Chemical concentrations associated with suspended sediment generally were highest during storm periods as compared to both dam releases and baseline periods (for metals, PAHs, butyltins, pesticides, dioxins/furans, and PCBs). Chemical concentrations on suspended sediment generally were higher than concentrations on fine bed sediment (less than 62.5 μm), which were higher than bulk bed sediment (less than 2 mm). Streamflow and suspended-sediment concentration generally were highest during dam releases, followed by storm periods, and lowest during baseline periods. This resulted in higher sediment and chemical-loading estimates during dam releases than storm sampling, both of which were greater than load estimates during baseline periods.

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

Data qualifiers were used by each of the two analytical chemistry laboratories, and amendments were made to these qualifiers to be consistent with Washington State Department of Ecology protocols.

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

B Analyte detected in an associated method blank.

J Estimated concentration when the value is less than the ARI established reporting limits: result is greater than the reporting limit [RL] and less than the detection limit [DL].

P The analyte was detected on both chromatographic columns but the quantified values differ by 40 percent or more relative percent difference with no obvious chromatographic interference.

Q A detected analyte with an initial or continuing calibration that does not meet established acceptance criteria (less than 20 percent Relative Standard Deviation, less than 20 percent drift, or minimum Relative Response Factor).

U Indicates that the target analyte was not detected at the DL and the RL is reported.

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 at less than 10 times the concentration in the associated blank.

C Congener co-elution.

D Dilution data.

J Indicates an estimated value where the concentration of the analyte is less than the RL, but greater than the DL.

NJ Results were qualified with “NJ” for one of two reasons: (1) Disturbance of the mass ion used to monitor instrument performance (lock-mass) present. Under the normal AXYS flagging convention, this would have been reported as “G.” (2) 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. Under the normal AXYS flagging convention, this would have been reported as “K.”

R Not quantifiable. Under AXYS’ normal flagging convention, this would have been reported as “NQ.”

T Result recalculated against alternate labeled compound(s) or internal standard.

UJ Not detected at DL and the DL is reported. Under the normal AXYS flagging convention, this would have been reported as “U.”

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 labs used in this study were made to be consistent with the Ecology 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, and 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-, J-, and N-containing qualifiers were amended following these protocols:

For AXYS:

B qualifiers were changed to UJ.

T qualifiers were changed to J.

Informational qualifiers (C and D) were removed for ease of viewing.

When multiple qualifiers were reported, only the most conservative qualifier was reported (that is, NJ or UJ)

For ARI:

Y qualifiers were changed to U.

Q and P qualifiers were changed to J.

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

If the sample concentration is greater than or equal to five times the associated lab blank, sample results are considered as positive without qualifiers (action: remove B). For metals and common laboratory contaminants (acetone, 2-butanone, methylene chloride, toluene, phthalate esters), 10 times was used instead of 5 times.

If the sample concentration was less than 5 times (less than 10 times was used for metals and common laboratory contaminants) the associated lab blank, it was reported at the detected sample concentration with a U qualifier.

Field tasks by sampling date are presented in [table A1](#). Field conditions during bridge-based sampling and bed-sediment sampling are presented in [tables A2](#) and [A3](#), respectively. The data presented in [tables A4–A18](#) are the quality control results and the complete results from Analytical Resources, Inc. and AXYS Analytical, Ltd., with amended qualifiers by the USGS. [Tables A1–A18](#) is a Microsoft® Excel file that can be downloaded from <http://dx.doi.org/10.3133/ds973>.

Table A1. Field tasks and sampling dates at Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A2. General hydrology, water quality, and field conditions during bridge-based sampling at Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A3. General hydrology and field sampling conditions during the bed-sediment sampling dates at Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A4. Concentrations of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, dioxins/furans, and polychlorinated biphenyls in unfiltered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A5. Concentrations of organic carbon and metals in filtered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A6. Concentrations of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, dioxins/furans, polychlorinated biphenyl congeners and Aroclors in suspended-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A7. Concentrations or percent of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, dioxins/furans, polychlorinated biphenyls, and particle-size distribution in bed-sediment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A8. Concentrations of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, and polychlorinated biphenyl Aroclors in trip blank and equipment blank water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A9. Concentrations of dioxins/furans and polychlorinated biphenyls in trip blank and equipment blank water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A10. Concentrations of volatile organic compounds in unfiltered-water trip blank samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A11. Concentrations or percent of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, dioxins/furans, polychlorinated biphenyls in suspended-sediment quality assurance samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A12. Concentrations or percent of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, polychlorinated biphenyls, volatile organic compounds, and particle size distribution in centrifuge recovery experiment samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A13. Concentrations of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, dioxins/furans, polychlorinated biphenyls in concurrent replicate water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A14. Concentrations or percent of organic carbon, hexavalent chromium, metals, polycyclic aromatic hydrocarbons and other semivolatile compounds, butyltins, pesticides, volatile organic compounds, dioxins/furans, polychlorinated biphenyls, and particle-size distribution in bed sediment field split samples sieved to less than two millimeters, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A15. Quality-assurance results for the Puget Sound Sediment Reference Material, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A16. Instantaneous chemical loads based on concentrations in unfiltered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A17. Instantaneous chemical loads based on concentrations in filtered-water samples, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

Table A18. Instantaneous chemical loads based on concentrations on suspended sediment, Duwamish River at Golf Course at Tukwila, Washington, 2013–15.

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